Woody fuel consumption and carbon in the changing climate of Australia

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Abstract:

Woody fuel consumption was assessed at prescribed burns in four different forest types across southern Australian eucalypt forests using variations of the line intersect technique. Research into the effect of climate change in fire potential in Australian ecosystems indicated that future climate scenarios will result in an increase in the severity of fire seasons and fire intensity. The study aimed to quantify the link between fireline intensity and the fraction of coarse woody fuel consumed and carbon released in bushfires. Results from 39 prescribed burns ranging in intensity between 53 and 5000 kW/m were analysed for the relationship between fireline intensity and proportion of woody fuel consumed. Without the ability to isolate the effect of fireline intensity from other variables such as fuel moisture, it was difficult to assess its direct relationship with woody fuel consumption. While fireline intensity appears to effect the consumption of fine fuels and to a lesser extent the small woody fuels (<2.5cm) and large woody fuels greater than 50cm, regression analysis indicates that the consumption of woody fuels between 2.5 and 50cm is not effected by variations in fireline intensity. This suggests that under prescribed burn conditions the consumption of woody fuels is little affected by fireline intensity alone however may be more influenced when coupled with other changes in the fire regime.

Introduction:

Fine fuels (<6mm diameter) play an important role in determining the flame characteristics and rate of spread in the flaming zone of a fire front. After the fire front passed it is the consumption of woody fuels (>0.6cm) that will largely influence the behaviour of the fire including the development of the convection plume, potential for re-ignition, difficulty of fire suppression and mop-up, radiant heat and smoke environment to which firefighters are exposed (Sullivan *et al.*, 2002). The combustion of this large woody fuels also play a significant role in first order fire effects, namely through the degree of soil heating and tree mortality associated with the heating of tree boles and superficial roots.

Woody fuel consumption and carbon

Coarse woody debris (CWD) are a significant store of carbon in forest ecosystems and can persist for many decades before being released to the atmosphere—either slowly through decay or rapidly through combustion when burnt in a forest fire. Several models have been developed and used internationally, particularly in the United States and Canada, to predict woody fuel consumption and carbon emissions at a fuel component and site specific scale. At the time of writing a suitable model has not been identified for Australian eucalypt forests. Woody fuel consumption research in Australia has focused on site specific studies of pre and post-fire fuel load assessments however little has been published. These have been successful in determining volume consumption for a particular area and forest type and giving fire and land managers an approximate figure to base woody fuel consumption rates on. Research undertaken in *Eucalyptus obliqua* regeneration burns in Tasmania (Marsden-Smedley and Slijepcevic 2001; Slijepcevic 2001) found that 58-63% of the total weight of organic material and its carbon content was lost to the atmosphere, a figure which is still used operationally by forest managers throughout Tasmania. The authors also found that the majority of carbon loss was from slash greater than 7.0cm in diameter.

In 2006 (Tollhurst *et al.* 2006) undertook more detailed research studying the variables affecting woody fuel consumption in *Eucalyptus dalrympleana* and *Eucalyptus radiata* forest in south-eastern New South Wales. This included detailed assessment of woody fuel moisture, density and wood decay. The authors found a strong relationship between woody fuel consumption and fire intensity and noted that the greater the degree of decay, the greater the proportion of consumption. This suggests that CWD age may also be an important variable affecting fuel consumption.

From 184 studies available in literature (Mackensen *et al.* 2003) found that in 57% of all cases, the calculated lifetime of CWD (time to when 95% of mass is lost) is longer than 40 years (the median of the distribution was 49 years and the mean 92 years). In fact, coarse woody debris in some species such as jarrah (*Eucalyptus marginata*) were found to have a lifetimes of up to 120 years.

CWD is significantly affected by fire disturbances making accurate accounting for its' contribution to the carbon stock of a forest ecosystem particularly complex. In Australian forests where CWD contributes approximately 18% of the total forest above-ground biomass and carbon stock in Australian dry sclerophyll forests and 16% in wet sclerophyll forests (Woldendorp et al. 2002), fire can significantly modify CWD volume resulting in changes to greenhouse gas emissions and carbon stocks. This will vary from forest to forest and due to differences in the conditions under which they are burnt. One of the studies by (Hingston *et al.* 1980) in the jarrah forest (*Eucalyptus marginata*) of southwest Western Australia, found coarse woody debris proportion of above ground biomass was 32%, significantly higher than the average found in the culmination of studies by (Woldendorp *et al.* 2002).

In the event of a fire, prescribed or otherwise, consumed CWD will directly add to carbon emissions (Apps *et al.* 2006), however, the event may not necessarily result in the equivalent reduction in the coarse woody debris fuel load. As a result of the fire, newly fallen trees and branches will be transferred from overstorey and understory trees to a new coarse woody debris load (Waterworth and Richards 2008) which could even be as high as the pre-fire load depending on variables such as species, stand structure, fire behaviour (e.g., fire intensity, residence time) and termite damage.

