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Final Report on the Mechanical Fuel Load Reduction Trials Draft 4.7

Editor - John Samuel (NSW DPI); contributors Scott Arnold (VicForests), Mark Dury (FCNSW), Michael Mclean, Kate Wright, Fabiano Ximenes, Amrit Kathuria (NSW DPI), Justine Edwards, Mark Brown (USC), Andrew Sullivan, Matt Plucinski, Will Swedosh (CSIRO), Jacki Schirmer, Mel Mylek (UC), Mauricio Acuna, Rick Mitchell (AFORA, USC), Glen Murphy (G.E Murphy & Associates), Paul de Mar, Seamus Hoban (GHD), Liubov Volkova, Christopher J. Weston (UoM)

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Acknowledgments

This report forms a component of the Mechanical Bushfire Fuel Load Reduction trials. The Australian Government is providing $1.5 million, under a National Partnership with the NSW Government, to undertake the Mechanical Bushfire Fuel Load Reduction trials. These trials are part of the National Bushfire Mitigation Programme (NBMP), which provided $15 million over a period of three years to states and territories to implement long-term bushfire mitigation strategies and improved fuel reduction activities. These trials were also granted $127,000 by the Commonwealth Department of Agriculture, Water and the Environment. On 1 July 2022, the agriculture and water component became the Department of Agriculture, Fisheries and Forestry (DAFF), while the environment component became the new Department of Climate Change, Energy, the Environment and Water.

The trials are indebted to the Oversight Committee members from DAWR (Julie Gaglia), NSW DPI (Dr. Christine Stone), Timber Queensland (Mick Stephens) and Forest Fire Management Group (FFMG)/ Forest Corporation of NSW (Tim McGuffog, later replaced by Peter Walters) and Technical Committee from University of Melbourne (Prof. Rod Keenan), CSIRO (Dr. Andrew Sullivan), NSW DPI (Dr. Fabiano Ximenes), University of Sunshine Coast (Prof. Mark Brown) and AFPA (Ross Hampton). Thanks to Pearl Fleming, Funding Arrangement Manager, Community Grants Hub, Department of Social Services.

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1 Executive summary

1.1 Rationale and study sites

The rationale for the mechanical fuel load reduction trials was to investigate an alternative form of fuel mitigation through mechanical intervention which could offer advantages over conventional prescribed fire in certain strategic locations. Mechanical reduction of fuel load offers a number of significant additional advantages alongside conventional prescribed fire in many hazard situations but is a relatively new concept in Australia despite being widely adopted in the United States and Canada. Its potential for application in Australia is significant.

These advantages relate to:

- community concerns over smoke and air quality
- the narrow window of weather days for undertaking fuel reduction burning
- risk management, in terms of managing fuel loads in areas that are in close proximity to population centres or other important assets including conservation areas and infrastructure
- addressing tree overstocking and upper strata (i.e. ladder) fuels
- utilising a potential market (i.e. return) from the sale of biomass fuels that can help offset treatment costs.

The trials, funded by the Commonwealth, were undertaken in New South Wales, Victoria and Western Australia in different forest types and growth stages. Forestry Corporation NSW partnered with NSW DPI, VicForests partnered with the University of Melbourne and the University of Sunshine Coast partnered with a consortium of WA Agencies. Fuel treatments consisted of mechanical-only (thinning trees), prescribed fire only and combined mechanical and prescribed fire, with a control of no treatment. Pre and post-treatment measurements of fuels, trees, coarse woody debris and biodiversity were undertaken. Mechanical treatment undertaken at the sites was the thinning of trees as proposed by the bidding agencies, responding to a competitive call for proposals.

This report utilises edited extracts of the trial participants reports. Prescribed fire is used in this report which is also referred elsewhere as prescribed burning or hazard reduction burning.

The Royal Commission into National Natural Disaster Arrangements[1] following the 2019-20 bushfires found that fuel management activities are generally designed to enhance and support the effectiveness of other complementary prevention, preparation and response measures; particularly fire suppression. However, in extreme bushfires, fuel loads do not appear to have a material impact on fire behaviour. Even in severe weather conditions, substantially reducing fuel availability in the areas surrounding assets should reduce fire intensities and consequent risk. Reducing available fuels in the landscape can also slow the initial rate of fire spread and fire intensity, which can provide opportunities for fire suppression and thereby reduce the risk of fires escalating into extreme fire events.

1.2 Key results

Operationally, following mechanical treatment, either prescribed fire is required unless the litter and near surface fuel loads generated by the mechanical treatment are reduced through mulching or removed. Removal is more likely needed in near urban interface forests, where burning may be unacceptable due to escape risks or health issue due to the smoke generated when prescribed fire is used. Mechanical treatment would allow a wider window of time in a year when hazard reduction burning can take place, through the reduction in ground fuel moisture content due to greater wind

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[1] Royal Commission into National Natural Disaster Arrangements Report 28 October 2020

and solar radiation on the forest floor. Mechanical treatment may be the only way to safely undertake fuel reduction burning in some damp forest floor contexts.

The fuel load results were used by CSIRO (Sullivan, Plucinski and Swedosh) to model expected changes in fire behaviour, (rate of spread, fireline intensity, and flame height), at each of the trial sites. These results were then combined and applied to a hypothetical landscape to assess the impacts of simulated bushfire spread using the Spark fire spread simulation framework. At two of the trial sites the removal of residual fuels from mechanical treatments did not occur due to site limitations, which consequently did not reduce the fuel hazard or surface fuel loads. This resulted in the same or slightly more intense simulated fire behaviour in mechanical only than in the control. They found prescribed fire, either burn-only or in conjunction with mechanical and burn, resulted in reductions in rate of fire spread and intensity.

A Benefit Cost Analysis (BCA) by GHD Pty. Ltd. (Hoban and de Mar) quantified the relative economic costs and benefits of applying fuel reduction treatments to a simulated forest environment. The BCA relied on the results of fire behaviour modelling completed by CSIRO and hence were subject to the trial limitations for the mechanical only treatments.

For mechanical treatment only, the Net Present Value (NPV) was -$9.23 million, indicating a net loss when the marginal costs exceed the marginal benefits. The Benefit-Cost Analysis showed a return of -1.1 times, indicating that this approach may not be economically beneficial.

Using mechanical treatment followed by prescribed burn, the NPV for this combined approach was +$16.42 million, suggesting that the benefits outweigh the costs. The Benefit-Cost Analysis showed a 7.6 times return on investment, making it a more economically viable option than mechanical treatment alone.

Prescribed burn only had the highest NPV of +$18.96 million, indicating the greatest economic benefit among the three options. The Benefit-Cost Analysis shows an impressive 353 times return on investment, making it the most economically advantageous.
These results suggest that using prescribed burns, either alone or in combination with mechanical treatment, could provide a better return on investment.

However, due to limitations on the removal of residual fuels for two of the sites for the mechanical treatments only, this represents only a partial assessment of their potential cost-effectiveness. More work is recommended on evaluating operational systems for removing near surface or sub-strata biomass fuels from mechanical only treatments and estimating the costs of removal and potential markets to assess their future cost-effectiveness.

The NSW and Victorian trial sites, despite the aim of the trials, did not remove tree heads following mechanical treatment due to a lack of local market for residues and the cost of removal and disposal. This led to increases in fuel loads following mechanical treatment, due to tree heads being left in the forest which decreased the financial benefits.

The results on the net societal benefits should therefore be interpreted with some caution in terms of their relative comparability and applicability into the future.

The trials have highlighted that Australian fire models would benefit from work to encompass mechanical treatment, as indicated by the post 2020 bushfire study on the Victorian trial site. Here, under fairly mild wildfire conditions (FFDImax. <4), thinning with prescribed fire limited the spread of wildfire.

The University of Canberra (Schirmer, Mylek and Clayton) studied the community and stakeholder acceptance of mechanical fuel load reduction. They found overall that it is an acceptable practice, but with caveats. The concerns revolved around whether it was part of an overall plan, its scale, proximity to assets, impacts to environmental values, frequency and, for some, whether the resulting material was sold.

The University of the Sunshine Coast (Acuna, Murphy and Mitchell) assessed the costs of mechanical treatments at the trial sites. They found that in mechanical treatments with the removal of small trees (DBHOB <15-20 cm), and reduced extraction distances (<250 m), the use of a full tree harvesting system ($16.70 per productive machine hour), is more cost-effective ($37.60 -$17.80 per productive machine hour) than a cut to length system, but the cost difference is marginal for trees above this size.

The 2019/20 bushfires burned through the Victorian trial site. The trials opportunistically engaged the University of Melbourne (Weston and Volkova) to re-assess the trial site following the bushfire; they had made the original pre and post treatment measurements for VicForests. The results showed that under low Forest Fire Danger Index (FFDI) conditions, previous fuel treatments are effective in halting the spread of wildfire, resulting in the creation of a mosaic of burnt and unburnt forest. The implications for management are clear and can be effective for several years post-treatment in limiting the spread of wildfire under low Forest Fire Danger Index (FFDI) phases of wildfires. The mechanical-only treated forests, that were not treated with prescribed fire, burned with greater fire severity than non-mechanically treated forest, showing the need to remove or reduce surface fuels as part of the mechanical treatment practice if wildfire risk reduction is a management aim. Co-benefits of more active fuel management in landscapes prone to wildfires includes enhanced refugia for biodiversity through increased likelihood of unburned areas.

1.3 Limitations of the trials

The trials had several limitations. They were carried out on only a few sites and do not provide definitive answers regarding mechanical treatment as a fire fuel reduction option on sites with different conditions and in different forest types. Further research is required to fully assess the benefits and disadvantages of different types of mechanical fuel treatments in different settings.

Although the aims of the trials were to reduce fuel loads, due to the techniques employed at the trial sites, as in, leaving felled head and tree branches in the forest in NSW and Victoria due to a lack of local market for residues and the cost of removal and disposal, the fuel loads increased in the mechanical-only treatments, and in the mechanical and burn in Victoria.

