Loss of carbon during controlled regeneration burns in *Eucalyptus obliqua* forest

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Abstract

The objective of this study was to estimate the amount of carbon lost to the atmosphere due to volatilisation during controlled regeneration burns. The work was undertaken in Eucalyptus obliqua *wet forests at the Warra Long-Term Ecological Research (LTER) Site in the Southern Forests of Tasmania. The results show that 58–63% of the total weight of organic material and its carbon content was lost to the atmosphere during burning. The majority of carbon loss was from slash greater than 7.0 cm in diameter.*

Little work has been done on the effect of slash burning on carbon emissions to the atmosphere. If a significant amount of carbon is lost annually as a consequence of controlled regeneration burns, this practice may need to be taken into account when calculating carbon sequestration for Australian forests.

Introduction

Australia is a signatory to the 1992 Framework Convention on Climate Change (FCCC) and the 1997 Kyoto Protocol. These agreements oblige nations to co-operate in order to achieve the objective of stabilising atmospheric concentrations of greenhouse gases at a level that reduces anthropogenic interference with the climate system. In these documents, the parties have agreed to adopt national policies aiming to return emissions of greenhouse gases to specified percentages of the 1990 levels. In September 1997, a meeting of experts on biomass burning and land-use change and forestry was held in Australia. It suggested that the effects of anthropogenic fires should be included in national inventories (IPCC 1997). Little work has been done on the effect of controlled regeneration burning on carbon emissions to the atmosphere. If a significant amount of carbon is lost annually as a consequence of controlled regeneration burning, this practice should be taken into account when calculating carbon sequestration for Australian forests.

In wet eucalypt forests, controlled regeneration burning is used to expose the seedbed for regeneration of the forest after harvesting. Burning acts to remove forest litter, bark and branches from the forest floor and heats the soil to provide better germination conditions. However, combustion of organic matter leads to the release of carbon dioxide (CO_2) into the atmosphere. During fires, carbon is (Beorner 1982):

- Lost to the atmosphere via volatilisation or ash convection;
- Deposited on site as ash; and
- Left on site as unburnt material.

The objective of this study was to estimate the amount of carbon lost to the atmosphere, due to volatilisation, during regeneration burns in *Eucalyptus obliqua* wet forests at the Warra Long-Term Ecological Research (LTER) Site in the Southern Forests of Tasmania (Figure 1).

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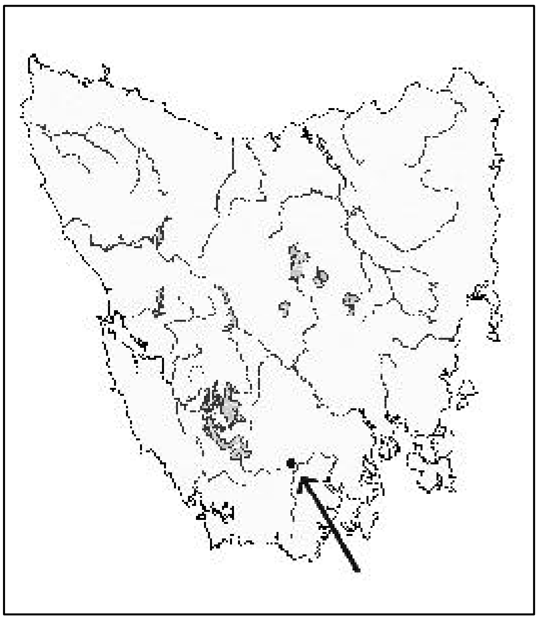

Figure 1. Location of the Warra LTER Site in southern Tasmania.

Method

Study area

Within the Warra LTER Site, *E. obliqua* wet forest is the dominant forest type. Fuel characteristics were examined in the following community types:

- *Eucalyptus obliqua* wet sclerophyll forest with a wet sclerophyll understorey;
- *Eucalyptus obliqua* mixed forest with a thamnic rainforest understorey and litter fuels; and
- *Eucalyptus obliqua* mixed forest with a callidendrous rainforest understorey and litter fuels.