As the mass of carbon in coarse woody debris is a function of carbon concentration (%) and density, uncertainties exist in determining the contribution of coarse woody debris to carbon stocks. This can be attributed to the scarcity of information on coarse woody debris volume and decay rates (Brown et al 1996), and the impact of decay on wood density in Australian forests (Grierson *et al.* 1992; Mackensen *et al.* 2003). As a result, reliable calculations of biomass, carbon stock values and CO_2 emissions are currently fraught with uncertainty until further data is collected through long-term studies of coarse woody debris in different environments (Mackensen *et al.* 2003). Current estimates of carbon in coarse woody debris mass range from 45 to 50% (Woodwell *et al.* 1978); Tilman *et al.* 2000; Mackensen and Bauhus 1999). For the purposes of this report, the conversion factor currently used by the Australian Greenhouse Office (Mackensen and Bauhus 1999) will be used where the average carbon content is 50% of the coarse woody debris biomass.

Woody fuels and climate change

Fires have long been part of the Australian bush and have played a major role in shaping vegetation structure and species composition (Bradstock *et al.* 2002; Burrows 2008; Gill *et al.* 1981). Australian fire behaviour and regimes are closely related to meteorological conditions including temperature, humidity, temporal and seasonal rainfall patterns (and their affect on fuel moisture content) and wind speed (Catchpole, 2002; Cheney 1981; Luke and McArthur 1977; McAurthur 1973; McCaw *et al.* 2003) as well as opportunities for ignition from lightning or man-made sources. Climate change projections for Australia indicate that each of these variables are likely to be impacted by climate change including a rise in annual mean temperatures as well as local variations in rainfall patterns that include precipitation regimes that have longer dry spells broken by heavier rainfall events (Lucas *et al.* 2007).

Climate change has the potential to alter a number of components of the fire regimes including fire frequency, size, intensity and length of the fire season including the period suitable for prescribed burning (Lucas *et al.* 2007). These changes have the potential to result in an increase in the area burnt by wildfires (Amiro *et al.* 2001; Gould and Cheney 2007) and as a result, increase instantaneous releases of greenhouse gases linked to biomass (including coarse woody debris). Understanding the effects that these changes could have on the amount and quality of coarse woody debris and improving our ability to predict fuel consumption and the resulting implications for carbon stocks and cycles within a forest ecosystem is becoming increasingly important.

In this paper we assess the particular impact of fire intensity on woody fuel consumption and carbon release at prescribed burns in 4 different forest types across Australia. This includes;

1. jarrah (*Eucalyptus marginata*) forest in the south-west of Western Australia
2. blue gum (*Eucalyptus globulus*)/ manna gum (*Eucalyptus viminalis*) forest in northern-central Victoria
3. mountain gum (*Eucalyptus dalrympleana*) / narrow-leaf peppermint (*Eucalyptis radiata*) forest in south-eastern New South Wales
4. stringybark (*Eucalyptus obliqua*) forest Tasmania

We test the hypothesis that fireline intensity is a significant variable determining woody fuel comsumption. This hypothesis will be tested over the spectrum of woody fuel size classes.

Methodology:

Woody Fuel Consumption Project (WFCP): Behind the Flaming Zone

Woody fuel consumption was assessed during three prescribed burns in southwest Western Australia including Wilga, Quilben and Hester blocks (Figure 1) in 2007 and 2008. Woody fuel consumption was also assessed in the Tallarook State Forest located in the Victorian northern central district (Figure 1). Multiple plots were burnt under the same weather, season and fuel conditions at the Hester site in order to determine the specific effect of varying fireline intensity. This was achieved by varying fire direction in each plot, i.e. head-fire, backing fire and flank fires.

Woody fuel loads (>0.6cm) were determined pre and post fire using Van Wagner's line intersect method (Van Wagner 1968) with four fixed 100m transects (400m total transect length) placed within the burning plots. Five size classes were adopted including; Size 1: 0.6-2.5cm, Size 2: 2.5-7.5cm, Size 3: 7.5-22.5cm, Size 4: 22.5-50.0cm, Size 5: >50.0cm. Fuels crossing each transect were counted and measured for diameter prior to the fire and wires were tied around the circumference of the fuels greater than 2.5cm to determine change in volume during post-fire assessment. Each fuel item was scored on a scale of 1-5 for decay, suspension, arrangement, charing and bark hazard. When possible, the species was also recorded. Pre and post-fire woody fuel loads were calculated using Brown's Woody Material formula (Brown 1974).

Rates of spread were calculated using thermologgers and the time intervals at which the fire passed known grid points at 320°C within the plots. Profile, near surface and surface fine fuel moisture (<1.0cm) was sampled prior to each burn and where possible during the burn for fire durations greater than 2hrs. Samples were oven dried at 105°C. Woody fuel moisture for size classes 1 and 2 were determined by randomly sampling fuels from in either 'suspended' or 'grounded' categories. Woody fuel moisture for size classes 3, 4 and 5 was obtained no more than 2 days before each fire by chainsaw cutting wood disks approximately 5cm in width, from random samples within close proximity to the burn area. Fuels were assessed for their decay, suspension, bark and heartwood condition and the species was recorded. These were cut into 5cm cubes using a bandsaw and oven dried for 5-7 days at a nominal temperature of 105°C in order to determine changes from the surface to the core in woody fuel moisture. After woody fuel moisture was determined, these wood cubes were used to determine species densities using the water displacement method (insert TAPPI Ref, 1994) which also provided the data to assess variation in species density from the surface through to the core of the log.