The NSW trial site was an uneven-aged native forest which was selectively harvested, including removing the largest trees. Smaller trees were left that may act as 'ladder fuels' that enable fire to reach the tree crowns. Treatments that remove more of the smaller trees, such as 'thinning from below', should be examined to reduce the risk of crown fires and therefore more aggressive wildfires.

The productivity and cost study of the mechanical treatment was assessed as a traditional forestry type study of cost per cubic meter processed, instead of cost per hectare treated for reducing fuel load and fire risk. Unfortunately, the results could not be converted into a cost per hectare.

Despite these limitations, lessons can be learned from these trials, to inform a more comprehensive set of trials that includes understanding how fuel loads change through time following treatment.

1.4 Recommendations

The Mechanical Fuel Reduction trials' final report provides an initial indication on the use of mechanical treatments in Australia. As such, this report should be utilised as a guide for future research into reducing fuel loads and bushfire risks through mechanical treatments. The trials results do not provide a comprehensive assessment of mechanical treatments in the Australian context.

The trials demonstrated the potential for mechanical fuel load reduction to modify fire behaviour and reduce risks and impacts. It is recommended that this research is expanded to increase the geographic scale of treatments, a wider range of treatments and to test these in a wider range of forest types. This will enable a more thorough understanding of the potential of mechanical treatments in Australia to manage risks and reduce impacts of bushfires. More work is also recommended on evaluating operational systems for removing near surface or sub-strata biomass fuels from mechanical only treatments and estimating the costs and potential markets to assess their future cost-effectiveness.

Australian fire behaviour models need to be improved to better examine the effects of mechanical treatment, as indicated by results from the post 2020 bushfire study on the Victorian trial site. This research should include the implications of greater solar radiation reaching the forest floor and increased wind speeds created by the removal of trees, which might extend the window available for prescribed fire but also increase rate of fire spread under more extreme fire weather.

1.5 Acknowledgements

This report forms a component of the Mechanical Bushfire Fuel Load Reduction trials. The Australian Government provided $1.5 million dollars, under a National Partnership with the NSW Government, to undertake the Mechanical Bushfire Fuel Load Reduction trials. These trials are part of the National Bushfire Mitigation Programme (NBMP), which provided $15 million dollars over three years to states and territories to implement long-term bushfire mitigation strategies and improve fuel reduction activities. These trials were also granted $127k by the Commonwealth Agriculture, Water and the Environment, On 1 July 2022, the agriculture and water component became the Department of Agriculture, Fisheries and Forestry (DAFF), while the environment component became the new Department of Climate Change, Energy, the Environment and Water.

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2 Literature review

Australia is one of the most fire-prone regions of the world, with the predominant eucalyptus forests evolving with bushfires. Though the 2019-2020 bushfires in Eastern Australia have not been the deadliest to humans in modern Australian history, there were 34 direct human deaths and 417 indirect deaths due to smoke inhalation[2]. The 2019-2020 bushfires have been estimated to have been the costliest at AUD 100 billion[3] as well as the largest, burning approximately 10.3 million hectares, of which 8.5 million hectares were forest, (inclusive of 24% of NSW commercial plantations)[4]. The 2019-2020 bushfires burned 3,500 homes and 5,880 other buildings and it is estimated that a billion animals died[5]. The causes of the bushfire are understood to have been initiated principally by lightning strikes then enhanced[6] by prolonged drought, highest temperatures on record, highest Forest Fire Danger Index on record for much of the South East and strong winds.

The Royal Commission into National Natural Disaster Arrangements[7] following the 2019-20 bushfires found the following in chapter 17 which has relevance to the trials and their outcomes.

> 17.44 …… even in severe weather conditions, substantially reducing fuel availability in the areas surrounding assets should reduce fire intensities and consequent risk. Reducing available fuels in the landscape can also slow the initial rate of fire spread and fire intensity, which can provide opportunities for fire suppression and thereby reduce the risk of fires escalating into extreme fire events.
>
> *A need for further research*
> 17.45 Considerable research and scientific attention has been dedicated to fuel management, particularly prescribed fire. There is a need for continuing research to address significant gaps in the science, including in relation to the role of fuels in extreme fires, and the effectiveness and efficiency of fuel management strategies and techniques.
>
> 17.34 Fuel management activities are generally not intended to stop or prevent bushfires on their own. They are designed to enhance and support the effectiveness of other complementary prevention, preparation and response measures; particularly fire suppression but also urban planning, building regulations and community preparedness.

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[2] Nicolas Borchers Arriagada, Andrew J Palmer, David MJS Bowman, Geoffrey G Morgan, Bin B Jalaludin and Fay H Johnston (March 2020) Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. Med J Aust 2020; 213 (6): 282-283. doi: 10.5694/mja2.50545

[3] Paul Read Richard Denniss (January 2020). "With costs approaching $100 billion, the fires are Australia's costliest natural disaster". The Conversation

[4] ABARES (January 2021) Forest fire area data for the 2019–20 summer bushfire season in southern and eastern Australia

[5] Parliament of Australia (March 2020) 2019–20 Australian bushfires—frequently asked questions: a quick guide Research Paper Series, 2019-2020

[6] BOM (January 2020) Hottest, driest year on record led to extreme bushfire season

[7] Royal Commission into National Natural Disaster Arrangements Report 28 October 2020

17.37 Weather has the greatest influence on bushfire behaviour and that, as fire weather conditions deteriorate, the influence of fuel declines. This means that the benefits of fuel load management activities also decline as fire weather conditions deteriorate. Research suggests that most bushfire-related impacts on lives and property in Australia have occurred in severe, extreme or catastrophic fire weather conditions.

17.42 We heard that, in extreme bushfires, fuel loads do not appear to have a material impact on fire behaviour.

Deloitte Economics (2014)[8] report that the Bureau of Transport Economics (BTE) found that total economic costs were around 2-3 times greater than insured costs for most natural disasters.

While mechanical fuel treatments and forest thinning to reduce fire impacts have been widely applied in the USA, there have been a relatively limited study of these treatments in Australia (Keenan et al. 2021[9]). For example, in a study of fire fuel hazard in thinned stands in East Gippsland, Victoria, Proctor and McCarthy (2015)[10] found Overall Fuel Hazard at thinned sites was on average lower than that on adjacent unthinned sites, primarily due to the reduction of elevated fine fuel. They also found that fine fuel from slash had largely decomposed by 4 years after thinning. In conclusion they suggested that thinning may reduce the likely suppression difficulty by substantially reducing the potential for vertical development of fire at the flaming fire front, with thinning not giving the fire hazard that had been assumed, rather lowering fire risk for at least 15 years.

The literature reviewed did not discover an assessment of the effectiveness of such treatments for reduction in bushfire risk. The trials were the first attempt anywhere in the world to try to quantify the effects, but due to budget restrictions, it had to be undertaken using simulations.

Johnstone *et al.* (2021)[11] found in Western American ponderosa pine forests, mechanical thinning can restrain fire even without the aim for follow up prescribed fire, as it significantly reduced crown fire immediately after thinning. It also moderated surface modelled fire behaviour 2-3 years later. Prescribed fire was seen as necessary to extend the positive benefits of thinning, especially where shrub and tree re-growth occurred.

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[8] Deloitte Access Economics. 2014. Scoping study on a cost benefit analysis of bushfire mitigation. A report prepared for the Australian Forest Products Association. Available from: http://ausfpa.com.au/wp-content/uploads/2016/01/AFPA-DAE-report-Amended-Final-2014-05-27.pdf

[9] R. J. Keenan, P. Kanowski, P. J. Baker, C. Brack, T. Bartlett & K. Tolhurst (2021): No evidence that timber harvesting increased the scale or severity of the 2019/20 bushfires in south-eastern Australia, Australian Forestry, DOI: 10.1080/00049158.2021.1953741

[10] Emma Proctor & Greg McCarthy (2015) Changes in fuel hazard following thinning operations in mixed-species forests in East Gippsland, Victoria, Australian Forestry, 78:4, 195-206, https://doi.org/10.1080/00049158.2015.1079289

[11] James D. Johnston, Julia H. Olszewski, Becky A. Miller, Micah R. Schmidt, Michael J. Vernon, Lisa M. Ellsworth, Mechanical thinning without prescribed fire moderates wildfire behavior in an Eastern Oregon, USA ponderosa pine forest, Forest Ecology and Management, Volume 501, 2021, 119674,, https://doi.org/10.1016/j.foreco.2021.119674

Mastication of shrubs in Victorian woodlands and open forest and subsequent likely fire impacts was investigated Grant *et al.*[12] (2021), when leaving the resultant material in-forest. This echoed similar studies in the US chaparral. Sites masticated within 0–2 years had an increase in dead fine fuel loads of approximately 300%, whilst the dead coarse fuel loads on the forest floor had an increase of 1100% compared with the controls. Though the finer fuels disappeared, the coarse fuel loads remained in part after 3–4 years. However, predicted flame heights were greatly reduced under severe fire weather conditions, but there was no change in the predicted spread rate of a bushfire.

Vaillant & Reinhardt (2017)[13], reported that in the USA between 2008-2012 an average of 219,186 hectares per year were mechanically treated on Federal National Forest System lands and 437,635 hectares per year treated with prescribed fire, meaning 33% of all treatments were mechanical. The 78 million hectare National Forest System comprises national forests, national grasslands, and various other designations across 43 states and Puerto Rico, with 87% of lands in the West[14]. The USDA Forest Service[15] has a 2018 Investment Strategy which includes:

"…*mechanical treatments are needed to reduce fuels before reintroducing fire. Many fire-adapted forests have such high fire deficits that returning fire too soon or in blocks too big could have devastating ecological effects, along with catastrophic consequences for local communities*."

The American Broadcasting Company (ABC) reports that Biden's administration wants to double the forest acreage thinned or treated with prescribed burns to 6 million acres (2.4 million hectares) annually[16]; this target would likely include forest outside the National Forest System.