Sampling

To determine the biomass loading in this study, destructive and non-destructive sampling methods were used. All the biomass less than 2.5 cm in diameter was sampled as part of another study (Marsden-Smedley and Slijepcevic 2001; Slijepcevic and Marsden-Smedley 2001).

Destructive sampling, using regular and stratified random sampling.—These methods were used to quantify the biomass less than 2.5 cm in diameter. The range in fuel characteristics present in the coupes was determined using regular sampling. The method involved running transects and recording biomass height / depth and cover at ten-metre intervals. On all transects, more than 100 sampling points were established (Marsden-Smedley and Slijepcevic 2001).

Fuel plots were selected using stratified random sampling in order to cover the full range of variation in fuels, determined from the transect data. Fuel loads were sampled using 1 m x 1 m plots. In each of the coupes, vegetation smaller than 2.5 cm in diameter was collected from 30 plots by using a hedge-trimmer and / or chainsaw to cut through the fuel array to the soil surface.

It was very difficult to separate litter (L horizon) and duff (F and H soil horizons) from slash after logging when the fuel was pushed to the ground. Litter was included in slash sampling, whilst duff was sampled as a part of soil within each plot. The vegetation collected from each plot was sorted into size classes of 0–0.1 cm, 0.1–0.6 cm and 0.6–2.5 cm. Biomass samples were then oven dried and weighed.

Non-destructive sampling, using the line intercept method.— This method was used to quantify the biomass greater than 2.5 cm in diameter. Three to five equilateral triangles with 15 m sides were located randomly within each burn site. The number of woody biomass pieces, between 2.5 and 7.0 cm in diameter, that intersected the sampling line were recorded by size class in the appropriate length of the sample lines (Figure 2). For example, pieces between 2.5 and 5.0 cm in diameter were only recorded in the first five metres of each side of the triangle and for each increase in size class the recording distance increased by five metres. The diameters of all pieces greater than 7.0 cm were recorded and a nail hammered in at the point of measurement so that post-burn diameter measurements could be made at the same place. The slope on each side of the triangle was measured using a clinometer. Counting and measurement of slash were carried out before and after the burn.

Weights of slash less than 7.0 cm and greater than 7.0 cm in diameter were calculated by using the following two equations respectively (after Van Wagner 1968; Brown 1971; Brown and Roussopoulus 1974; McRae *et al.* 1979; Robertson 1998):

$$W = \frac{\frac{\Pi^2}{8} \times n \times QMD^2 \times s \times a \times c}{L}$$

or

$$W = \frac{\frac{\Pi^2}{8} \times (\sum d^2) \times s \times a \times c}{L}$$

where

W	=	weight of slash expressed in tonnes per hectare (t/ha),
n	=	number of intersections,
QMD	=	quadratic mean diameter, can be used in place of d,
d	=	diameter (cm),
s	=	wood density (g/cm^3),
a	=	angle correction (see Table 1),
c	=	slope correction (see Table 2),
L	=	length of line (m).

The angle correction factor (Table 1) adjusts biomass weight estimates for the fact that all particles do not lie horizontally as assumed in the line intercept theory. Brown and Roussopoulus (1974) show that if no adjustment for non-horizontal orientation of slash is made biomass weight loadings could be underestimated by 8–39%.

Slope correction factors (Table 2) convert biomass loadings on a slope basis to loadings on a horizontal basis and are calculated using the following formula:

$$c = \sqrt{1 + (\frac{\%slope}{100})^2}$$

(McRae *et al.* 1979).

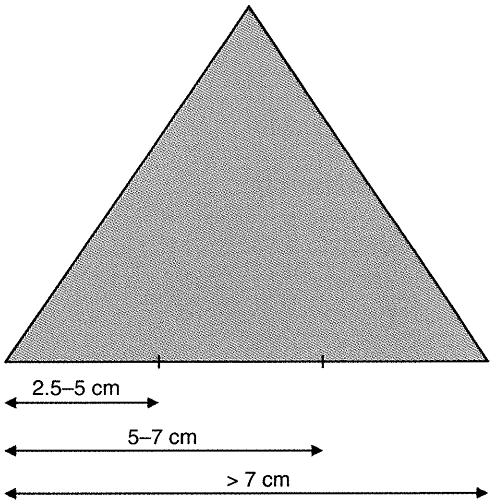

Figure 2. Line intercept triangle, and the size class measurements required along each side of the triangle (after Robertson 1998).