A meteorological station was located in close proximity to each burn site where rainfall, temperature, relative humidity and wind speeds were monitored prior to and during the fire. Fireline intensity was calculated using the fuel low heat of combustion (kj/kg), weight of fuel consumed per unit area (kg/m^2) and rate of spread (m/s) using Byram's fireline intensity equation (Byram 1959).

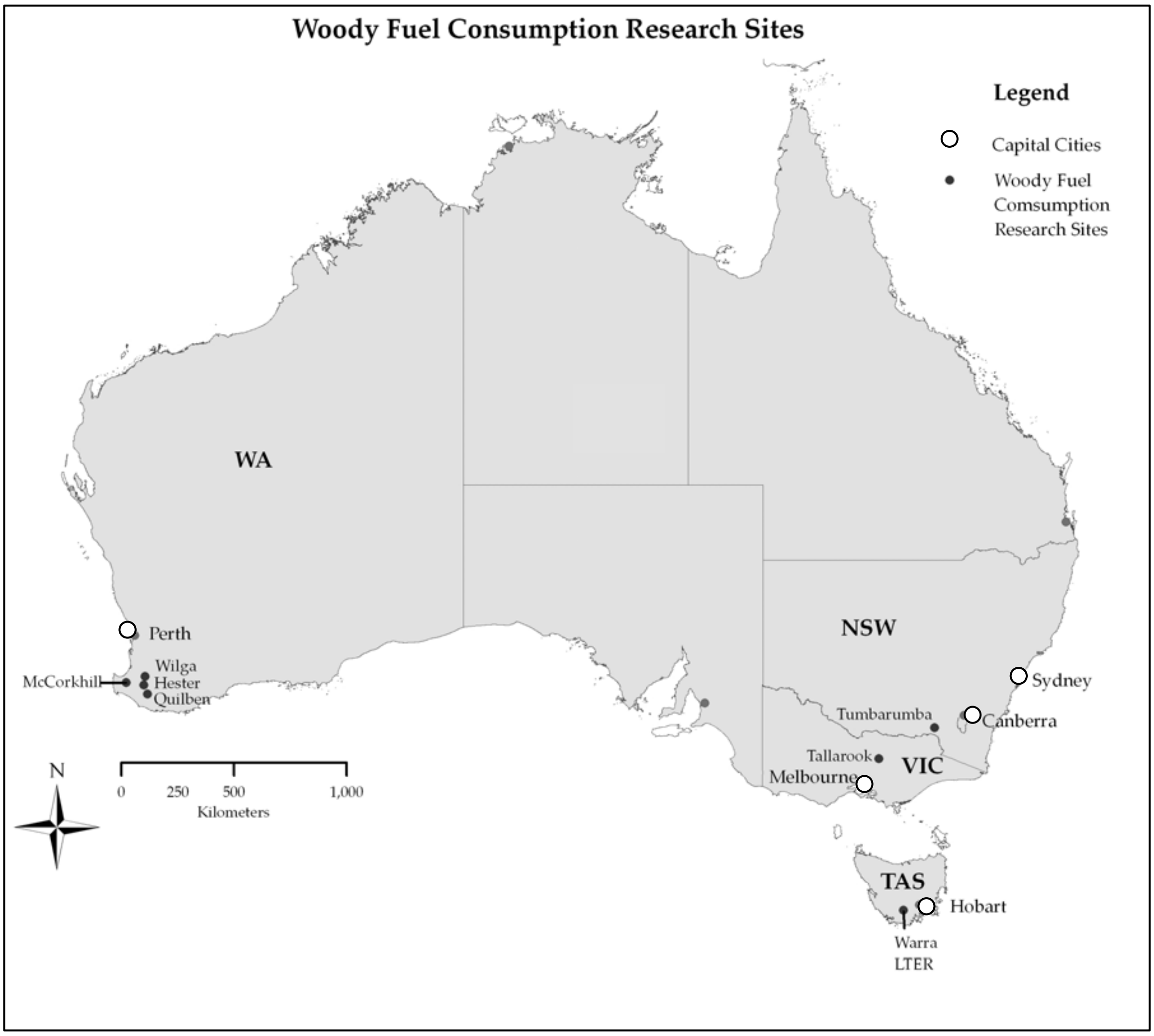

Figure 1 – Location of woody fuel consumption research sites across Australia including Wilga, Quilben, Hester and McCorkhill (Project Aquarius) in Western Australia, Tallarook in Victoria, Tumbarumba in New South Wales and the Warra LTER site in Tasmania

Project Aquarius

Woody fuel consumption was assessed at 32 experimental fires ignited under dry summer conditions at McCorkhill block in the southwest of Western Australia in 1983 (Figure 1).