3 Overall Methods

3.1 Trial study sites and treatments by location

The trials were carried out in a range of forest types in geographically and climatologically diverse areas of the country. To identify potential trial sites 'expressions of interest' were sought from forest management agencies and research organisations by an Oversight Committee. This resulted in nine (9) proposals that were scored by the Technical Committee against two mandatory criteria, seven (7) General Criteria (30% weighting), four (4) specific criteria (50%) and five (5) additional criteria (20%). The top four ranking trial site providers were then requested to provide firm price and other details. Due to budget limitations, only three were chosen by the Oversight Committee in August 2016: Burrawan State Forest, 10 km south, south-east of Wauchope, New South Wales (NSW); Drummer State Forest 16 km east of Cann River, Victoria (Vic.); and Ree's forest block, 6 km north east of Collie, Western Australia (WA).

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[12] Grant, M.A.; Duff, T.J.; Penman, T.D.; Pickering, B.J.; Cawson, J.G. Mechanical Mastication Reduces Fuel Structure and Modelled Fire Behaviour in Australian Shrub Encroached Ecosystems. *Forests* 2021, *12*, 812. https://doi.org/10.3390/f12060812

[13] Vaillant, Nicole & Reinhardt, Elizabeth. (2017). An Evaluation of the Forest Service Hazardous Fuels Treatment Program—Are We Treating Enough to Promote Resiliency or Reduce Hazard?. Journal of Forestry. 115. 300-308. 10.5849/jof.16-067.

[14] Katie Hoover & Anne A. Riddle (2019) National Forest System Management: Overview, Appropriations, and Issues for Congress Updated September 5, 2019 Congressional Research Service https://crsreports.congress.gov R43872

[15] The USDA Forest Service Toward Shared Stewardship Across Landscapes: An Outcome-Based Investment Strategy (2018)

[16] ABC News Climate change, logging collide -- and a forest shrinks. 16 September 2021

Three treatments were specified: mechanical-only, prescribed fire only and combined mechanical and prescribed fire. A control consisted of no treatment.

Three replicates of each treatment and control at each trial site were implemented. The total area in the trials was about 120 hectares at each site, approximating 10ha for each treatment area in each replicate.

Three very different forest types were sampled in the trials, these varied in species composition and age class (Table 1).

In New South Wales the mixed age and species forest with considerable understorey, had approximately 700 stems per hectare, averaging 21.8 cm DBH a mean height of 31m and basal area of 30 m^2 per hectare. The Burrawan State Forest trial site is approximately 10km SSE of Wauchope, 20km SW of Port Macquarie and a 1 km North of the Pacific Highway on the Mid North Coast of NSW. The forest has a long history of forest management and is dominated by native regrowth Blackbutt (*Eucalyptus pilularis*) forests. The stands were previously harvested using a mixture of group selection and selective harvesting leaving a range of stand conditions from mature regrowth dominated by 50-70 cm diameter at breast height (DBH) trees to groups from harvesting in 2006 of about 10-year-old (15-20 cm DBH) trees or from 1995 group selection and regeneration harvesting of 23-year-old trees (35 cm DBH or so).

In Victoria the forest was even aged closed canopy regrowth from a 1983 bushfire, principally Silvertop Ash with little understorey, appearing somewhat like a hardwood plantation requiring a thinning operation. Drummer State Forest, near Cann River, had not been burnt since a severe bushfire in 1983, regeneration was mainly from seed. These predominantly even-aged forest of Silvertop Ash (*E. sieberi* ~80%) with some older messmate stringybark (*E. obliqua*, ~17%), had very high stocking rates of 1,518 stems per hectare and mean diameter of 19.1cm DBHob. The burn treatments were not able to take place the same year as the mechanical treatments, occurring a 15 months later in two of the three replicates. Further, in one of the replicates moist conditions in the burn only treatments did not give a satisfactory outcome of the fire treatment. The unburnt plots within treatments were not remeasured.

The excavator harvester used to undertake the mechanical treatments was not best suited to the small diameter of the trees, leading to lower productivity and greater damage to retained trees. Trees were debarked in-situ with material down to 80mm extracted by a forwarder, the remainder left in the forest, giving rise to high fuel loads.

In the WA site, the even aged Jarrah (*Eucalyptus marginata*) and Marri forest (*Corymbia callophylla)* was more open with canopy gaps at 620 stems/ha with little understorey, an average of 20.8cm DBH, a mean tree height of 11.6m and a mean Basal area of 27 m^2 per hectare.

They also varied in the type of mechanical treatment. Whole tree removal of thinned trees was only done in Collie, Western Australia. The machinery used was also different between the sites with a feller buncher in WA, an excavator based tracked harvester processor in Victoria and a purpose-built tracked harvester processor in NSW. NSW and Victoria both undertook cut to length operations with a forwarder removing the resultant material but leaving the tree heads in the forest whereas in WA a feller-buncher concentrated the stems which were then extracted to roadside whole. The mechanical fuel load reduction trial (MFRT) was established on land owned and managed by the state Department of Water and Environmental Regulation (DWER). The DWER are a major stakeholder in the trial and have made significant contributions to the undertaking of the works. The site, known as Rees Block (33°19’15”S, 116°12’17”E, 262 m elevation) is situated 8 km north east of the Collie townsite, on the Collie-Williams Rd. In addition to its proximity to a townsite, the site is bordered by mine site accommodation, a recreational facility and production plantation forest and therefore requires careful and ongoing fire control management.

The site has a gently undulating topography consisting of shallow ironstone gravels. The vegetation is dominated by Jarrah and Marri with small patches of *E. wandoo* (wandoo). The understory is dominated by Jarrah and Marri saplings and *Xanthorrhoea australis* (grass trees). The clearing history is unknown, but the area has been heavily cut by illegal fire wood operators. This, in addition to the presence of *Phytophthora cinnamomi* (dieback), illegal recreational activities and feral pig damage has led to a generally degraded forest. The site was last control burnt in 1993, by the Williams Road Brigade, but there are no records of fire behaviour, type etc. Prior to this, the area had not been burnt for between 28 – 35 years.

The mechanical treatments in New South Wales removed 49% of the stems per hectare to approximately 350 stems for hectare, with the basal area dropping by 45% to about 16 m^2/ha. In Victoria, 86% of stems were removed in the mechanical treatments leaving about 260 stems for hectare, with a 59% drop in basal area to 23 m^2/ha. In WA about 74% of stems were removed, leaving 115-160 stems for hectare, dropping the basal area by 58% to roughly 17 m^2/ha.

Table 1 Overview of forests in the trials

Metric	Burrawan SF NSW	Drummer SF Vic.	Ree's Forest WA
Forest type	Multi-aged mixed species predominantly Blackbutt (*E. pilularis*)	Even aged 1983 fire regrowth Silvertop ash (*E. sieberi*)	Even aged Jarrah (*E. marginata*) and Marri (*Corymbia calophylla*)
Mechanical treatment machine	Purpose built tracked harvester and processor	Excavator based tracked harvester and processor	Feller buncher
Silvicultural treatment	Thinning from above	Thinning from below, bay and out-row method	Thinned
Mechanical treatment type	cut-to-length, tree heads left in forest	cut-to-length, tree heads left in forest	whole tree removal to trackside
Average Stem DBH [cm] (SE)	21.8 (0.3)	19.1 (0.1)	20.8 (0.2)
Overstorey Mean Height [m]	31.2	22.7	11.6

Figure 1 Trial site locations

As part of their modelling, CSIRO found several data issues due to differing methodology, data loss and inconsistent presentation.

3.1.1 Pre-treatment biomass assessment method

Circular plots were placed on a systematic grid with a random starting point. Within plots, all trees with a DBH>10 cm were labelled with a uniquely numbered tag. Plot centres are permanently marked.

3.1.1.4 Tree species, status (alive, standing dead), DBH, biomass and height

Tree species, status and DBH were recorded for every tree with DBH > 10 cm in each circular plot. The measurement of tree heights for every tree in the circular plots was only required if a robust allometric relationship does not exist already for the predominant species in the sites. The trial managers were required to demonstrate that the chosen allometric equation(s) includes a suitable range of tree sizes (i.e., that it covers the range of DBHs included in the site), and that the relationship can be confidently applied to the geographical area where the sites are located. If a suitable allometric equation is not available, then all the trees in the plot will need to be measured to determine the total volume, with biomass derived using published basic density figures.

3.1.1.5 Bark thickness

Bark thickness measurements were only carried out for sites subjected to fire treatments. This is an important parameter for biomass estimations, as in the case of some species such as Silvertop ash, the bark component can represent approximately 15% of the total above-ground biomass of the trees

(Ximenes *et al.* 2016[17]) and may be substantially consumed by fire. Bark measurements were taken at the four cardinal points at two different heights on the stem: 50 cm and 130 cm (breast height). The same trees were measured before and after treatment. These measurements were carried out for a sub-section of the trees in each circular plot, covering at least two trees in each diameter class represented in the plots (0-10 cm, 10-20, 20-30, 30-40, 40-50 and >50 cm). An alternative method is also provided in the Technical Report for Project Vesta (Gould et al. 2007[18]).

All measurements described above were also carried out for trees < 10 cm DBH in the 0.004 ha nested subplot in each of the 0.04 ha circular plots.

3.1.1.6 Other parameters

The mineral soil sampling was in three of the circular plots within each treatment unit, with depths of 0-10 cm. This will give a total of 36 samples, which was determined to be sufficient to provide a baseline.

3.1.1.7 Coarse woody debris (CWD)

CWD measurements are important for three main reasons: for biomass quantification and detection of changes in biomass / carbon due to the treatments (CWD represents an important component carbon stock in native forests); as an additional parameter useful to better understand the impacts of fire treatments (mainly via changes in moisture content and fuel structure), and also because of their biodiversity value.

CWD is defined as detrital biomass that includes standing dead trees (stags), stumps, whole fallen trees, dead branches, coarse roots and wood pieces left following tree mortality and/or the fragmentation of larger timber structures (Woldendorp *et al.* 2002[19]).