Table 1. Average angle correction factor of non-horizontal particles.

Size class diameter (cm)	Angle correction factor (a)
2.50–4.99	1.1
5.00–6.99	1.1
7.00+	1.0

Table 2. Slope correction factors (c) (McRae *et al.* 1979).

Slope (%)	Correction factor
0	1.000
10	1.005
15	1.011
20	1.020
25	1.031

For the 2.50–4.99 and 5.00–6.99 cm size classes, two diameter measurements at the mid point of the branch, with a 90 degree angle between measurements, were recorded. The quadratic mean diameter (QMD) for each

Table 3. Quadratic mean diameter for species and size classes.

Species		Diameter class (cm)	
Scientific name	Common name	2.50–4.99	5.00–6.99
Eucalyptus obliqua	stringybark	3.81	5.27
Nothofagus cunninghamii	myrtle	4.10	5.69
Atherosperma moschatum	sassafras	4.75	5.86
Leptospermum lanigerum	woolly tea-tree	4.25	5.67
Phyllocladus aspleniifolius	celery-top pine	3.95	6.16
Acacia melanoxylon	blackwood	-	-

size class and species can be seen in Table 3. The QMD is calculated using the following formula (Van Wagner 1982):

$$QMD = \sqrt{\frac{\sum d^2}{n}}$$

where

d = diameter measurement

n = number of measurements taken.

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 (Table 4). Wood pieces were fully saturated in distilled water prior to obtaining displacement weight. The surface of samples was then cleaned of any remaining sawdust and dirt, and green weights were recorded. A bucket of distilled water was placed under the scales and the scales set to zero. The sample was then lowered into the bucket until it was just covered by water and the displacement weight (DW) in grams recorded. The green volume (GV) is equivalent to green weight minus the water displacement weight.

All samples were placed in the 105°C oven until no further weight loss occurred and the oven dry weight (ODW) in grams recorded. The following formula allows calculation of density (s) in g/cm³.

$$s = \frac{ODW}{GV}$$

Table 4. Species density.

Species	Diameter class (cm)	Wood density (g/cm³)
Eucalyptus – solid	2.50–4.99	0.5996
	5.00–6.99	0.5702
	> 7.00	0.5615
– rotten	> 7.00	0.5299
Myrtle	2.50–4.99	0.5501
	5.00–6.99	0.5697
	> 7.00	0.5844
Sassafras	2.50–4.99	0.6343
	5.00–6.99	0.5770
	> 7.00	0.6223
Celery-top pine	2.50–4.99	0.6409
	5.00–6.99	0.6959
	> 7.00	0.6439
Tea-tree	2.50–4.99	0.6754
	5.00–6.99	0.6447
	> 7.00	0.6666
Blackwood	2.50–4.99	0.5301
	5.00–6.99	0.5615
	> 7.00	0.6421

Bark heaps and landings

The volume of the bark heaps and landings were measured and then sub-sampled to determine the ratio of bark and woody material in them. The volume was determined using mensuration formulas (Beyer 1984). Weights of bark content were obtained by drying the bark at 105°C in trays of known volume until no further weight loss occurred.

Analysis of soil carbon content

Soil organic carbon was estimated by the Walkley and Black method, which involves wet oxidation by a dichromate-sulfuric acid mixture (Rayment and Higginson 1992).

From each corner of a triangle, six samples of mineral soil (0–10 cm) were collected and bulked. To determine the bulk density, three additional soil samples were taken from each corner. Sample positions were marked on maps to ensure that the post-burn sampling would represent the same area and depth. All samples were air dried at 30–40°C for at least 27 hours, and then ground and sieved to less than 2 mm. The bulk density samples were taken for two separate layers: 0–5 and 5–10 cm. Samples were then oven dried and weighed. The bulk density was estimated using the following formula:

$$bd = \frac{ODW}{V}$$

where

bd = bulk density (g/cm^3),
ODW = oven-dry weight of whole sample (g),
V = volume (cm^3).