Woody fuel loads (>1.0cm) were determined pre and post fire using Van Wagner's line intersect method (Van Wagner 1968) with 20m transects placed at regular intervals along established grid lines placed 100m apart within each fire plot. The total transect length for each plot varied according to plot size. Fuels in eight size classes were counted including; 10-25mm, 25-50mm, 50-75mm, 75-100mm, 100-150mm, 150-200mm, 200-300mm and >300mm where the fuels horizontal diameter was also measured. These were subsequently converted to those used in the Woody Fuel Consumption Project to enable comparison across projects. Pre and post-fire woody fuels loads were calculated using

Brown's Downed Woody Material formula (see above Equation 1 and 2 where the fuel diameter is known).

Patterns of fire development within the plots was measured from periodic mapping with an infra red line (IR) scanner. The digital data from the scanner was corrected for scale, scene compression, jitter by aircraft movements and geometrically rectified onto a known planar map to enable fire spread rates to be calculated.

Profile and surface fine fuel moisture (<1.0cm) was determined by taking periodic grab samples throughout the fire duration. Woody fuel moisture for each size class; 1-2.5cm, 5-7.5cm, 10-15cm was obtained before each fire by chainsaw cutting a sample of the fuel and collecting the sawdust. All samples were oven dried at a nominal temperature of 105°C.

A meteorological station was located in close proximity to the McCorkhill block where temperature, relative humidity and wind speeds were monitored. Fire intensity was calculated using Byram's equation (Byram 1959).

Warra Long Term Ecological Research Site

Carbon release was assessed at 11 controlled regeneration burns undertaken in wet sclerophyll and mixed stringybark (*Eucalyptus obliqua*) forests within the Warra Long Term Ecological Research Site (LTER) approximately 52 kms southwest of Hobart in southern Tasmania (Figure 1).

Detailed methodology for the Warra LTER research has been reported in Marsden-Smedley and Slijepcevic (2001) and Slijepcevic (2001). Fine and woody fuel loads <2.5cm were determined by collecting vegetation using a 1x1m plot using a hedge-trimmer and/or chainsaw to cut through the fuel array to the soil surface. 30 samples within each site were sorted into three size classes; 0-0.1cm, 0.1-0.6cm and 0.6-2.5cm and oven dried to determine biomass. Woody fuel loads >2.5cm were determined using the Van Wagner (1968) line intersect method with 15m transects for fuel diameters of 2.5-5.0cm, 30m transects for 5.0-7.0cm and 45m transects for fuels >7.0cm. Brown's equation (1974) was adopted to calculate fuel load which incorporates an angle correction factor as well as a slope correction factor from Brown and Roussopoulus (1974). The quadratic mean diameter (QMD) for size classes 2.5-5.0cm and 5.0-7.0cm was determined during field sampling by recording diameters within each size class and using Van Wagner's equation to calculated the QMD (Van Wagner 1982). Species densities were calculated using the water displacement method (TAPPI, 1994) and were means of at least 20 branches in each diameter class for each species. The ignition method used, center fire ignition (convection), did not allow detailed measurements of fire behaviour properties. Flame heights were estimated to be 4 m. In the absence of fire behaviour information fireline intensity was estimated based on the Gould et al (2007) relationship between mean flame height and mean fire intensity.

Tumbarumba

Woody fuel consumption research was undertaken in February 2004 within the Maragle State Forest, Tumbarumba, located in south-eastern New South Wales.

Detailed background, methodology and fire behaviour from this research was given by Tollhurst *et al.* (2006). Pre and post fire woody load (>2.5cm diameter) was determined using the Van Wagner (1968) line intersect method with 3 x 30m transects in each of the plots (i.e. 90m transect lengths). The diameter of fuels intersecting the transect was recorded along with a rating for decay and suspension class. Each fuel circumference was tied with 2mm wire to determine volume consumed. Four size classes were adopted including 2.6-7.5cm, 7.6-22.5cm, 22.6-50cm and >50cm diameter.

Woody fuel moisture was assessed across experimental blocks. Three measures of fuel moisture were obtained for each wood sample including two by oven determination; from 'inner' and 'outer' locations of the sample, and one by electronic moisture meter (T-H Fine Fuel Moisture Meter (Chatto and Tolhurst 1997)) from the saw dust generated during the cutting of the sample . Woody density was measured in a range of diameter and decay classes by determining the volume of wood samples from the weight increase after submersion in water.

Plot ignition was from a 100m continuous line and on the up-wind, down-slope position of the block with a final burn area approximately 4ha. Fire intensity was calculated using Byram's (1959) fireline intensity equation as described previously.

