Fuel characteristics and low intensity burning in *Eucalyptus obliqua* wet forest at the Warra LTER Site

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Abstract

Eucalyptus obliqua *wet forest fuel characteristics and burning were studied at the Warra Long-Term Ecological Research (LTER) Site in Tasmania's Southern Forests. The study examined pre-logging, post-logging and post-burning variation in fuel characteristics in wet sclerophyll and mixed forest. The utility of low intensity burning in coupes with 10% dispersed retention was also studied. The mean, near-surface, fine-fuel loads (i.e. fuel diameters less than or equal to 25 mm) in unlogged* E. obliqua *wet forest varied from about 13 t/ha in mixed forest to about 20 t/ha in wet sclerophyll forest. These fuel loads increased to between about 40 and 85 t/ha following logging. High intensity regeneration burns removed the majority of the fine fuel. In low intensity burns, the amount of fuel removal was dependent on the fuel moisture.*

Two low intensity burns removed 50–90% of the fuel less than 25 mm in diameter and required significantly higher numbers of personnel than high intensity burns. Low intensity burns were lit in mid to late autumn when fuel moistures are higher than in late summer/early autumn when high intensity burns are normally performed. Although it was possible to perform low intensity burns in E. obliqua *wet forest, their effectiveness needs to be assessed by forest managers. Factors influencing the planning of low intensity burns include the amount of ash bed required for eucalypt regeneration, the desired reduction in fire risk, the resources needed to perform the burn and the number of burns needed.*

Introduction

The aim of this paper is to summarise the results of a project examining *Eucalyptus obliqua* wet forest fuel characteristics and burning at the Warra Long-Term Ecological Research (LTER) Site. *Eucalyptus obliqua* is the major wood production species in Tasmania's Southern Forests and dominates the forests of the Warra LTER Site (Packham 1995).

The Warra LTER Site is located in Tasmania's Southern Forests between the Huon and Weld Rivers, approximately 60 km south-west of Hobart (Figure 1). The site has an area of 15 900 ha. Packham (1995) has summarised the aims and background of the Warra LTER Site, which are to:

- Foster long-term ecological research and monitoring in Tasmanian forests;
- Assess the suitability of the Montreal Process criteria and indicators for assessing forest management sustainability under Tasmanian conditions; and
- Facilitate the development and demonstration of sustainable forest management practices.

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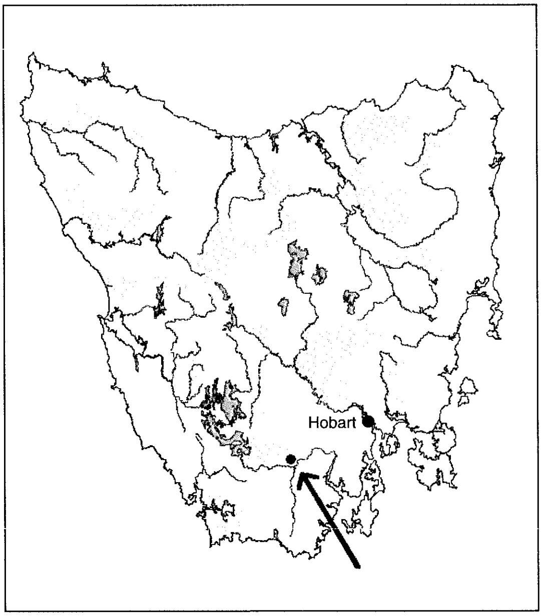

Figure 1. Location of the Warra LTER Site in southern Tasmania.

Within the Warra LTER Site, a silvicultural systems trial is being conducted in a 200 ha area of mixed regrowth/oldgrowth *E. obliqua* wet forest (Forestry Tasmania 1997; Hickey and Neyland 2000). This silvicultural systems trial aims to compare different logging treatments and how they affect factors such as biodiversity, soils, visual impacts, economic costs, worker safety and fire management. The silvicultural systems examined at the Warra LTER Site are:

- Clearfall, burn and sow using ground-based machinery;
- Clearfall, burn and sow using ground-based machinery while retaining understorey islands;
- Patchfall and burn using cable machinery;
- Stripfall using cable machinery;
- Dispersed retention of 10% of the original basal area using ground-based machinery;
- Aggregated retention of 30% of the original forest area using ground-based machinery; and
- Single tree/small group selection.

The overall aims of this project were to describe:

1. The fuel characteristics of *E. obliqua* wet forest.

   The types of forest examined were:

   - Wet sclerophyll forest with a broadleaf understorey dominated by *Gahnia*, *Bauera* and litter;
   - Mixed forest with a thamnic rainforest understorey and litter fuels; and
   - Mixed forest with a callidendrous rainforest understorey and litter fuels.

2. The effect of different logging regimes on fuel characteristics.

   The logging treatments examined were:

   - Clearfall, burn and sow using ground-based machinery;
   - Patchfall and burn using cable machinery; and
   - Dispersed retention of about 10% of the original basal area using ground-based machinery.

3. How fuel characteristics change at different stages of the logging process.

   The stages at which fuel characteristics were examined were:

   - Prior to logging;
   - After logging and before burning; and
   - After logging and burning.

4. The utility of conducting low intensity burning in coupes with dispersed retention of about 10% of the original basal area.