CWD was determined from three randomly selected circular plots in each experimental unit (36 measurements in total) using the line-intercept method with a transect size of a minimum of 100 m. In each transect, the number of intersecting downed woody stems in different time lag size classes were recorded (25–75 mm, and greater than 75mm). Previously the 0–6 mm and 6–25 mm categories were also included but these are better described as fine fuels and are now covered by the fire behaviour assessment. The diameter of each intersecting piece of CWD should be recorded to allow volume determination. CWD here includes downed woody stems as well as Standing dead trees (>20 cm DBH); and Stumps >20 cm in diameter and 1.3 m in height (Roxburgh *et al.* 2006). Characterization of the decay of logs was to be also required for assessing biodiversity values. An example of a suitable decay characterization table is included below. Presence and size of any hollows in intersecting pieces were recorded. Samples of the two different sizes of CWD were collected from three of the five

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[17] Ximenes, F.; Roxburgh, S.; Cameron, N.; Coburn, R.; Bi, H. Carbon stocks and flows in native forests and harvested wood products in SE Australia. Report prepared for Forest and Wood Products Australia. 2016. Available online: http://www.fwpa.com.au/images/resources/Amended_Final_report_C_native_forests_PNC285-1112.pdf

[18] Gould, S.D. 2007 Project Vesta: Fire in Dry Eucalypt Forest : Fuel Structure, Fuel Dynamics and Fire Behaviour. Ensis (Organization), Western Australia. Department of Conservation and Land Management, CSIRO (Australia), Scion (Organization : N.Z.), Project Vesta ISBN 0643065342, 9780643065345

[19] Woldendorp, G & Spencer, R & Keenan, Rodney & Barry, S. (2002). An Analysis of Sampling Methods for Coarse Woody Debris in Australian Forest Ecosystems. Bureau of Rural Sciences. https://www.researchgate.net/publication/265066682_An_Analysis_of_Sampling_Methods_for_Coarse_Woody_Debris_in_Australian_Forest_Ecosystems

randomly selected circular plots per experimental unit, with a total collection of a maximum 72 pieces. These samples were used to determine moisture content and density of the CWD.

The volume of wood per unit area (m^3 / m^2) can be calculated using the following equation:

Equation 1 CWD volume per unit area (m^3/m^2), where “d” is diameter (m) and “L” is transect length (m)

$$\text{CWD Volume} = \left\{\frac{\pi^2 \sum d^2}{8L}\right\}$$

Dry biomass (0 % moisture content) is derived for wood in each of the decay classes listed in the Table below using the basic density values determined from samples from each of the decay classes.

Method	State of Decay	Description
Transect 1	1	Sound
	2	Outer layers and sapwood showing signs of decomposition
	3	Signs of decomposition extend to heartwood

Samples of CWD collected are to be dried at 103°C to determine moisture content and density (AS/NZ 1080 (1997)). The duration of the drying period will depend on the size of the CWD piece – as a minimum, samples will need to be dried for three days and then their weight will need to be checked regularly until there is no significant change detected. The volume of the samples used for density determination is determined by the water displacement method (ASTM D2395-93). For rotten samples, the pieces were either dipped in wax or wrapped in cling wrap before volume determination using the water displacement method. Moisture content (Equation 2) and basic density (Equation 3) were calculated for each sample.

Equation 2 Moisture content

$$\text{Moisture Content \%} = \frac{\mathit{Green\ weight}\ (g) - \mathit{Oven\ dry\ weight}\ (g)}{\mathit{Green\ weight}\ (g)}\ x\ 100$$

Equation 3 Basic density

$$\text{Basic Density} = \frac{\mathit{Oven\ dry\ weight}\ (g)}{\mathit{Green\ Volume}\ (m^3)}\ x\ 1000$$

3.1.1.8 Post-treatment biomass assessment

The sites were revisited some weeks post-treatment in line with the data requirements for the bushfire modelling work. Tree survival data (status, basal area) were measured in each circular plot, and bark thickness were measured for those trees that were measured pre-treatment. Reassessment of control plots could be required depending on the period since last fire, as sites may not have be in equilibrium in terms of fuel hazard.

Mineral soil sampling was determined as described previously, in the same plots that were sampled prior to treatments. Similarly, CWD determinations and sampling was carried out for the same plots that were measured and sampled before.

3.2 Machinery Productivity in Mechanical Fuel Load reduction method– Acuna, Mitchell & Murphy

Dr. Mauricio Acuna and Rick Mitchell of University of Sunshine Coast and Dr. Glen Murphy of G.E Murphy & Associates studied machine productivity at the three trial sites.

In all the studies, three plots of approximately 100 by 100 m each were laid out to collect the machine productivity data. Trees >12 cm in the NSW, > 15 cm in VIC, and > 10 cm WA trials to be removed during the thinning operation were painted as per diameter classes. Pre-harvest inventory data collected by research collaborators and information provided by personnel from FCNSW, VicForests, and FPC were used for determining the location of the plots. The plot locations were selected to give a range of DBHOB. The terrain was uniform and relatively flat (< 5°) within each of the study plots.

Before conducting the harvesting (time and motion) studies, all the trees within each plot were identified with a painted colour code as per their DBHOB class. There were seven 10-cm classes ranging from <15 cm to >65 cm in the NSW site, five 10-cm classes ranging from <12 cm to >40 cm in the VIC site, and four 10-cm classes ranging from <15 cm to >35 cm in the WA site. The number of DBHOB classes were determined from a pre-thinning inventory as per the DBHOB range of the trees present in the plots. The DBHOB mark in one class (e.g., 12.5 cm for the 10-15 cm class) was attached to all the trees harvested in that class, and that DBHOB mark was then used to compute tree volumes.

During the time study, the work elements of the purpose-built harvester/processor in NSW and the excavator-based feller buncher in WA were accurately timed in decimal minutes and manually recorded from a safe distance using the time study software UMT plus™ v19. The harvesting operations were also recorded using a handheld digital video recorder, and a second camera mounted in the harvester cabin to allow post-harvest data validation. In VIC, the operation was recorded with a camera mounted in the harvester and a custom build database was used to time the work elements. Work elements in the NSW and VIC trials included felling, processing, brushing or clearing, moving, and travel time. In the WA trial, work elements include positioning to cut, cut, swing to bunch, adjust bunch, brushing or clearing, moving, and travelling.

During the detailed time study, small delays (less than 15 min) were recorded and classified as mechanical, operational, or personal delays.

Data collected during the time and motion studies was used to develop harvesting productivity and cost models. Felling times were added to processing times for individual trees in the NSW and VIC trials. Then, times of prorated elements (Clearing BLT, Moving, Moving Piles, Positioning to Fell, and Travelling) were added for each plot. Mechanical, Operational, and Personal Delays were not included. Prorated times were kept separate for each plot and a combined prorated time was also calculated for all three plots in NSW, VIC, and WA. The sum of all the times per tree was then converted to trees per productive machine hour (PMH).

3.3 Fire modelling - behaviour and landscape spread method - CSIRO

This component of the Mechanical Fuel Load Reduction trial project, undertaken by CSIRO's Andrew Sullivan, Matt Plucinski and Will Swedosh, focused on analysing changes in vegetation structure, arrangement and amount (as quantified by standard fuel attributes) as a result of fuel modification treatments and the resultant likely effect on fire potential as defined by a set of fire behaviour metrics. Calculated fire behaviour metrics were then extended to quantify changes in fire spread over the landscape for the purpose of supplying fire propagation maps for the Benefit Cost Analysis conducted by GHD.

- Quantification and assessment of the effect of fuel modification treatments on fuel attributes critical for determining fire behaviour were undertaken by the trial participants at each site according to detailed methodologies developed for this purpose. These fuel attributes were surface fuel hazard score, surface fuel load, near-surface fuel hazard score, near-surface fuel height, elevated fuel hazard score and bark fuel hazard score.

- Additional measurements of effect of fuel modification treatments at the NSW site were undertaken by CSIRO to quantify second order (indirect) effects on wind and fuel moisture on fire behaviour metrics.

- Fire behaviour metrics assessed in the study are fire rate of forward spread, fireline intensity, headfire flame height, and maximum spotting distance.

- The Dry Eucalypt Forest Fire Model (DEFFM, Cheney *et al.* 2012[20]) was used to calculate fire behaviour metrics. Fireline intensity was calculated using the model of Byram (1959) and a heat yield value of 18,600 kJ/kg.

- Fire behaviour findings were applied at the landscape scale using the Spark wildfire spread simulation framework (Miller *et al.* 2015[21]).

3.4 Cost benefit analysis method - GHD

Seamus Hoban and Paul de Mar of GHD evaluated the economic merit of adopting mechanical fuel reduction (MFR) techniques to reduce fire impacts. The study outlined the estimated net societal benefits and costs associated with the adoption of mechanical fuel reduction techniques, as compared to the current methods of fuel reduction, primarily focused on prescribed fire. Mechanical fuel reduction in combination with prescribed fire was also evaluated.

This study sought to quantify the relative economic impacts of applying MFR within a particular location and situation. Specifically, the study considered how different treatments applied to a 660 ha forested area outside a rural township, impacted on fire behaviour and therefore economic loss. The area chosen for the fire modelling is an actual landscape, which represents a likely situation where MFR might be considered suitable if adopted by Australian fire agencies and land managers in the future. To avoid impacting on local residents the location used for this modelling has been obscured.

The study considered the economic impact under 60 simulated fire events, representing variations in:

- Ignition points: 1km, 4km, 10km from township
- Fire Danger Rating (FDR): Moderate, High, Very High, Severe, and Extreme.
- Treatments within the 660 ha treatment area:
  - control = no treatment
  - MFR
  - prescribed fire
  - MRF + prescribed fire

Fire damage was calculated based on areas of different land types burnt, with fire intensity used to estimate the probability of dwellings being lost. Benefits were calculated as net savings in fire damage and suppression costs, as compared to the control, while costs were calculated as net increases in treatment costs as compared to the control.