Table 1 - Site and Burn Characteristics

Burn ID	Average Annual Rainfall (mm)	Dominant Species	Burn Type	Ignition Technique
WCFP - Wilga	830	*Eucalyptus marginata*	Silvicultural	Long Line
WCFP - Quilben	1012	*Eucalyptus marginata*	Ecological / Fuel Reduction	Long Line
WCFP - Hester	830	*Eucalyptus marginata*	Ecological / Fuel Reduction	Long Line
WCFP - Tallarook	595	*Eucalyptus globulus* *Eucalyptus viminalis*	Ecological / Fuel Reduction	Long Line
Project Aquarius - McCorkhill	1140	*Eucalyptus marginata*	Ecological / Fuel Reduction	Long Line / Multiple Ignition Point
Warra LTER	883	*Eucalyptus obliqua*	Silvicultural	Central Ignition
Tumbarumba	975	*Eucalyptus dalrympleana* *Eucalyptus radiate*	Ecological / Fuel Reduction	Long Line

Results and Discussion:

Pre-fire fuel load distribution

The pre-fire fuel load distribution by size class is similar across sites with the exception of the Warra LTER sites which appear to have significantly higher fuel loads in each of the size classes (Figure 2). The Quilben site in Western Australia also has a higher than average fuel load for fuels greater than 50cm (size class 5). At each of the sites, the larger size classes, particularly sizes 4 and 5, form much of the overall site woody fuel load (on average 35% and 30% respectively, combined 65%)). This highlights the importance of the larger fuels to overall woody fuel consumption. This is an important characteristic of the problem under analysis, namely when we attempt to investigate and understand the effect of different environmental variables and fire behaviour characteristics, such as fireline intensity, on fuel consumption.

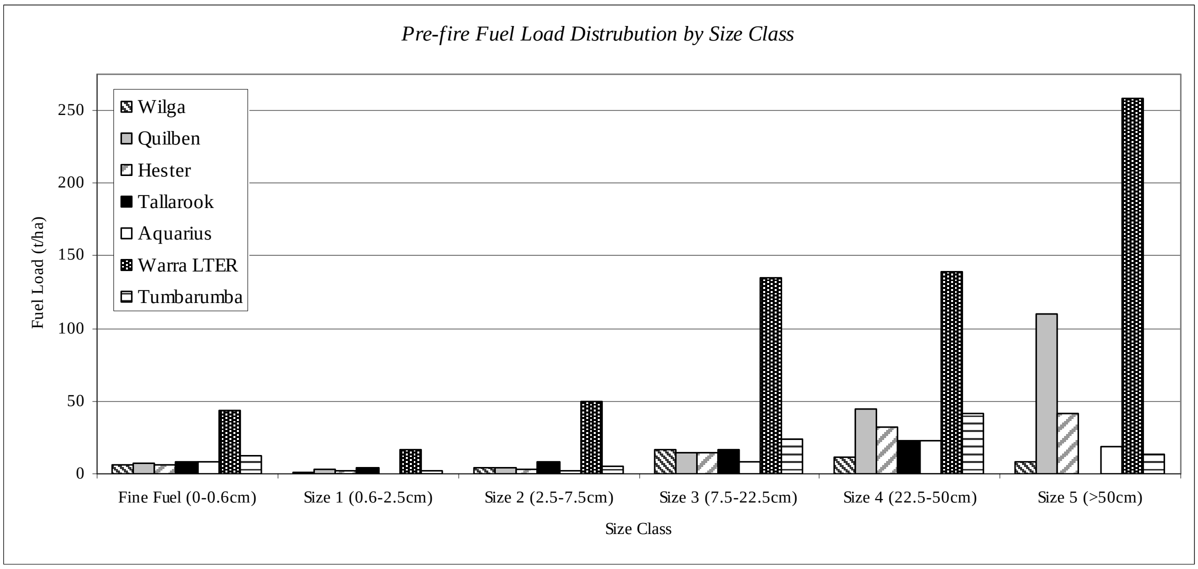

Figure 2 – Pre-fire fuel load distribution by size class.

Table 2 – Summary of average fire behaviour characteristics across burn sites. Range across multiple burns (minimum to maximum) in *italics*.

Site / Mean Characteristics	Number of fires	RH %	Temp (DegC)	10m Open Wind Speed (kph)	KBDI	SDI	ROS (m/hr)	Residence Time (s)	Fireline Intensity (kW/m)
WFCP - Wilga	1	27.5	24.9	7.8		42.9	97.7	93.7	299.0
WFCP - Quilben	1	68.5	21.1	5.5		84.9	52.2	26.9	209.9
WFCP - Hester	4	56.4 *(48-63)*	24.8 *(23-27)*	13.7 *(11-17.5)*		147.5 *(148-148)*	105.0 *(15-217)*	21.6 *(10-40)*	348.7 *(53-678)*
WFCP - Tallarook	2	50.1 *(34-66)*	16.5 *(13-20)*	8.6 *(8.2-8.9)*	36.8 *(14-60)*	139.5 *(136-143)*	52.3 *(20-85)*	77.5 *(28-127)*	234.0 *(76-393)*
Project Aquarius	18	45.7 *(20-61)*	24.5 *(18-33)*	5.2 *(2.5-24)*		139.1 *(129-163)*	372.8 *(153-774)*	not measured	1680.5 *(585-3304)*
Warra LTER	11	67.4 *(52-90)*	18.1 *(17-19)*	not measured		51.0 *(51-51)*	not measured	not measured	5000.0 *(5000-5000)*
Tumbarumba	2	32.5 *(20-45)*	27.0 *(26-28)*	7.3 *(6.5-8)*	122.0 *(122-122)*		369.9 *(122-618)*	not measured	2430.6 *(955-3906)*