In the silvicultural systems trial at the Warra LTER Site, the 10% dispersed retention treatment aimed to retain a minimum of ten trees per hectare followed by a low intensity burn. The low intensity burn was intended to be similar to a top-disposal burn rather than the high intensity regeneration burns normally utilised in these forests in order to minimise crown scorch in the retained

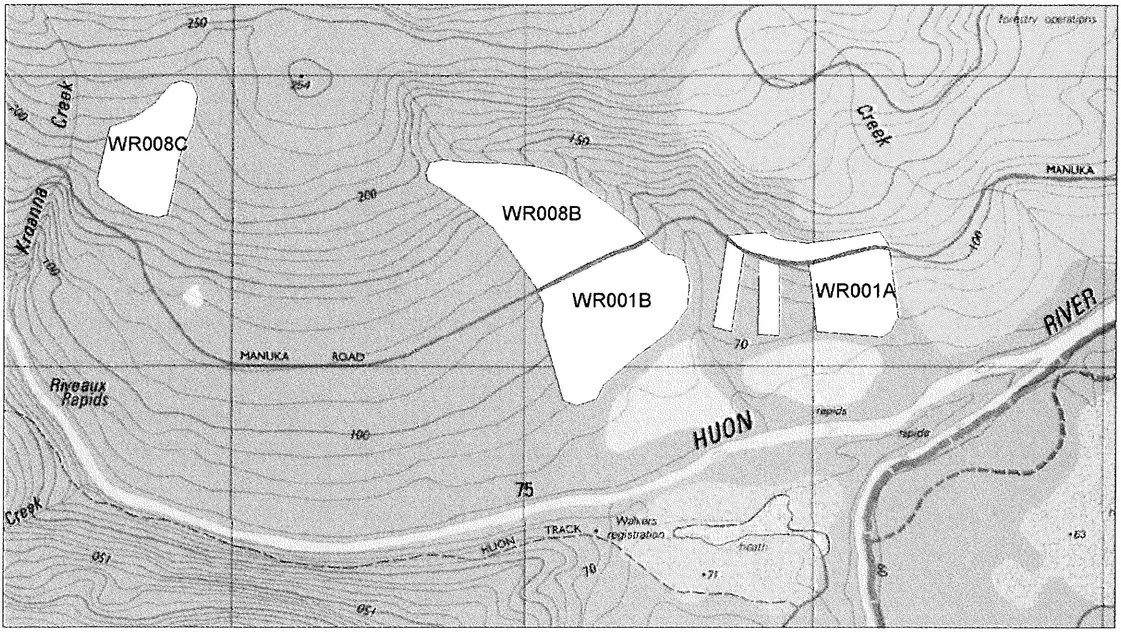

Figure 2. Location of the coupes sampled for fuel characteristics in the silvicultural systems trial at the Warra LTER Site.

overstorey. The coupes which were clearfelled using ground-based or cable machinery were burnt using a conventional high intensity regeneration burn. The aims and strategies of different regeneration and fuel hazard-reduction methodologies have been detailed in Forestry Commission (1993) and Forestry Tasmania (1998). Additional information regarding this study is included in Marsden-Smedley and Slijepcevic (2001).

The primary objectives of the 10% dispersed retention treatment in wet eucalypt forests have been summarised by Burgess *et al.* (1997). This logging system aims to:

- Harvest and regenerate the forest cost-effectively and safely;
- Provide suitable conditions for eucalypt regeneration and long-term growth;
- Enhance the potential fauna habitat value of the stand; and
- Meet the constraints which limit the effects of operations on other forest values, such as flora, fauna, landscape, soils and water.

Methods

Study area

All of the coupes are located on Manuka Road in State forest within the Warra LTER Site in the Huon District of Forestry Tasmania (Figure 2, Photos 1–3). The fuel characteristics were sampled in two dispersed retention coupes (WR001B and WR008C), a patchfall cable logging coupe (WR001A), and a conventional clearfall coupe using ground-based machinery (WR008B).

The location and site characteristics of the coupes are summarised in Table 1.

Vegetation characteristics prior to logging

Prior to logging, the overstorey in the silvicultural systems trial coupes at the Warra LTER Site was mixed regrowth and oldgrowth *E. obliqua* (Table 1). The understorey vegetation communities present at the site range from wet sclerophyll forest (coupes WR001B and WR008C, and the southern half of WR008B) through thamnic rainforest (northern half