Conversion of biomass to carbon contents

The amount of carbon stored within terrestrial ecosystems can be estimated by applying a conversion factor to biomass estimates. The average per cent carbon contents of softwood and hardwoods are reported to be 52.1% and 49.1% of dry matter by mass, respectively (Birdsley 1990). A conversion factor of 50% is frequently used to estimate the organic carbon content of plant tissues (Matthews 1993) and was used in this study. This conversion factor was also used for calculating the carbon content of ash. The amount of ash was estimated using the method of Marsden-Smedley and Slijepcevic (2001).

Results

Before burning

Following logging, fuel loads were between 509 and 774 t/ha. The differences in fuel loads are probably the result of variation in fire history, geological type and the different logging techniques used (Table 5, see Marsden-Smedley and Slijepcevic 2001). Most of the fuel loads in WR001A, WR008B and WR008C (i.e. 359.4, 609.9 and 365.8 t/ha respectively, Appendix 1) were in large fuels (> 7.0 cm) spread throughout the coupes. Bark heaps and landings accounted for 199.4, 6.7 and 15.4 t/ha (Appendix 2) respectively. Fine fuels (< 2.5 cm in diameter) contributed an additional 40 to 71 t/ha (Appendix 1).

After burning

This study found that 58–63% of the total weight of organic material and its carbon content was lost to the atmosphere during burning (Table 6). The majority of weight loss was from slash greater than 7.0 cm in diameter (Appendix 1).

In most cases during the post-burn sampling, it was not possible to separate the remaining biomass into size classes because most of it was in the form of ash. For that reason, most of that post-burn biomass is shown as fine fuels (Appendix 1).

Ninety-four per cent of the biomass that was pushed into bark/log heaps and landings was burnt as a result of fuel arrangements. The bark/log heaps and landings remained burning and smouldering for at least two weeks after burns were conducted. The heaviest fuel load was in WR001A as a result of the logging technique used (Table 5, see Marsden-Smedley and Slijepcevic 2001).

Soil carbon

Data from all three sites sampled are very inconclusive and therefore did not provide any evidence of carbon loss or gain from the upper soil layers after burning (Table 7).

Table 5. Understorey types and logging techniques.

Coupe	Understorey	Logging technique
WR001A	Callidendrous rainforest	Patchfall/stripfell using cable
WR008B	Wet sclerophyll/thamnic rainforest	Clearfall using ground machinery
WR008C	Wet sclerophyll forest	10% dispersed retention using ground machinery

Table 6. Average biomass and carbon loss for all coupes included in this study.

	Biomass			Carbon			
						Loss	
Coupe	Pre-burn (t/ha)	Post-burn (t/ha)	Loss (t/ha)	Pre-burn (t/ha)	Post-burn (t/ha)	(t/ha)	(%)
WR001A	667.2	248.8	418.4	333.6	124.4	209.2	63
WR008B	773.3	320.5	452.8	386.7	160.3	226.4	58
WR008C	509.3	201.1	308.2	254.7	100.6	154.1	61

Table 7. Average soil carbon content (t/ha) for all coupes included in this study.

Coupe	Pre-burn	Post-burn
WR001A	52.7	51.4
WR008B	39.4	47.4
WR008C	52.7	51.4

Discussion

The amount of carbon released to the atmosphere during controlled regeneration burning was between 154.1 and 226.4 t/ha (an average of 196.7 t/ha). The result shows that most (64–76%) of the carbon released came from fuels greater than 7.0 cm in diameter. This finding contradicts a common opinion that during regeneration burns only fine fuels are removed.