Fire behaviour and fuel condition

A wide range of weather and seasonal influences are represented in the dataset including burns conducted under typical spring and autumn prescribed burning conditions as well as those characteristic of dry summer wildfires (see Table 2 where burning conditions have been averaged for each site). The broad range of burning conditions is also reflected by fireline intensity which ranged from 53 to 5000 kW/m and in the fine (profile) and woody fuel (log average) moisture contents, ranging from 8-72% and 33-56% respectively (Table 3).

Table 3 – Summary of fuel moisture conditions and fuel consumption outcomes across burn sites. Range across multiple burns (minimum to maximum) in *italics*.

Site / Mean Characteristics	Profile Fuel Moisture Content (%)	Log Moisture Content >0.6cm (%)	Total Pre-fire Fine Fuel Load <0.6cm (t/ha)	Total Post-fire Fine Fuel Load <0.6cm (t/ha)	Pre-fire Woody Fuel Load >0.6cm (t/ha)	Post-fire Woody Fuel Load >0.6cm (t/ha)	Woody Fuel Consumption (%)	Carbon Release (t/ha)
WFCP - Wilga	11.6	38.7	5.9	0.2	42.3	22.1	47.6	10.1
WFCP - Quilben	24.6	37.3	7.8	3.0	175.0	121.7	30.5	26.7
WFCP - Hester	16.6 *(16.6-16.6)*	32.9 (33-33)	6.6 *(6.0-7.0)*	0.6 *(0.1-1.3)*	93.8 *(76-106)*	47.3 *(40-62)*	49.4 *(42-57)*	23.3 *(17-30)*
WFCP - Tallarook	51.9 *(32.3-71.5)*	45.0 (35-56)	8.1 *(7.3-8.9)*	1.4 *(0.3-2.6)*	52.2 *(49-55)*	31.6 *(28-36)*	39.7 *(36-43)*	10.3 *(10-11)*
Project Aquarius	10.4 *(8.3-13.2)*	not measured	8.8 *(6.3-12.0)*	0.0 *(0-0)*	60.5 *(33-107)*	27.1 *(5-54)*	54.9 *(33-90)*	16.7 *(8-36)*
Warra LTER	not measured	not measured	44.1 *(30-53)*	9.0 *(6.7-10.6)*	599.5 *(226-1322)*	336.8 *(71-795)*	46.4 *(9-69)*	131.4 *(31-263)*
Tumbarumba	11.0 *(11.0-11.0)*	47.2 (47-47)	12.8 *(12-13)*	0.0 *(0-0)*	86.3 *(49-123)*	52.3 *(22-83)*	44.2 *(33-56)*	17.0 *(14-20)*

Woody Fuel Consumption and fireline intensity

At a plot/fire specific level woody fuel (>0.6cm) consumption ranged from 9 to 90%. However the average for each site ranged from 31 – 55% (Table 3). Using the amount of fuel consumed at each plot this equates to a range of carbon release between 8 and 263t/ha, for an average of 50t/ha. At a plot/fire level woody fuel consumption appears to increase with fireline intensity up to approximately 700 kW/m (Figure 3) after which no definable relationship appears to exist. This is illustrated in the weak regression relationship for site fuel consumption with fireline intensity (sizes 1-5 combined) (R^2= 0.01) in Table 4 below.

By following the diameter reduction relationships of individual fuel items at each of the Woody Fuel Consumption Project (WFCP) burns, it has been possible to assess woody fuel consumption by size class and intensity. Figure 4 illustrates the scatter of the consumption (by intensity) across the WFCP sites. There appears to be a weak relationship between fireline intensity and wood fuel consumption of the fine (R^2 = 0.48) and size class 5 (R^2 = 0.41). The regression explanatory power for the other classes was weaker, with an R^2 of 0.23 obtained for size class 1, and R^2 below 0.1 for sizes 2, 3 and 4.

This supports the hypothesis that fireline intensity is an influencing variable in the consumption of fine fuels and possibly the small woody fuels (i.e. size class 1 (0.6-2.5cm). It also appears that fireline intensity may influence the consumption of fuels greater than 50cm (size 5). This may suggest that the consumption of larger proportions of the fine and small woody associated with higher fireline intensities, is required to ignite and consume the fuels greater than 50cm.