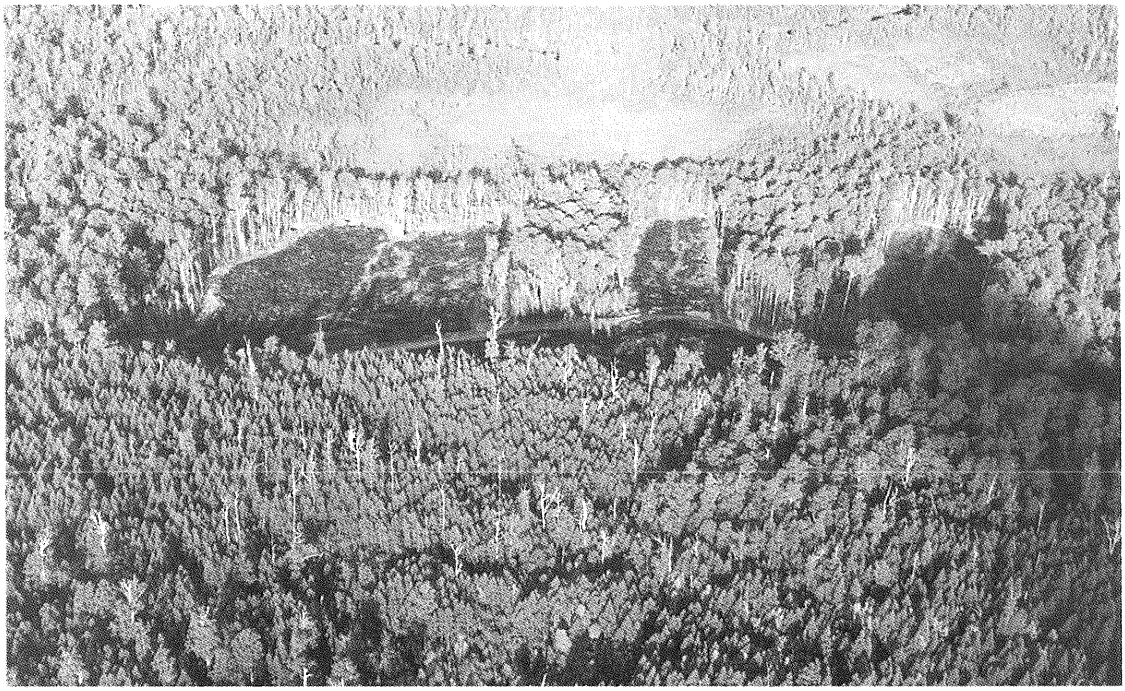

Photo 1. *WR001A coupe, after patchfall/stripfall treatment.*

Photo 2. *WR008C coupe.*

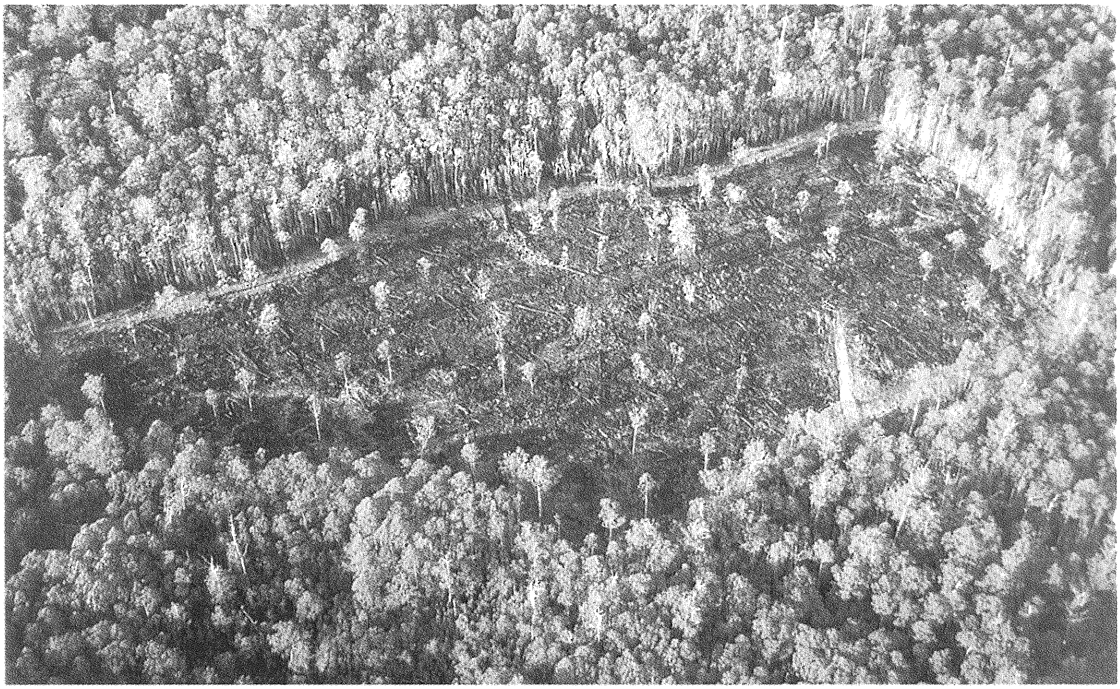

Table 1. Characteristics of the coupes WR001A, WR001B, WR008B and WR008C.

Coupe	Aspect	Slope (°)	Altitude (m)	Understorey	Logging technique	Grid reference
WR001A	S	15	80	callidendrous rainforest	patchfall/stripfall using cable	4760 52283
WR001B	SSE	8	100	wet sclerophyll	10% dispersed retention	4752 52281
WR008B	SSE	10	130	wet sclerophyll/ thamnic rainforest	clearfall using ground machinery	4750 52284
WR008C	SSW	10	200	wet sclerophyll	10% dispersed retention	4737 52287

of the coupe WR008B) to callidendrous rainforest (coupe WR001A).

The wet sclerophyll understorey community had an elevated fuel stratum dominated by *Melaleuca squarrosa, Leptospermun lanigerum, Pomaderris apetala, Nematolepis squamea* and *Acacia verticillata*; a near-surface fuel stratum dominated by *Gahnia grandis* and *Bauera rubioides;* and a ground stratum dominated by litter (Photos 4–6). The thamnic rainforest understorey had an elevated fuel stratum dominated by *Anodopetalum biglandulosum, Atherosperma moschatum* and *Nothofagus cunninghamii* and a ground stratum dominated by litter (Photo 7). The callidendrous rainforest understorey had a tall elevated stratum dominated by *Nothofagus cunninghamii* and *Atherosperma moschatum* and a ground stratum dominated by litter (Photos 8, 9).

The methods used to describe the fuel arrays of undisturbed *E. obliqua* wet forest were modified from McCaw (1988) and Gould (1993). In undisturbed *E. obliqua* wet forest the fuel array consists of four main strata:

- Litter;
- Near-surface;
- Elevated; and
- Canopy fuels.

The litter stratum consists of dead fuel which is mostly horizontal in orientation and is in contact or near contact with the ground surface. The near-surface fuels consist of shrubs, *Gahnia* and juvenile trees which are mostly vertical in orientation and consist of a mixture of live and dead fuels which are mostly less than about three metres tall. The elevated fuels consist of understorey trees 6–12 m tall which are mostly vertical and contain both live and dead fuels. The

Photo 3. Coupe WR001B (background) showing 10% dispersed retention and coupe WR008B (foreground) showing clearfall treatment with understorey islands.

Photo 4. Wet sclerophyll fuels dominated by Melaleuca squarrosa, Leptospermum lanigerum, Pomaderris apetala, Nematolepis squamea *and* Acacia verticillata *in WR008C.*

Photo 5. Wet sclerophyll fuels dominated by Gahnia grandis *in WR008C.*

Photo 6. Wet sclerophyll fuels dominated by litter in WR008C.

canopy fuels consist of overstorey tree crowns and are normally more than 25 m above the ground surface. Only very minor amounts of bark-dominated fuel were observed in these coupes prior to logging.