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[20] Cheney NP, Gould JS, McCaw WL, Anderson WR (2012) Predicting fire behaviour in dry eucalypt forest in southern Australia. Forest Ecology and Management 280, 120–131. doi:10.1016/J.FORECO.2012.06.012

[21] Miller, Claire & Hilton, J.E. & Sullivan, Andrew & Prakash, Mahesh. (2015). SPARK – A bushfire spread prediction tool. IFIP Advances in Information and Communication Technology. 448. 262-271. 10.1007/978-3-319-15994-2_26.

3.5 Social acceptability of Mechanical fuel load reduction method - University of Canberra

Jacki Schirmer, Mel Mylek, Helena Clayton at the University of Canberra were commissioned to examine the social acceptability of MFLR ('social acceptability study'). The objectives of the social acceptability study were to identify the extent to which using MFLR is considered acceptable by different people and groups, and to understand key factors that influence social acceptability of using mechanical fuel load reduction. While multiple studies have examined the social acceptability of various natural resource management practices, relatively little has examined acceptability of MFLR.

Two means of eliciting views were used

- Quantitative - 11,500 rural and regional Australians answered questions in the 2016 Regional Wellbeing Survey, about acceptability of mechanical fuel load reduction and controlled burning, and over 9,000 answered other questions related to mechanical fuel load reduction and controlled burning.
- Qualitative – 49 stakeholders in 6 workshops close to the locations of the trials, with phone interviews of some stakeholders who could not make the workshops.

Methods

Both quantitative and qualitative data were collected and analysed in this study. Quantitative data were collected via a survey of people living across Australia, in which they were asked their views about MFLR. This provided a robust assessment of initial views about the use of MFLR across the population and for different types of people and people living in different locations. Data were collected by including questions about MFLR in the University of Canberra's annual Regional Wellbeing Survey (RWS). Survey items were designed in a multiple stage process that included focus group and pilot testing. The sample frame involved recruiting stratified random samples from different regions and groups. A total of 13,302 people took part in the 2016 RWS; of these, over 11,500 answered questions about acceptability of mechanical fuel load reduction and controlled burning, and over 9,000 answered other questions related to mechanical fuel load reduction and controlled burning. Individual response figures are given when results are presented for each question in this report. Weighting of the data set was used to correct deliberate biases introduced due to the stratification of the sample, as well as to correct unintentional biases, and ensure where appropriate results were representative of the adult population.

Qualitative data were collected via stakeholder workshops held in each of the three trial site locations, as well as phone interviews for those who were interested in the project but could not attend a workshop. MFLR is not a familiar practice amongst the general public, and views are likely to be influenced by how key stakeholders view the use of MFLR. Interviewing these stakeholders provided important insight into the factors influencing social acceptability of MFLR amongst key groups who are involved in land and fire management, and who are key influencers of public opinion about different management practices. A total of 49 stakeholders participated in workshops and interviews. The aim was to ensure that as wide a diversity of views was included as possible, with the overall criteria for inclusion being that a stakeholder group had interest in, knowledge or, or may be affected by the implementation of MFLR. Most participants represented either bushfire management, environmental non-government organisation (ENGO), forest industry or natural resource and land management organisations. Fewer represented recreational users, Traditional Owners, and commercial users other than the forest industry, with lower interest in participating from these groups despite active efforts to involve them in the study.

3.6 Post wildfire evaluation of Mechanical fuel load reduction impacts on the Victorian trial site method - University of Melbourne

Chris Weston and Luba Volkova, of the University of Melbourne Forest Ecology and Silviculture research group, set out to discover if the previously applied fuel treatments resulted in lower severity and intensity of the bushfire when other reasons for severity and intensity variation are removed, such as weather effects, wind direction changes and fire-fighting efforts.

A wildfire burnt into the Drummer SF fuel reduction trial area in the early hours of 5 January 2020 from about 0100. A fire line-scan taken at 0240 on 5 January indicates two fire fronts, one on the western boundary of the trial plots, and one on the eastern boundary. Weather records from Orbost suggest 5-10 km h-1 west-southwest winds at this time, consistent with the deeper fire-front on the western edge of the trial. The line-scan indicates a narrower fire on the eastern edge, consistent with a backing fire from the east burning down into the trial area from the elevated eastern flanks of Mt Drummer.

Among the 240 trial plots assessed for fire severity, all 160 plots that were not burnt experimentally in 2018 were ignited and burnt by the wildfire. Twenty of the 80 plots experimentally burnt in 2018 were ignited by the wildfire – these being the un-thinned plots that were burnt in a very low intensity and patchy prescribed fire and sixty plots that did not burn.

When the 2020 wildfires approached the trial site there were:

1. 80 unburnt and not thinned forest plots (3 blocks x 20 plots = 60 plots [control treatment] plus 20 plots that had not been burnt to create the “prescribed burnt” treatment in Block 1).
2. 80 mechanically thinned plots with harvest residues (40 plots in block 1 plus 20 plots in each of blocks 2 and 3).
3. 40 thinned and burnt plots (20 plots in each of blocks 2 and 3) and,
4. 40 plots treated with prescribed fire only (20 plots in each of blocks 2 and 3,).

Wildfire severity was assessed in winter 2020 following the Management Standards in Victoria’s State Forests (DEPI 2014[22]), Table 1. Wildfire severity was assessed within a 5-15 m radius from the centre point for each of the 240 plots in the trial. The plot fire severity score was calculated from percentage of burnt, scorched or green canopy and percentage of ground area burnt.

Table 1 Fire severity specifications after Management Standards in Victoria’s State Forests.

Severity Class	Severity type	Fire severity	Description
5	Crown scorch	Extreme	60 – 100 % of eucalypt and non-eucalypt crowns are scorched, some crowns are burnt. An intense understorey fire with complete crown scorch of most eucalypt and non-eucalypts.
4	Moderate crown scorch	High	30 – 65 % of eucalypt and non-eucalypt crowns are scorched. A variable intensity of fire ranging from a warm ground burn with no crown scorch to an intense understorey fire with complete crown scorch of most eucalypt and non-eucalypts.
3	Light crown scorch	Medium	1 – 35 % of eucalypt and non-eucalypt crowns are scorched. A light ground burn with isolated patches of intense understorey fire and some crown scorch.
2	No crown scorch	Low	< 1 % of eucalypt and non-eucalypt crowns are scorched, understorey may be burnt or unburnt.
1	Unburnt	Unburnt	

Fuel hazard was assessed using the overall fuel hazard assessment guide (OFHG, Hines *et al.* 2010[23]) applied to four understorey strata categories: surface, near-surface, elevated and bark fuels. Within a 5-10 m radius from each plot centre point, hazard rating (Nil, Low, Moderate, High, Very High or Extreme) was assigned based on fuel layer arrangement, continuity, cover, fuel bed depth, fuel height,

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[22] DEPI. (2014). The Management Standards and Procedures for timber harvesting operations in Victoria’s State forests, *Fire Salvage Harvesting*. Victoria: The State of Victoria, Department of Environment and Primary Industries 2014.

[23] Hines F., Tolhurst K., Wilson A. A. G., and McCarthy G. J. (2010). Overall fuel hazard assessment guide. 4th edition July 2010. Fire and adaptive management, report no. 82. Victorian Government Department of Sustainability and Environment. Melbourne, Australia. ISBN 978-1-74242-677-8

proportion of dead fuels or bark type. The overall fuel hazard rating (OFHR) was determined from a combination of four ratings as described by Hines *et al.* (2010). For the analysis, ratings were converted to overall fuel hazard scores (OFHS, 0–4, where 0 is 'Nil', 3.5 is "Very high' and 4 is 'Extreme'). While OFHS was assessed in winter 2020, the results of OFHS assessments made at the completion of fuel treatments in 2017 and 2018, were used for interpretation of the fire severity measurements.

Sampling of surface fuel loads and char

Surface fuels including live and dead leaves, bark, fruits, small branches and twigs with d<2.5 cm, and duff comprised of well decomposed materials on the mineral soil were sampled within a metal ring of 0.05 m^2 placed on the forest floor in each of the plots. Char was collected from the same locations. Surface fuels were assessed as freshly fallen after the wildfires or as litter remaining from the previous treatments. Surface fuel samples were transferred to the laboratory and oven dried to 60°C for at least 48 hours prior to further analysis. Oven dried samples were sieved through a fine mesh (25 mm) to remove stones, roots and char that were excluded from the surface fuel load estimates.

Wildfire conditions and fire simulations

The date and time of wildfire activity at the study sites was inferred from fire scan images, accessed through Emergency Management Victoria website, through internal app EM-COP. A fire line scan dated 5 January at 0240 showed active wildfire within the trial area and burning in some treatments. Sequential images over several hours were not available so that it is not possible to estimate the rate of fire spread from the fire-line scan. Therefore, fireline intensity and the rate of fire spread were simulated using the fire behaviour platform *Amicus* (Plucinski *et al.* 2017[24]). Input fuel parameters (fuel hazard scores, fuel loads, height of elevated and near surface fuels) were extracted from our previous study (Volkova and Weston 2019[25]) using values from after the fuel reduction treatment. Fuel consumption was estimated based on the assessment of the percentage of ground burnt minus duff and char material after the wildfire.

Hourly air temperature, relative humidity (RH), wind speed and wind direction data for the period December 2019 to February 2020 were accessed from the Australian Bureau of Meteorology (BoM) automatic weather station (AWS) nearest to the study site. The nearest AWS with the required level of observations was Orbost (84145), 61.3 km away. The two nearest AWSs to the study sites are Combienbar (84143, 27.6 km away) and Mallacoota (84084, 50.8 km) were damaged in wildfires and no information was available for the required period (Table 2). Gridded weather data and fire danger index information was also assessed for the trial location from the online resource *VicClim*.