The results from this study show that a significant amount of carbon is lost to the atmosphere as a result of regeneration burning. Further research is required under a wide range of heavy fuel moisture (predicted by the Soil Dryness Index, Mount 1972, see Marsden-Smedley and Slijepcevic 2001) to develop a system for modelling carbon loss from controlled burns in wet *E. obliqua* forests. Further work is also required in all Tasmanian forest types in which timber production takes place. A review of the national extent of prescribed burning is needed to determine whether the practice should be included in calculation of carbon sequestration of Australian forests.

Acknowledgements

Thanks to Dr Jon Marsden-Smedley for his effort and advice throughout this study. The comments provided by Dr Mick Brown, Dr Wendy Catchpole, John Hickey and Ben Merritt are greatly appreciated. The contribution of Phil Pennington of CSIRO on the soil carbon section is also appreciated.

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Appendix 1. Pre- and post-burn biomass and carbon loads (t/ha).

Biomass component	Size class (cm)	Biomass Pre-burn (t/ha)	Biomass Post-burn (t/ha)	Biomass Loss (t/ha)	Carbon Pre-burn (t/ha)	Carbon Post-burn (t/ha)	Carbon Loss (t/ha)	Carbon Loss %
WR001A								
Fine fuels	0.0–0.60	29.6	6.7	22.9	14.8	3.4	11.4	77
combined	0.61–2.50	14.2	2.3	11.9	7.1	1.2	5.9	84
E. obliqua	2.51–5.00	2.9	0.0	2.9	1.5	0.0	1.5	100
– solid	5.01–7.00	6.6	0.0	6.6	3.3	0.0	3.3	100
	7.01+	252.4	182.6	69.8	126.2	91.3	34.9	28
E. obliqua	2.51–5.00	0.0	0.0	0.0	0.0	0.0	0.0	0
– rotten	5.01–7.00	0.0	0.0	0.0	0.0	0.0	0.0	0
	7.01+	2.4	0.0	2.4	1.2	0.0	1.2	100
Sassafras	2.51–5.00	5.7	0.0	5.7	2.8	0.0	2.8	100
	5.01–7.00	16.5	0.0	16.5	8.3	0.0	8..3	100
	7.01+	32.8	19.6	13.2	16.4	9.8	6.6	40
Blackwood	2.51–5.00	0.0	0.0	0.0	0.0	0.0	0.0	0
	5.01–7.00	0.0	0.0	0.0	0.0	0.0	0.0	0
	7.01+	9.8	2.3	7.5	4.9	1.1	3.8	78
Myrtle	2.51–5.00	0.5	0.0	0.5	0.2	0.0	0.2	100
	5.01–7.00	7.2	0.0	7.2	3.6	0.0	3.6	100
	7.01+	62.0	33.6	28.4	31.0	16.8	14.2	46
Celery-top pine	2.51–5.00	0.0	0.0	0.0	0.0	0.0	0.0	100
	5.01–7.00	0.8	0.0	0.8	0.0	0.0	0.0	100
	7.01+	0.0	0.0	0.0	0.0	0.0	0.0	100
Totals	2.51–5.00	9.1	0.0	9.1	4.5	0.0	4.5	100
	5.01–7.00	31.1	0.0	31.1	15.6	0.0	15.6	100
	7.01+	359.4	238.1	121.3	179.7	119.0	60.7	34
Total (all sizes)		443.4	247.3	196.1	221.7	123.7	98.0	44
WR008B								
Fine fuels	0.01–0.60	47.3	10.6	36.7	23.6	5.4	18.2	77
combined	0.61–2.50	18.3	5.2	13.1	9.1	2.6	6.5	71
E. obliqua	2.51–5.00	3.2	0.0	3.2	1.6	0.0	0.6	100
– solid	5.01–7.00	10.5	0.0	10.5	5.3	0.0	5.3	100
	7.01+	266.4	170.2	96.2	133.2	85.1	48.1	36
E. obliqua	2.51–5.00	0.0	0.0	0.0	0.0	0.0	0.0	0
– rotten	5.01–7.00	0.0	0.0	0.0	0.0	0.0	0.0	0
	7.01+	183.3	98.9	84.4	91.7	49.5	42.2	46
Sassafras	2.51–5.00	4.4	0.0	4.4	2.2	0.0	2.2	100
	5.01–7.00	20.1	0.0	20.1	10.0	0.0	10.0	100
	7.01+	48.7	6.6	42.1	24.4	3.3	21.1	86

Appendix 1. Continued.