The wildfire history of the silvicultural systems trial in the Warra LTER Site has been studied by Alcorn *et al.* (2001). The most recent major wildfires that affected some or all of the coupes we studied occurred in 1933/34, 1914 and 1897/98. Within the life of the oldgrowth *E. obliqua* trees, there appear to have been at least two fires prior to the 1897/98 fire.

Geological substrates

Observations from within the coupes indicated that the WR001A coupe is underlain by sandstone with occasional dolerite talus, the WR001B coupe is partly underlain by sandstone and partly by dolerite talus while the WR008B and WR008C coupes are underlain by dolerite talus.

Fuel sampling

Fuel sampling was performed prior to logging; after logging and before burning; and after logging and burning. The dates when the different coupes were sampled, logged and burnt are given in Table 2.

The range in fuel characteristics present in the coupes was determined using regular sampling. This involved running transects through each coupe prior to each stage of the fuel sampling. On these transects, visual estimates of the fuel type, cover and depth were made at ten-metre intervals. On all transects, more than 100 sampling points were made.

Fuel plots were selected using stratified random sampling in order to cover the full range of variation in fuels, determined from the transect data. In the first stage of the fuel sampling (i.e. pre-logging), only the litter and near-surface fuel strata were sampled. Fuels from all four strata were sampled after logging.

Photo 7. *Thamnic rainforest fuels in WR008B.*

Photo 8. *Callidendrous rainforest fuels in WR001A.*

Table 2. Fuel sampling, logging and burning dates.

Coupe	Pre-logging sampling	Logging	Post-logging, pre-burning sampling	Burning	Post-logging, post-burning sampling
WR001A	Jun 1998	Feb–Mar 1999	Feb 2000	Mar 2000	May 2000
WR001B	Nov 1997	Jan–Mar 1998	Mar 1998	Apr 1998	Apr 1998
WR008B	June 1998	Nov–Dec 1998	Mar 1999	Mar 2000	May 2000
WR008C	Nov 1997	Sep–Nov 1999	Mar 2000	Apr 2000	May 2000

Fuel loads were sampled using 1 m x 1 m plots (Photo 10). A petrol driven hedge-trimmer and/or chainsaw was used to cut down through the fuel array to the soil surface. In the pre-logging fuel sampling, litter fuels were easy to differentiate from the near-surface fuels and so the litter and near-surface fuels were collected as separate samples. After logging, it was not possible to separate the litter fuels from the slash fuels due to compaction, so the fuel from each plot was collected as a single sample (Photo 11). For each fuel plot, data were collected on fuel cover and fuel depth. The fuels within each coupe were divided into the fuel types shown in Table 3.

Fuel particle size has a very important influence on fire behaviour. During most wildfires, the fire front typically burns only fuel particles less than about 6 mm in diameter (Luke and McArthur 1978). However, in this study, the dense fuel arrays were composed almost entirely of dead fuel so the fuel sampling was extended to include particles up to 25 mm in diameter.

Photo 9. Callidendrous rainforest fuels in WR001A.

Photo 10. Sampling wet sclerophyll litter fuels in WR001B.

Photo 11. Post-logging, pre-burning fuel structure in wet sclerophyll litter fuels in WR008C.

Table 3. Fuel types recorded from the Warra coupes.

Fuel type	Fuel components
Branch	*Bauera*, branches and leaves elevated above the ground surface
Wet sclerophyll litter	Dead twigs, leaves and branches in close contact with the ground
Gahnia	*Gahnia* elevated above the ground surface
Thamnic rainforest litter	Dead twigs, leaves and branches in close contact with the ground
Callidendrous rainforest litter	Dead twigs, leaves and branches in close contact with the ground
Bark	Bark in close contact with the ground

Table 4. Subjective (visual) scale for estimating the degree of burning.

Score	Notes
1	Unburnt
2	Only elevated slash less than 1 mm in diameter burnt
3	Elevated and surface slash burnt, including particles less than 1 mm in diameter
4	Ash bed, all slash less than 6 mm in diameter burnt

The fuel samples collected were sorted in the laboratory into live versus dead material and then further subdivided into less than 1 mm diameter, 1–6 mm diameter and 7–25 mm diameter classes.

Since by definition the litter stratum only consists of dead fuel, any live material included in the pre-logging litter fuel sample collected in the field was assumed to be part of the near-surface stratum. Fuel samples were oven dried at 80°C until constant weights were obtained. Fuel weights were expressed as dry weight of each fraction in tonnes per hectare.

During the post-logging, post-burning fuel assessment transects, visual assessments were also made of the type of burn at each sampling point (Table 4). This information was then used to design the sampling regime and to ensure that the full range of fuels present within each coupe was sampled.

At each stage of the fuel sampling, the actual fuel load present was estimated by first dividing the fuel plot data into fuel types (Table 3) and then dividing each of these fuel types into cover classes. The fuel plot data were then used to calculate the average fuel weight for each cover class. Finally, the fuel load was estimated by multiplying the area covered by each fuel cover class by its average fuel weight.

The cover classes used were 0–20%, 21–40%, 41–60%, 61–80% and 81–100%. In addition, following logging and burning in the WR001A, WR008B and WR008C coupes, fuel loads were estimated by assuming that:

- 50% of the post-logging, pre-burning fuel was removed in the poorly burnt areas;
- 75% was removed in the well-burnt areas; and
- All of the fuel was removed in the fully burnt areas.

These estimates of the amount of fuel burnt in different intensity fires were derived from the data collected in the WR001B coupe.