Statistical analysis

A linear model was applied to test the relationship between fire severity and fuel parameters (hazards scores, loads). Generalised pairs plot function was used to assess the data for correlations, and variables with a correlation coefficient above 0.5 were excluded from further analysis. Analyses were conducted in R statistical software (R Core Team 2020[26]).

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[24] Plucinski M. P., Sullivan A. L., Rucinski C. J., and Prakash M. (2017). Improving the reliability and utility of operational bushfire behaviour predictions in Australian vegetation. *Environmental Modelling & Software*, **91**, 1-12.

[25] Volkova L., and Weston C. J. (2019). Effect of thinning and burning fuel reduction treatments on forest carbon and bushfire fuel hazard in Eucalyptus sieberi forests of South-Eastern Australia. Science of the Total Environment, 694, 133708.

[26] R Core Team. (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

4 Trial site reports

4.1 Victorian Trial site - Drummer State Forest

Scott Arnold VicForests

Drummer State Forest, near Cann River, had not been burnt since a severe bushfire in 1983, regeneration was mainly from seed. This predominantly even-aged forest of Silvertop Ash (*E. sieberi* ~80%) with some older messmate stringybark (*E. obliqua*, ~17%), had very high stocking rates of 1,518 stems per hectare and mean diameter of 19.1cm DBHob.

A group of three adjacent coupes were selected because of:

- Prior inclusion in the VicForests Timber Release Plan,
- Uniformity of the trial site,
- Proximity to suitable markets,
- Good roading access,
- Good natural fire containment lines,
- A common and representative stand across West and East Gippsland regions.

Each coupe hosted one replicate of each of the four treatments.

The burn treatments were not able to take place the same year as the mechanical treatments, occurring a 15 months later in two of the three replicates. Further, in one of the replicates moist conditions in the burn only treatments did not give satisfactory outcome of the fire treatment. The unburnt plots within treatments were not remeasured.

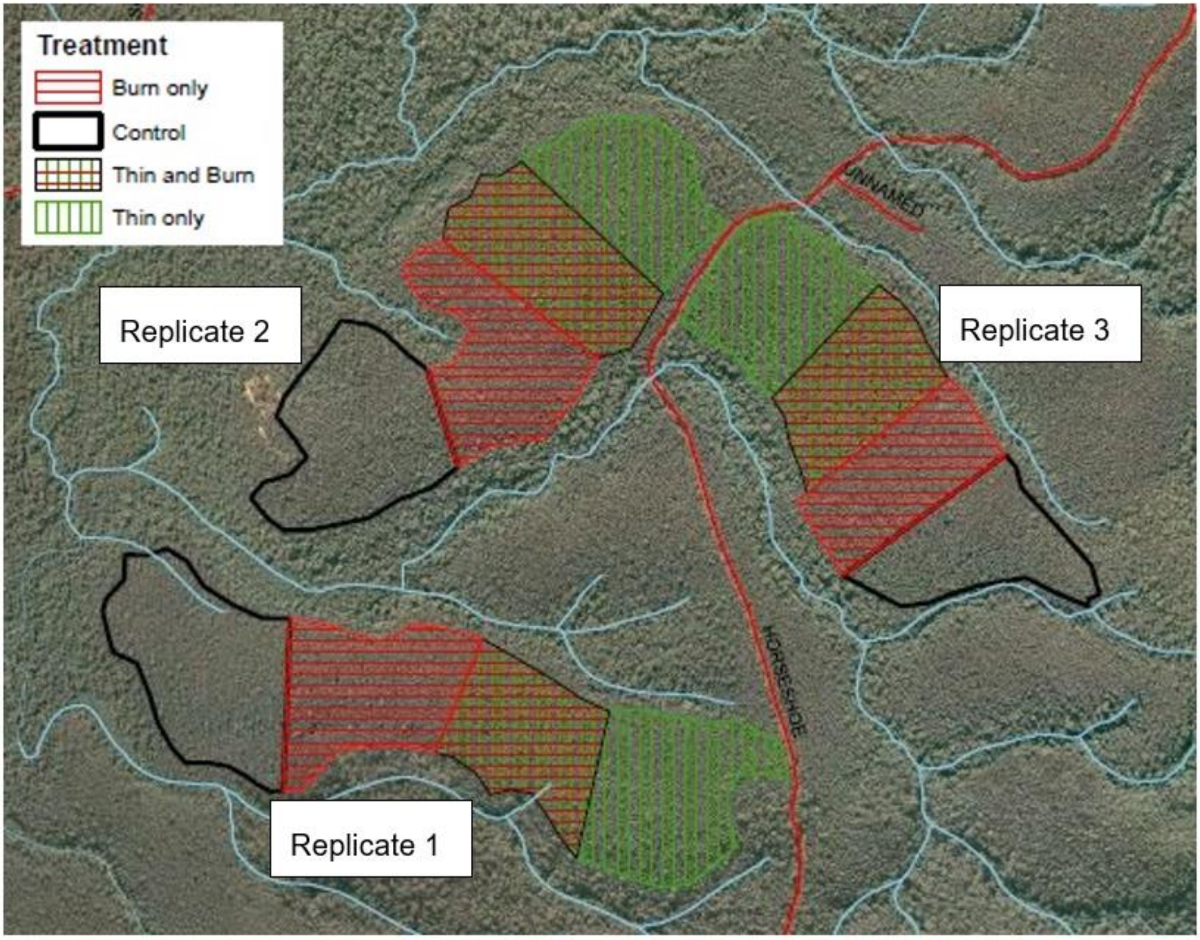

Figure 2 Drummer SF Trial site

The excavator harvester used to undertake the mechanical treatments was not best suited to the small diameter of the trees, leading to lower productivity and greater damage to retained trees. Trees were debarked in-situ with material down to 80mm extracted by a forwarder, the remainder left in the forest, yielding to high fuel loads.

4.2 Drummer SF Issues

The main issues that arose during the trial are discussed below.

4.2.1 Stem Density

The site is predominantly 1983 fire regrowth with a stem density of 1,518sph and mean diameter of 19.1cm DBHob. The high density and small piece size resulted in lower rates of production for the mechanical treatment; from 1ha/day to 0.6ha/day. Those lower rates of production impacted the timing for the mechanical treatments, causing delays in the completion of mechanical treatments.

The high density also led to inefficiencies with the biomass sample plot design. Many plots had more than 60 stems. This meant it was not feasible to measure the height of each stem (as specified in the sample design) and a height sampling system was used instead.

4.2.2 Burning Treatments

The burn treatments were not able to be conducted in the autumn of 2017. This was a result of a short burning season (caused by unusually dry conditions in East Gippsland region). VicForests sought approval from the Department of Environment, Land, Water and Planning (DELWP) to conduct the burns in spring 2017 but approval was not given.

Consequently, the burn treatments were carried over to the autumn 2018 burning season. There was little change in the site conditions from spring 2017 to spring 2018 in terms of fuel composition or regrowth of green vegetation on the forest floor. The autumn 2018 burning season was also very short and only replicates 2 and 3 were able to be burnt.

4.2.3 Land Management Arrangements

Responsibility for the management of public land in Victoria lies with DELWP, while VicForests has ownership of the commercial timber resources over parts of the State forest estate. This arrangement adds complexity and reduces autonomy for VicForests when conducting burning operations.

VicForests' ability to respond flexibly to favourable burning weather is limited by the requirement to comply with the regime for fire management on public land. The relatively narrow burning seasons experienced in autumn of 2017 and 2018 were further reduced by compliance processes.

4.3 Drummer SF Diameter, Basal Area and Dominant Height

The values and standard errors for mean DBHob (in cm), basal area (in m2/ha), mean height (in m) and stocking (in stems per hectare[27]) for each treatment before treatment are shown in Table 2.

Table 2 Drummer SF Stand characteristics

Parameter	Treatment			
	M	MB	B	C
Trees ha^{-1}	1576±39	1520±33	1444±38	1217±42
BA, m^2 ha^{-1}	57.4±1.3	55.9±1.0	57.9±1.5	55.8±1.5

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[27] Includes only stems>10cm DBHob.

Mean height, m	22.3±0.1	22.4±0.1	22.9±0.2	23.2±0.2
Mean dbh, cm	19.3±0.1	19.6±0.1	20.6±0.3	21.7±0.3

4.4 Drummer SF Carbon Characteristics

The values and standard errors for total carbon mass, in tonnes per hectare are shown in Table 3.

Table 3: Drummer SF Carbon, tonnes per hectare

Parameter	Treatment			
	Mechanical	Mechanical & Burn	Burn only	Control
Aboveground live				
Overstorey	207±5.8	209±6.0	225±7.5	215±7.14
Understorey	6.9±0.56	4.7±0.51	5.32±0.63	5.01±0.51
Deadwood				
Overstorey and stumps (dbh>10cm)	21.2±4.22	25.2±6.02	21.1±4.82	24.4±5.01
Understorey (dbh<10 cm)	3.45±0.39	2.86±0.33	1.76±0.23	1.89±0.31
CWD (d≥2.5cm)	60.6±13.7	67.9±9.18	54.3±4.69	58.5±7.89
Litter				
Surface litter	1.43±0.07	1.34±0.09	1.37±0.08	1.41±0.08
Twigs (6-25mm)	1.40±0.28	1.21±0.16	1.08±0.16	1.53±0.18
Duff	7.45±0.61	7.23±0.55	7.69±0.66	7.62±0.50
Soil				
Soil (0-10 cm)	47.2±2.41	51.2±4.50	46.2±4.52	46.9±2.57
TOTAL	**355±10**	**373±33**	**362±25**	**359±26**

4.5 Drummer SF Flora and Fauna impacts

The survey results for the flora plots are expressed as a tally of species detected from all plots within each treatment. For example, for the pre-treatment survey of the Burn Only treatment, there were 61 different species found in the 20 sample plots in Replicate 1, a further 11 different species in Replicate 2 and another 15 in Replicate 3, giving a total of 87 species.

Figure 3 shows the results of both the pre-treatment and post-treatment flora surveys.