Biomass component	Size class (cm)	Biomass Pre-burn (t/ha)	Biomass Post-burn (t/ha)	Biomass Loss (t/ha)	Carbon Pre-burn (t/ha)	Carbon Post-burn (t/ha)	Carbon Loss (t/ha)	Carbon Loss %
WR008B (continued)								
Celery-top pine	2.51–5.00	4.0	0.0	4.0	2.0	0.0	2.0	100
	5.01–7.00	22.0	0.0	22.0	11.0	0.0	11.0	100
	7.01+	57.5	0.3	57.2	28.7	0.1	28.6	100
Tea-tree	2.51–5.00	3.5	0.0	3.5	1.8	0.0	1.8	100
	5.01–7.00	20.6	0.0	20.6	10.3	0.0	10.3	100
	7.01+	54.0	28.2	25.8	27.0	14.1	12.9	48
Totals	2.51–5.00	15.1	0.0	15.1	7.5	0.0	7.5	100
	5.01–7.00	73.2	0.0	73.2	36.6	0.0	36.6	100
	7.01+	609.9	304.2	305.7	305.0	152.1	152.9	50
Total (all sizes)		763.8	320.0	443.8	381.9	160.0	221.9	58
WR008C								
Fine fuels combined	0.01–0.60	53.1	8.5	44.6	26.6	4.3	22.3	84
	0.61–2.50	17.9	4.3	13.6	9.0	2.2	6.8	76
E. obliqua – solid	2.51–5.00	4.7	0.4	4.3	2.4	0.2	2.2	92
	5.01–7.00	4.6	0.0	4.6	2.3	0.0	2.3	100
	7.01+	208.5	95.6	112.9	104.2	47.8	56.4	54
E. obliqua – rotten	2.51–5.00	0.0	0.0	0.0	0	0.0	0.0	0
	5.01–7.00	0.0	0.0	0.0	0	0.0	0.0	0
	7.01+	121.2	71.8	49.4	60.6	35.9	24.7	41
Sassafras	2.51–5.00	2.1	0.0	2.1	1.1	0.0	1.1	100
	5.01–7.00	5.9	0.0	5.9	2.4	0.0	2.4	100
	7.01+	12.1	4.6	7.5	6.1	2.3	3.8	62
Tea-tree	2.51–5.00	9.4	1.1	8.3	4.7	0.6	4.1	87
	5.01–7.00	27.2	2.4	24.8	13.6	1.2	12.4	91
	7.01+	24.0	11.9	12.1	12.0	6.0	6.0	50
Totals	2.51–5.00	16.2	1.5	14.7	8.1	0.7	7.4	86
	5.01–7.00	37.7	2.4	35.3	18.9	1.2	17.7	94
	7.01+	365.8	183.9	181.9	182.9	92.0	90.9	50
Total (all sizes)		490.7	200.7	290.0	245.4	100.4	145.0	59

Appendix 2. Bark heap or landing weights.

Coupe	Biomass			Carbon			
	Pre-burn (t/ha) (total)	Post-burn (t/ha)	Loss (t/ha)	Pre-burn (t/ha)	Post-burn (t/ha)	Loss (t/ha)	Loss %
WR001A							
bark	24.4 (146.5)	0.5	23.9	12.2	0.25	12.0	98
wood	199.4 (1196.3)	1	198.4	99.7	0.5	99.2	99
WR008B							
bark	2.8 (56.8)	0.5	2.3	1.4	0.25	1.1	79
wood	6.7 (137.8)	0.0	6.7	3.4	0.0	3.4	100
WR008C							
bark	3.2 (33.9)	0.4	2.7	1.6	0.2	1.4	88
wood	15.4 (162.8)	0.0	15.4	7.7	0.0	7.7	100