Low intensity burning in wet eucalypt forests following logging

Part of this project was to assess the utility of conducting burning in dispersed retention coupes (i.e. in coupes WR001B and WR008C). The aim was to have a similar burn intensity to that which occurs

Table 5. Planned burning prescriptions for burning the dispersed retention coupes.

Temperature	about 15°C
Relative humidity	above 60%
Surface wind speed	below 5 km/hr
Time since rain	> 2 days
Spacing between the lines of fire	10–30 m
Hazard-stick moisture	> 14%
Light-up time	15:00–16:00
Cloud cover	< 25%

in a low intensity top-disposal burn (see Forestry Commission 1993) in order to minimise death and/or defoliation in the retained trees.

A set of prescriptions was designed as a guide to achieve these aims in the present experiment. These prescriptions indicated the required meteorological conditions and fire lighting pattern that should achieve the desired fire intensity. However, they need to allow for interactions between heavy fuel moisture (predicted by the Soil Dryness Index, Mount 1972) and fine fuel moisture (predicted from the hazard-stick moisture, Eron 1991).

The prescriptions for low intensity burning in wet eucalypt forest at the Warra LTER Site are detailed in Table 5.

Results

Pre-logging; post-logging, pre-burning; and post-logging, post-burning fuel loads

Prior to logging, there were marked differences between the coupes in the area covered by the different fuel types and in the average cover and height of these fuels (Figure 3). These differences are probably the result of variation in fire history and geological type.

The estimated fuel loads of each of the coupes prior to logging are summarised in Appendix 1. Following logging, it was not possible to differentiate the slash fuels from the litter fuels due to compaction by logging machinery. Therefore, the estimates of the fuel loads of different fuel types following logging and/or burning have been made by assuming that the litter fuel load has not varied between the pre- and post-logging fuel sampling periods. The estimated fuel loads of each of the coupes post-logging but pre-burning are summarised in Appendix 2.

Following burning, the coupes were assessed for the degree of fuel removal (Table 6). In WR001A, WR008B and WR008C, the fire was of sufficient intensity to remove the majority of the slash fuel while in WR001B the intensity was much lower and much of the fuel was left unburnt. The degree of burning was scored on the four-point scale shown in Table 4 and the degree of burning in the different coupes is shown in Table 6. The post-burn fuels in WR001B were measured using the methods outlined above while the post-burning fuels in WR001A, WR008B and WR008C were estimated subjectively from the areas covered by different burn types. The post-logging, pre-burning and post-logging, post-burning fuel loads are shown in Appendix 2, Figure 3 and Tables 7–9.

Low intensity burning in E. obliqua *wet forest*

WR001B was burnt over two days in late April 1998 while WR008C was burnt in March 2000. The data recorded during these burns have been summarised in Table 10. WR001B was burnt under very mild conditions, which resulted in the fire being hard to light and a very patchy burn. A total of 14 person-days and 170 l of drip-torch fuel were required over two days to burn WR001B.

During the WR001B burn, only areas with a high cover of eucalypt leaves, bark, tea-tree and/or paper-bark burnt, with the fire failing to sustain in other fuel types. In addition, the fire burnt very poorly in shaded areas (e.g. within about 75 m of the eastern, northern and western boundaries). There was little evidence of canopy scorch following the burn.