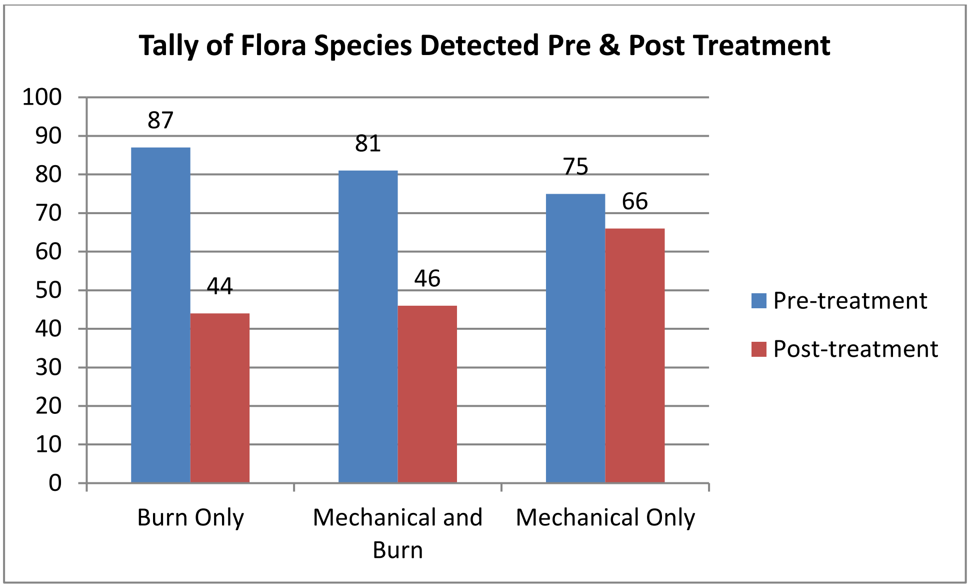

Figure 3 Drummer State Forest Flora survey results.

The survey results for birds are expressed in the same way as for the flora plots. Figure 4 shows the results of both the pre-treatment and post-treatment bird surveys.

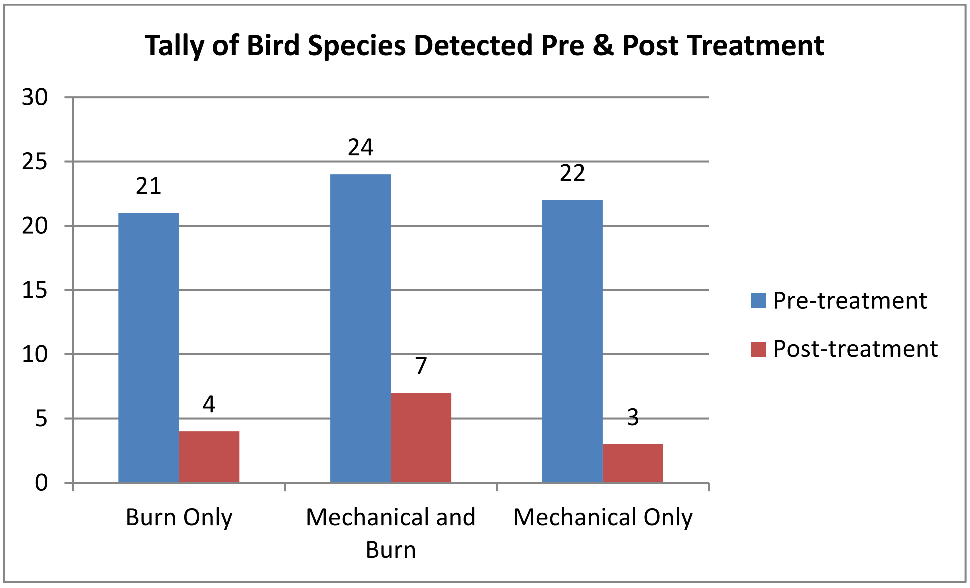

Figure 4 Drummer State Forest Bird survey results.

For both flora and birds there was a reduction in the number of species detected after all three of the treatment types. The extent of that reduction, expressed as a percentage of the number of species found pre-treatment, is shown in Table 4.

Table 4: Drummer State Forest Reduction in species abundance after treatment.

Treatment	**Flora**	**Birds**
Burn Only	49%	81%
Mechanical & Burn	43%	71%
Mechanical Only	12%	86%

The reduction in flora species is much less for the Mechanical Only treatment (12%) when compared to the Burn Only and Mechanical & Burn treatments (49% and 43% respectively).

The reduction in bird species is relatively similar across all treatments, ranging from 71% to 86%, and is much greater than the reduction in flora species.

Between the two survey there is an apparent reduction in the number of bird species detected. However, given the different seasonal timing, and in particular impact on flowering, for each survey it is difficult to draw firm conclusions regarding any impacts.

The mobility of birds allows them to move into adjacent forests while the treated forests regain their food production and nesting capacity. On this basis, it is probable that bird species will be able to quickly re-occupy the treated forests as they recover.

4.6 NSW Trial site - Burrawan State Forest

Mark Dury FCNSW

Burrawan State Forest is representative of widespread young regrowth commercial Blackbutt (*Eucalyptus pilularis*) native forests near local communities. Recent and proposed regeneration harvesting is creating a large resource of young regeneration that is at risk of significant damage from high intensity wildfire. The proximity of the forests to local communities creates a fire risk from the State forest estate which may be mitigated by Mechanical Fuel Load Reduction. Commercial thinning of these regrowth stands has the potential to increase forest productivity and value in the medium term. Thinning is also expected to change forest structure that may have ecological benefits such as encouraging crown development on retained trees to improve, increasing heterogeneity to improve species diversity, creating canopy gaps that may improve foraging opportunities for bats and basking sites for reptiles.

The site was burnt during a wildfire in 2002 but the fire intensity in the trial site area was mostly low-moderate intensity with it being burnt during back-burning operations rather than as part of the wildfire front. The site had not been burnt in the subsequent 17 years.