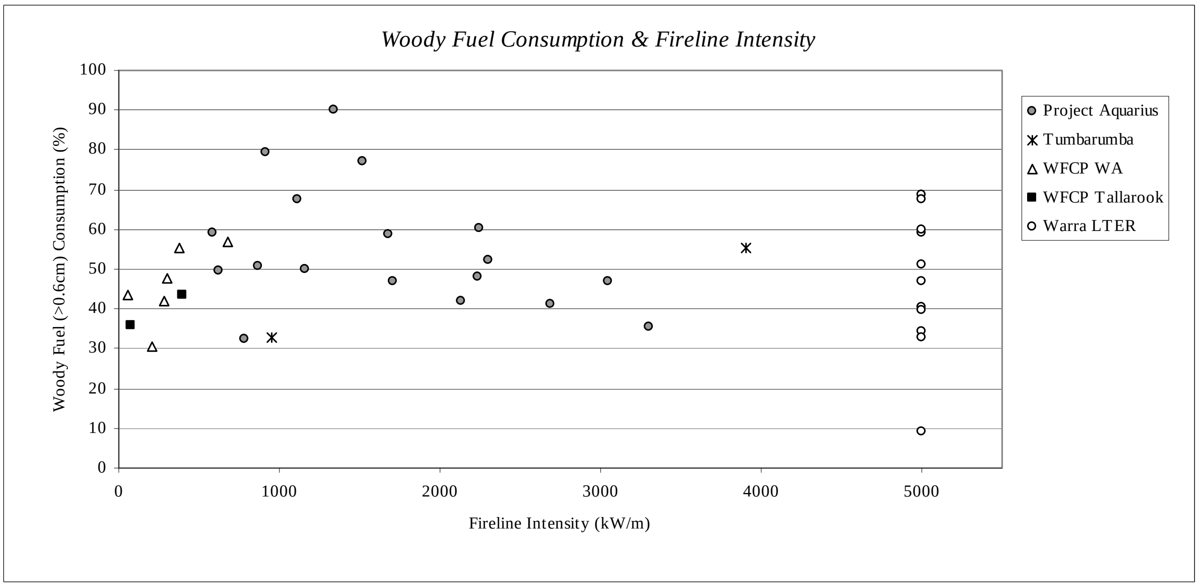

Figure 3 – Scatterplot of consumption and fireline intensity across all prescribed burns.

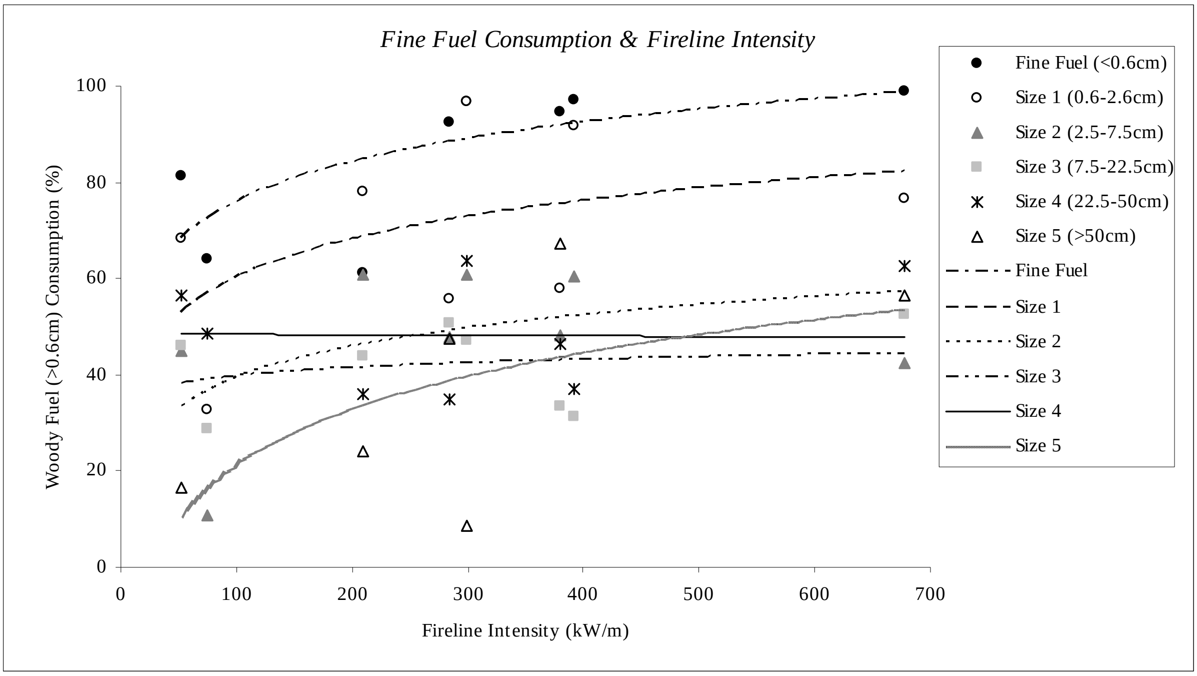

Figure 4 – Scatterplot and regression (y=a ln(x)) analysis of consumption and fireline intensity by size class at the Woody Fuel Consumption Project (WFCP) sites.