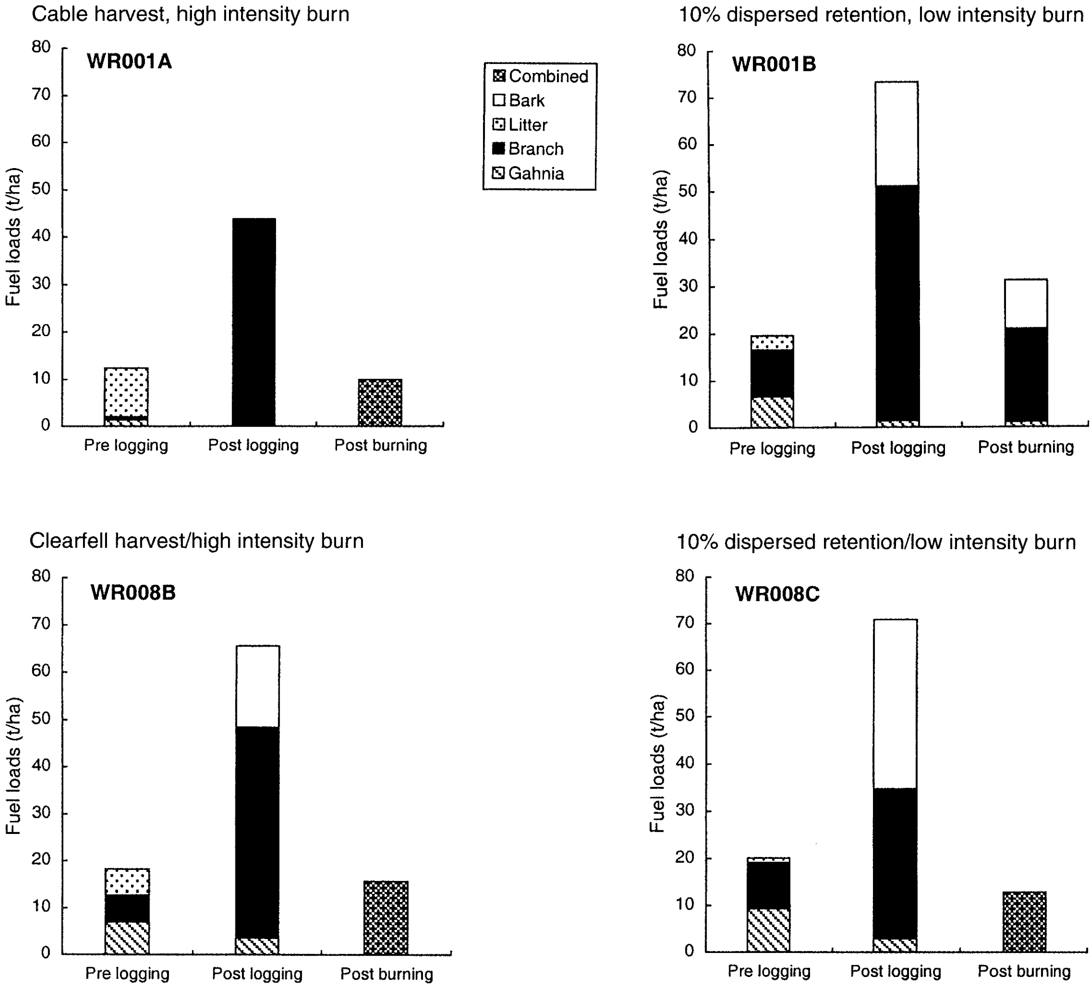

Figure 3. Pre-logging; post-logging, pre-burning; and post-burning fuel loads and composition in all sampled coupes.

The degrees to which the burns affected the retained overstorey in the WR001B and WR008C coupes were measured by J. Dingle and M. Neyland (pers. comm.) and will be published elsewhere. However, the retained trees in WR008C exhibited higher amounts of crown scorch than in WR001B.

Discussion

The major purpose of this study was to examine the fuel characteristics in wet *E. obliqua* forest and the utility of low intensity burning in dispersed retention coupes.

Fuel characteristics

Prior to logging in these forest types, the average near-surface fine fuel load varies from about 13 t/ha in sites with a rainforest understorey up to about 20 t/ha in sites with a wet sclerophyll understorey. These differences are probably the result of variation in the ecological strategy between the different forest types. In wet *E. obliqua* forest, the understorey tends to be dominated by wet sclerophyll species when the burning interval is between about 25 and 100 years while the understorey tends to be dominated by rainforest species when the

Table 6. Post-logging, post-burning percentage of the area of different coupes covered by different burn types.

	Burn class			
Coupe	unburnt	poor	moderate	fully
WR001A	8.3	27.1	4.2	60.4
WR001B	35.7	17.0	27.5	19.9
WR008B	2.6	34.6	15.4	47.4
WR008C	1.7	16.7	31.7	50.0
Average, not including WR001B	4.2	26.1	17.1	52.6
Average, all coupes	12.1	23.9	19.7	44.4

Table 7. Post-logging, post-burning measured fuel loads (t/ha) for different fuel types and diameter classes (mm) in WR001B.

	Live fuel			Slash/litter fuel			Total
Type	< 1	1–6	7–25	< 1	1–6	7–25	fuel
Branch	< 0.1	0.0	0.0	8.3	4.6	6.9	19.8
Bark	-	-	-	5.4	1.0	3.8	10.3
Gahnia	< 0.1	0.1	0.0	0.7	0.1	0.2	01.1
Total	< 0.0	0.1	0.0	14.4	5.8	10.9	31.2

Table 8. Changes in the fuel load (t/ha) following logging and/or burning in WR001B.

	Live fuel			Slash fuel			Litter fuel			Total
	< 1	1–6	7–25	< 1	1–6	7–25	< 1	1–6	7–25	fuel
Post-logging, pre-burning	-2.3	-1.3	-0.9	+18.6	+22.2	+18.4	-	-	-	+54.7
Post-logging, post-burning	-2.4	-1.4	-0.9	+8.2	+2.7	+8.5	-	-	-	+14.7

Table 9. Estimated post-logging, post-burning fuel loads (t/ha) in WR001A, WR008B and WR008C.

	Burn class				
Coupe	unburnt	poor	moderate	fully	Total fuel
WR001A	3.6	5.9	0.5	0.0	10.0
WR008B	1.7	11.3	2.5	0.0	15.6
WR008C	1.2	5.9	5.6	0.0	12.8
Average	2.2	7.7	2.9	0.0	12.8

Table 10. Weather and fire behaviour during the WR001B and WR008C burns.

	28-04-98										29-04-98		
	10:00	11:10	12:00	12:25	12:45	13:30	13:42	14:18	15:05	16:05	11:35	14:00	15:20
WR001B													
Hazard stick: forest	32.0		31.5										
Hazard stick: coupe	24.0	20.5	19.5		19.0								
Temperature, °C	9.0		13	12.0	15.0	16.0		13.5	14.0	13.0	15	14	13
Relative humidity, %	100			92		67		83	90	90	71	90	95
Wind speed, km/hr				0.5		1	0.5	0.5	0.5	0.1	0.5	0.5	0.1
Wind direction				NW		NW	NW	NW	NW	NW	N	NW	NW
Fuel moisture, %				29.0		19.2			24.6			24.8	
Cloud cover				3/8		6/8		7/8	7/8	8/8	5/8	7/8	7/8
Flame height, m						1.25	1.25	1.75	2.5	0.5		<1.5	0.25
Soil Dryness Index:													
Geeveston		58											
Hartz Mt.		23											
Scotts Peak		5											

	09-04-00				
	11:00	12:00	12:30	13:00	13:45
WR008C					
Hazard stick: forest	23.5	19.0			
Hazard stick: coupe	20.0	19.0	18.0	17.5	
Temperature, °C	14.0	16.5	19.0	19.5	20.0
Relative humidity, %	80	72	68	66	66
Wind speed, km/hr	0-5	0-5	0-5	0-5	0-5
Wind direction	NW	NW-W	NW-W	W	W
Cloud cover	2/8	2/8		1/8	1/8
Flame height, m		4.0	4.0	4.0	4.0
Soil Dryness Index:					
Geeveston			145		
Hartz Mt.			51		
Scotts Peak			7		

burning interval is between about 80 and 350 years (Jackson 1968; Jackson and Brown 1999). In order to achieve the relatively high fire frequencies required in wet sclerophyll forests, the forests would need to carry high fuel loads which have a high flammability. In contrast, mixed forests have a lower fire frequency and tend to have correspondingly lower fuel loads and a lower flammability.