Table 4 – Prediction equations for woody fuel consumption by size class using fireline intensity at the Woody Fuel Consumption Project (WFCP) sites.

Fuel size class	Regression Equation (linear)	R^2
Fine fuel (<0.6cm)	69.9 + 0.0534 Fireline Intensity	0.48
Size Class 1 (0.6-2.5cm)	11.511Ln(Fireline Intensity) + 7.2271	0.23
Size Class 2 (2.5-7.5cm)	9.3444Ln(Fireline Intensity) - 3.6022	0.24
Size Class 3 (7.5-22.5cm)	37.7 + 0.0138 Fireline Intensity	0.09
Size Class 4 (22.5-50cm)	44.6 + 0.0123 Fireline Intensity	0.04
Size Class 5 (>50cm)	13.6 + 0.0731 Fireline Intensity	0.41
Site (class 1-5 combined) *	51.7 - 0.00081 Fireline Intensity	0.01

** Includes data across entire dataset*

It is noted that the variety of conditions under which each plot and site have been burnt will also contribute significantly to the varied consumption outcomes. Some of the variables are also likely to be highly correlated, for example woody fuel moisture – log decay, and fireline intensity - Soil Dryness Index. Given this, the best example of the effect of fireline intensity on woody fuel consumption was found at the Hester site burns which were burnt concurrently (same day, same time). Through this method we were able to burn the various plots under the same fuel moisture conditions, and variable fireline intensity. This was achieved by burning distinct areas of the plot by head, back and flank fires. For this prescribed burn woody fuel consumption ranged from 42.2 – 56.9% with the highest consumption occurring within the plot with the highest fireline intensity (678 kW/m) (Table 5). Within each of the size classes, fine fuel consumption increased with increasing intensity however the same relationship was not clear in any of the woody fuel size classes greater than 0.6cm. It appears that the low intensity (53 kW/m) of the Hester 4 burn may have had an effect on the consumption of the woody fuels greater than 50cm (size 5) which was minimal (16.7%). This could be the result of the small energy quantity being released by the surface fire not meeting the energy requirements to ignite the large fuels.

Table 5 – Woody fuel consumption by size class at the Hester site burns.

	Fireline Intensity (kW/m)	Fuel Consumption by Size Class (%) Fine Fuels	1	2	3	4	5	Woody Fuel >0.6cm (sizes 1-5 combined)
Hester 1	678	99.0	76.7	42.6	52.4	62.5	56.5	56.9
Hester 2	380	94.5	57.8	48.3	33.5	46.4	67.3	55.2
Hester 3	284	92.4	55.8	48.0	50.8	35.0	47.4	42.2
Hester 4	53	81.3	68.2	45.0	46.2	56.5	16.7	43.5

Climate Change Implications associated with fireline intensity

Climate change has the potential to affect fire regimes by modifying fire intensity. While the relationship between fine fuel consumption and fireline intensity appears to support theories that fire intensity influences the burn patchiness and proportion of fine fuels consumed (e.g., Moreno & Oechel, 1989), the effect on woody fuel consumption and carbon release is unclear. This could be because there are so other variables, some of them correlated, that affect woody fuel consumption, making it difficult to isolate the relationship between fireline intensity and woody fuel consumption. It may also be that the relationship between woody fuel consumption and fireline intensity is very weak, possibly less important than other variables such seasonal dryness and associated large fuel moisture content. It is reasonable to expect that under the future altered fire climate, with longer and more severe (drier) fire seasons, the consumption of woody fuels will increase as a greater proportion of areas are burned under drier, more intense (high fire danger indices) wildfire conditions. This is an important aspect to take into consideration when planning and conducting prescribed burns.

It is possible that fireline intensity plays a role in influencing the consumption of large size 5 fuels (>50cm), and further research is required to look at this relationship as they form a large proportion of the CWD fuel load (on average 30%). Their ignition and consumption are important processes responsible for the release of large quantities of stored carbon.

Conclusions:

The relationship between fireline intensity and the consumption of woody fuels (>0.6cm) and associated carbon release in southern Australian eucalypt forests is unclear making it difficult to assess the affect of potential climate change scenarios if only fireline intensity is considered.. While fireline intensity appears to effect the consumption of fine fuels and to a lesser extent the small woody fuels (<2.5cm) and large woody fuels greater than 50cm, regression analysis would indicate that consumption of woody fuels between 2.5 and 50cm are not dependent on fireline intensity.. When combined with other climate change scenarios such as drier fine and woody fuels and higher fire danger indices, the relationship may become more apparent.

Further research is required in order to accurately account for changes in forest floor biomass, carbon stocks and emissions as a result of fire, particularly regeneration burning and wildfire. This includes the collection of more base data on consumption outcomes per size class under pseudo-controled fuel moisture, weather and fire behaviour conditions. This data will be basis to sound coarse woody fuel modelling.

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