Following logging, these fuel loads increased to between about 40 and 85 t/ha. The differences in post-logging fuel loads almost certainly relate to differences in logging technique. In the cable-logged WR001A coupe, a large proportion of the fuel was located in the coupe's very large bark dump. In contrast, in WR001B and WR008C, the bark dumps were much smaller and as a result the fuel loads in the coupe were correspondingly higher. WR008B had bark dumps which were intermediate in size and its fuel loads were correspondingly intermediate in weight. Where these coupes have been burnt in a typical high intensity regeneration burn, the majority of the fine fuel was removed. In contrast, in the WR001B coupe which was burnt in a lower intensity fire, about half of the fuel remained unburnt.

Low intensity burning in wet eucalypt forests following logging

The second major aim of this project was to assess the applicability of low intensity burning in these forests following logging. In WR001B when the fuel moisture was high, it was relatively easy to perform a low intensity burn following logging, although at the cost of removing only about half the fine fuel and creating only relatively small areas of ash bed. In WR008C, the fire encountered considerably lower moistures in the medium to heavy fuels (reflected in its higher Soil Dryness Index, Table 10) than was the situation during the WR001B burn. It can also be seen from the data on the degree to which the retained trees were affected by the burn (J. Dingle and M. Neyland, pers. comm.) that the fuel moisture during the burn is a critical factor determining the outcomes of the burn.

The utility of low intensity burning in these wet eucalypt forests depends on several factors. These factors include:

- Whether the regeneration of the next crop of eucalypts is considered adequate;
- Survival and growth rates of the regeneration;
- Degree to which species such as *Gahnia* grow and compete with the eucalypts;
- Whether the level of fire risk is considered to have been adequately reduced; and
- Resources required to perform the burns.

In WR001B, the fire appears to have had minimal adverse effects on the retained overstorey trees (J. Dingle and M. Neyland, pers. comm.). However, a significant proportion of the fuel remains unburnt and should a subsequent fire occur under dry conditions then it is highly likely that the fire will be of high enough intensity to kill any regenerating eucalypts, possibly along with the retained overstorey trees. In addition, observational evidence in WR001B suggests that there may be high covers of *Gahnia* within the next few years. If this is the case, then high levels of fuel risk in the WR001B coupe will be maintained for the foreseeable future. In contrast, the fire in WR008C was of significantly higher intensity and resulted in almost all of the fuel being removed but also resulted in considerable crown scorch (J. Dingle and M. Neyland, pers. comm.).

The prescriptions detailed in Table 5 provide a useful indication of the suitable conditions for performing low intensity burns in dispersed retention coupes. However, it is recommended that these prescriptions be further refined to include the Soil Dryness Index. From the observed weather (Table 10) and data on impacts of burns on retained trees, we recommend that these low intensity burns should be conducted using prescriptions detailed in Table 5 and when the Soil Dryness Index is between 30 and 40.

Another factor that needs to be considered with low intensity wet eucalypt burns relates to the personnel required to perform the burns. Due to the small coupe size and the presence of retained overstorey trees, the use of helicopters to perform aerial ignition is not feasible and so the only option is hand ignition. During the WR001B burn, a total of 14 person-days were required, while during the WR008C burn seven person-days were required. Operationally, the requirement for these numbers of personnel means that it would not be feasible to perform more than about two burns of this type per day.

Within the silvicultural systems trial at the Warra LTER Site, all of the coupes were orientated north–south (Figure 2, Photos 1– 3). With the exception of WR008B (which was wider than the other coupes and had a low ridge running through its centre, Photo 3) the orientation and aspect of the coupes resulted in the edges of the coupes being shaded and therefore having high fuel moistures along their boundaries. This edge shading was particularly a problem along the western and southern edges of the coupes. It may also be a significant problem in the retained overstorey coupes where the remaining trees could act to shade the surface fuels and possibly reduce wind speeds at ground level. During the WR008C burn, this problem resulted in the fire not drawing in from the edges and partly as a result crossing its boundaries on the eastern side. In order to address this issue, consideration should be given to increasing the size of coupes which have southerly aspects and/or a retained overstorey to a minimum of about 20 ha and avoiding long narrow coupe shapes.

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Appendix 1. Pre-logging fuel loads (t/ha).

	Fuel type and cover class (%)																				
	Gahnia					Branch					Litter wet sclerophyll					Litter rainforest					
	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	Total fuel load
WR001A—patchfall using cable machinery																					
Live 0–6 mm	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Live 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dead 0–6 mm	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Dead 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Litter 0–6 mm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.1	0.0	0.1	0.4	0.4	0.0	0.3	0.9	3.2	2.9	9.3
Litter 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.2	0.7	0.8	2.0
Total fuel load	0.2	0.2	0.3	0.3	0.3	0.1	0.2	0.1	0.4	0.0	0.1	0	0.1	0.5	0.6	0.0	0.3	1.1	3.9	3.7	12.4
WR001B—10% dispersed retention using ground-based machinery																					
Live 0–6 mm	0.1	0.3	0.6	0.7	0.2	0.1	0.3	0.6	0.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9
Live 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Dead 0–6 mm	0.0	0.2	0.8	0.7	0.1	0.1	0.9	0.6	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
Dead 7–25 mm	0.0	0.0	0.1	0.1	0.0	0.0	0.4	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Litter 0–6 mm	0.1	0.6	0.6	0.6	0.2	0.3	0.6	1.0	1.5	0.2	0.1	0.3	1.2	0.6	0.1	0.0	0.0	0.0	0.0	0.0	8.0
Litter 7–25 mm	0.0	0.2	0.2	0.1	0.0	0.1	0.1	0.2	0.3	0.1	0.0	0.1	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	2.0
Total fuel load	0.2	1.3	2.3	2.2	0.5	0.6	2.4	3.1	3.4	0.6	0.1	0.4	1.5	0.8	0.2	0.0	0.0	0.0	0.0	0.0	19.6
WR008B whole coupe—clearfall using ground-based machinery																					
Live 0–6 mm	0.1	0.2	0.1	0.6	1.2	0.1	0.2	0.2	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2
Live 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Dead 0–6 mm	0.1	0.2	0.2	0.6	0.6	0.1	0.7	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Dead 7–25 mm	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Litter 0–6 mm	0.3	0.5	0.1	0.5	1.0	0.4	0.5	0.3	0.8	0.2	0.0	0.0	0.2	0.8	0.2	0.2	0.5	0.4	1.1	1.0	9.0
Litter 7–25 mm	0.1	0.1	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.1	0.1	0.3	0.2	2.1
Total fuel load	0.6	1.0	0.4	1.9	3.0	0.7	1.9	1.0	1.6	0.5	0.0	0.0	0.3	1.1	0.3	0.2	0.6	0.5	1.4	1.2	18.2
WR008B wet sclerophyll zone																					
Live 0–6 mm	0.2	0.4	0.2	0.8	1.7	0.1	0.3	0.2	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6
Live 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Dead 0–6 mm	0.2	0.2	0.2	0.9	0.8	0.1	1.0	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
Dead 7–25 mm	0.1	0.0	0.0	0.2	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Litter 0–6 mm	0.5	0.7	0.2	0.7	1.4	0.5	0.6	0.4	1.1	0.3	0.0	0.1	0.3	1.1	0.3	0.0	0.0	0.0	0.0	0.0	8.2
Litter 7–25 mm	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.1	0.4	0.2	0.0	0.0	0.0	0.0	0.0	2.1
Total fuel load	1.1	1.5	0.7	2.7	4.2	0.8	2.6	1.2	2.3	0.7	0.0	0.1	0.4	1.5	0.5	0.0	0.0	0.0	0.0	0.0	20.3
WR008B rainforest zone																					
Litter 0–6 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.7	1.5	3.5	3.4	0.0	0.0	0.0	0.0	0.0	10.7
Litter 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.9	0.8	0.0	0.0	0.0	0.0	0.0	2.2
Total fuel load	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.9	1.7	4.4	4.2	0.0	0.0	0.0	0.0	0.0	12.9
WR008C—10% dispersed retention using ground-based machinery																					
Live 0–6 mm	0.1	1.0	0.6	0.3	0.3	0.1	0.5	0.4	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
Live 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Dead 0–6 mm	0.1	0.7	0.8	0.3	0.2	0.1	1.4	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
Dead 7–25 mm	0.0	0.1	0.1	0.1	0.0	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Litter 0–6 mm	0.3	2.0	0.6	0.3	0.3	0.7	1.0	0.7	1.0	0.2	0.2	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9
Litter 7–25 mm	0.1	0.6	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Total fuel load	0.6	4.4	2.3	1.1	0.9	1.1	3.9	2.1	2.2	0.5	0.2	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.1

Appendix 2. Post-logging, pre-burning fuel loads (t/ha).

	Fuel type and cover class (%)																				
	Gahnia					Branch					Bark					Litter*					
	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	0 to 20	21 to 40	41 to 60	61 to 80	81 to 100	Total fuel load
WR001A																					
Live 1–6 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dead 1–6 mm	0.0	0.0	0.0	0.0	0.0	1.0	2.3	5.3	9.7	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.6
Dead 7–25 mm	0.0	0.0	0.0	0.0	0.0	0.5	1.2	2.8	4.9	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2
Totals	0.0	0.0	0.0	0.0	0.0	1.5	3.5	8.1	14.6	16.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.8
WR001B																					
Live 1–6 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Dead 1–6 mm	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.6	2.5	31.6	0.0	0.0	1.1	1.5	14.0	0.0	0.0	0.2	0.0	0.0	52.6
Dead 7–25 mm	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	1.2	13.3	0.0	0.0	0.2	0.2	5.0	0.0	0.0	0.0	0.0	0.0	20.4
Totals	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.9	3.7	45.0	0.0	0.0	1.3	1.7	19.0	0.0	0.0	0.2	0.0	0.0	73.1
WR008B																					
Live 1–6 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Dead 1–6 mm	0.0	0.0	0.5	0.0	2.4	0.2	0.2	0.6	4.1	26.1	0.0	0.4	1.4	1.4	9.9	0.0	0.0	0.0	0.0	0.0	47.2
Dead 7–25 mm	0.0	0.0	0.2	0.0	0.4	0.1	0.1	0.3	2.1	11.0	0.0	0.2	0.2	0.2	3.5	0.0	0.0	0.0	0.0	0.0	18.3
Totals	0.0	0.0	0.7	0.0	2.8	0.3	0.3	0.9	6.2	37.2	0.0	0.6	1.6	1.6	13.4	0.0	0.0	0.0	0.0	0.0	65.6
WR008C																					
Live 1–6 mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dead 1–6 mm	0.0	0.0	1.0	0.0	1.4	0.5	0.2	0.9	3.5	16.7	0.0	0.4	0.0	13.2	15.0	0.0	0.0	0.3	0.0	0.0	53.1
Dead 7–25 mm	0.0	0.0	0.3	0.0	0.2	0.3	0.1	0.5	1.8	7.0	0.0	0.2	0.0	2.1	5.3	0.0	0.0	0.1	0.0	0.0	17.9
Totals	0.0	0.0	1.3	0.0	1.6	0.8	0.3	1.4	5.3	23.7	0.0	0.6	0.0	15.3	20.3	0.0	0.0	0.4	0.0	0.0	71.0

* Note: some litter fuel loads were able to be sampled in areas unaffected by logging.