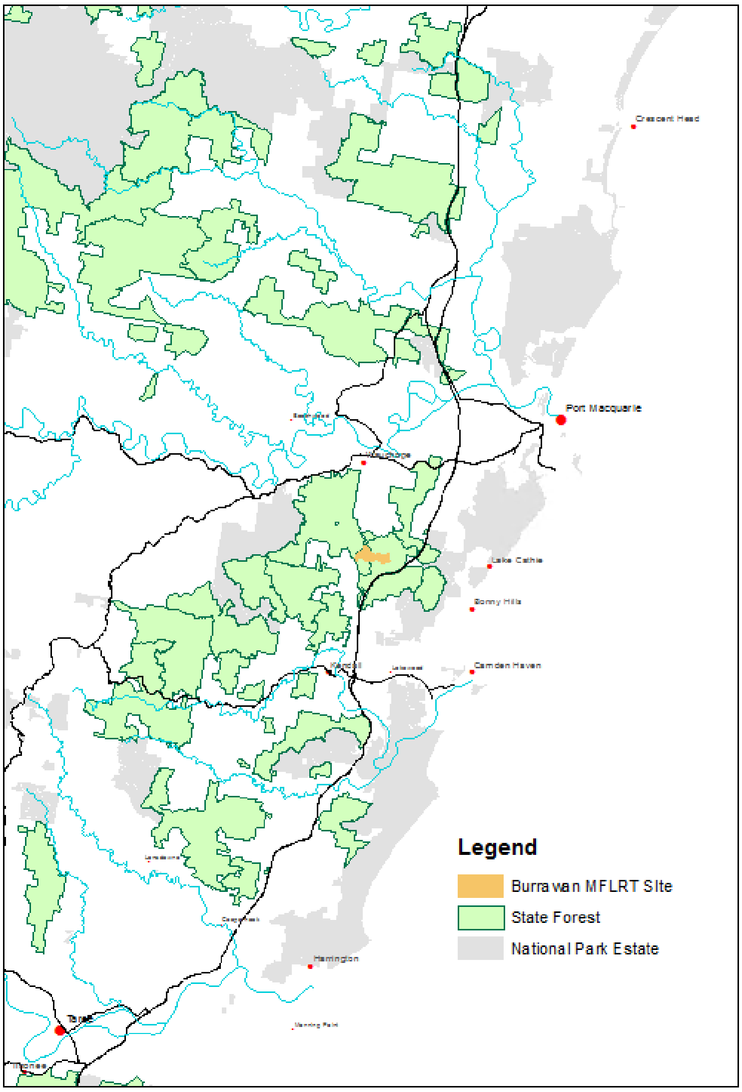

Figure 5 NSW Trial site location

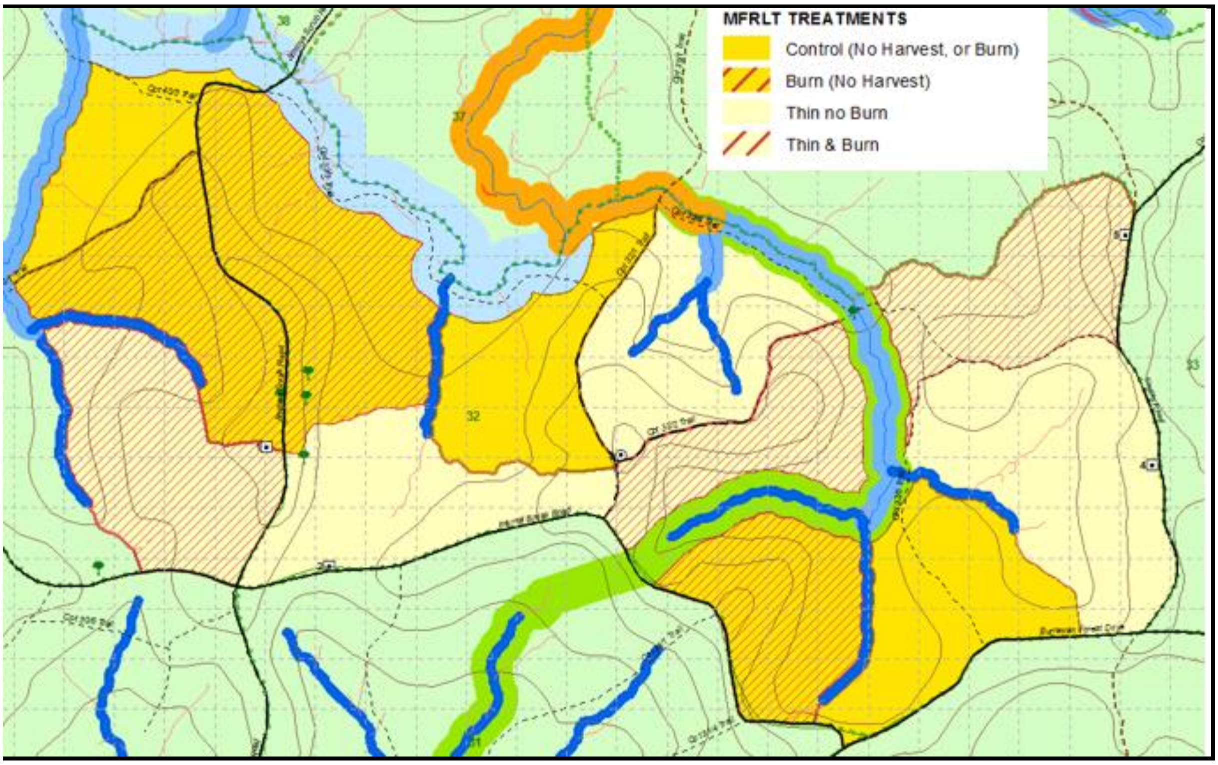

Figure 6 Burrawan SF Layout of treatments in NSW. (the blue and green shaded strips are buffers that exclude treatments)

4.6.1 Burrawan State Forest Changes in above-ground biomass and soil carbon following NSW mechanical fuel load reduction treatments

NSW DPI Forest Science Michael Mclean, Kate Wright, Fabiano Ximenes, Amrit Kathuria

In this component of the NSW Mechanical Fuel Load Reduction (MFLR) project the impacts of the treatments on biomass were determined for above-ground biomass (live tree, CWD and litter), as well as a limited assessment of soil carbon.

The site was dominated by young regrowth blackbutt, with the DBH profile dominated by trees in the smaller size classes of 2 to 9.9 cm and 10 to 24.9 cm. The basal area for blackbutt and stringybark species was consistently higher than that of other species across the study site. Overall, the basal area was reduced by around 50% for the thinning treatments (ranging from 14.8 to 17.5 m^2/ha), impacting all size classes and resulting in a major change in forest structure; a high proportion of the trees with DBH < 10 cm was removed (78 and 86% for thin and thin & burn). The basal area in the burn only treatment was only minimally affected by the treatment.

The pre-treatment fuel load of litter did not vary much between the treatments. The levels of litter removal were very variable across different burning treatment sites, resulting in a lower consumption of litter than would have been assumed. Pre-treatment control fuel load for 1 and 10 hour fuels and for live above-ground biomass (small and large) were not significantly different from those in the treatment sites. Following treatment, the increase in fuel loads (66.5 t/ha) and reduction in live ABG biomass was significant for the thin only treatments, and for “small” and “large” biomass in the “thin and burn” treatments (total increase of 17.6 t/ha). As expected, the thinning treatments significantly reduced above-ground live tree biomass– on average approximately 76 t/ha of biomass was removed off site as commercial logs. Biomass in burn only treatments was largely unchanged.

Pre-treatment soil carbon ranged from 11.2 to 13.3 t/ha. Based on the combined information on soil carbon and bulk density from the limited number of plots assessed, there was as small increase in soil carbon levels for burn only and thin and burn treatments, and a small reduction in the thin only treatment. All the treatments resulted in a net loss of carbon, with the thinning treatment resulting in a smaller loss overall (9.5 t C/ha).

The assessments relate to biomass levels prior to and immediately after treatments. Repeated measurements over time would be required to determine the long-term impacts of the treatments on biomass levels. An assessment of the use of the biomass removed from the mechanically treated sites is included to understand the broader life-cycle implications of the treatment.

4.6.2 Burrawan State Forest Fuels

The pre-treatment fuel load of one-hour fuels (litter) did not vary much between the treatments (Table 5). It is often assumed that hazard reduction burning removes all the litter. However, in this trial the levels of litter removal were very variable across different burning treatment sites, resulting in a lower consumption of litter than would have been assumed (Table 5). Fuel load decreased by 47.3t/ha across burning treatments and increased by 66.5 t/ha and 17.6t/ha in thin only and thin and burn treatments, respectively. We extrapolated the litter values across the treatment areas to provide an indication of the variability of values. There are some potentially confounding factors impacting on this result, including the length of time between treatment and post-treatment measurements and the dynamics of CWD following burning. It is possible that in the period between burning and post-treatment measurements (4-6 weeks), some level of smaller fresh biomass fractions may have been added to the smaller fuel fractions (1, 10 and 100 hour fuels) due to weather events. Also, the burning treatment may have shifted some previously larger biomass fractions more directly affected by the fire into smaller fractions. This may also help explain the significant reduction in 10,000 hour fuel levels for burning treatments (Table 5). This effect was not seen in the "thin & burn" treatments because of the new fresh material generated by the thinning of the trees and the limited removal of the biomass for commercial purposes.

Table 5 Burrawan State Forest Average pre-and post-treatment fuel loads Burrawan (t/ha), (standard error)

	1-hour	10-hour	100-hour	1,000-hour	10,000-hour	Small Stags	Stags	Total
Pre-treatment								
Control	14.5	3.1	3.2	21.8	72.4	0.6	4.1	119.7
	(0.3)	(0.4)	(0.4)	(2.6)	(2.3)	(0.1)	(1.1)	
Burn Only	15.6	2.8	3.4	18.9	98.7	0.8	11.3	151.5
	(2.1)	(0.2)	(0.6)	(3.2)	(20.3)	(0.3)	(1.7)	
Thin Only	13.8	3.0	3.3	19.9	53.3	0.4	3.3	97.0
	(0.5)	(0.2)	(0.7)	(3.6)	(14.9)	(0.1)	(0.9)	
Thin & Burn	15.0	3.1	3.8	24.6	40.4	0.8	8.8	
	(1.0)	(0.3)	(0.7)	(2.9)	(6.8)	(0.05)	(3.3)	96.5
Post-treatment								
Burn Only	12.0	3.5	4.4	18.9	49.8	1.1	14.5	104.2
	(0.7)	(0.4)	(1)	(4.1)	(2.9)	(0.3)	(4.9)	
Thin Only	25.6	9.0	9.3	39.4	78.9	0.2	1.1	163.5
	(1.6)	(0.5)	(2.2)	(5.3)	(6.5)	(0.1)	(0.1)	
Thin & Burn	11.2	3.3	11.2	36.2	46.4	1.1	4.7	114.1
	(2)	(0.3)	(1.4)	(5.1)	(2.5)	(0.6)	(1.4)	

Pre-treatment control fuel load for 1 and 10 hour fuels and for live above-ground biomass (small and large) were not significantly different from those in the treatment sites (Table 6). Following treatment, the increase in fuel loads and reduction in live ABG biomass was significant for the thin only treatments, and for "small" and "large" biomass in the "thin and burn" treatments.

Table 6 Burrawan State Forest Testing of Apriori contrasts. The values are the differences, e.g. Control Vs Burn-Only is the difference of Control minus Burn Only. The values in the parenthesis are the probabilities. Probability values <0.05 is significant at 5% level.

Contrast Tested	1-Hour	10-Hour	Small Biomass	Large Biomass
Pre-Treatment Comparisons				
ControlVsBurnOnly	-1.1(0.89)	0.3(0.86)	0.0(1.0)	46.3(0.26)
ControlVsThinOnly	0.7(0.97)	0.1(0.99)	-2.8(0.79)	54.4(0.16)
ControlVsThin&Burn	-0.5(0.99)	0.0(1.00)	-1.9(0.92)	65.4(0.08)
Pre Vs Post Treatment Comparisons				
PostVsPreBurnOnly	-3.6(0.09)	0.7(0.04)	-0.3(0.4)	-4.9(0.3)
PostVsPreThinOnly	11.8(0.001)	6.0(0.000)	-14.2(0.000)	-101.2(0.000)
PostVsPreThin&Burn	-3.8(0.08)	0.2(0.3)	-15.2(0.000)	-81.3(0.000)

4.6.3 Burrawan State Forest Biodiversity

NSW DPI Leroy Gonsalves, Brad Law, Tamara Potter, Isobel Kerr and Traecey Brassil, FCNSW Chris Slade, and Mark Drury

We assessed the short-term (<18 months) effects of mechanical and burning treatments and the combination of both on key habitat features for biodiversity, vegetation structural complexity and fauna groups that are likely to respond rapidly to treatment. Habitat complexity was greatest in the control treatment and lowest after thinning & burning, with other treatments being intermediate. However, complexity differences among treatments from pre- to post-treatment were not significant. Forest fauna responded differently to fuel reduction treatments, with responses generally positive or neutral and not necessarily corresponding to the response of habitat complexity. Bats (nightly activity) responded positively in the thin only and thin & burn treatments. Bird diversity was unaffected by treatments, though the composition of the bird community in each treatment changed from pre- to post-treatment. Native non-volant mammal activity was also not affected by treatment but was significantly lower across the study area post-treatment, which corresponded to 25 % lower rainfall in the 12-months preceding post-treatment sampling. However, the composition of non-volant mammals was affected by treatments, with red-necked wallabies (*Macropus rufogriseus*) moving into the study area post-treatment whereas bush rat (*R. fuscipes*) activity declined in the control and burn only treatments but remained relatively stable in the thin only treatment and was not detected in the thin & burn treatment.

Although the responses of broad fauna groups to fuel reduction were mostly positive or neutral, the responses of individual species were idiosyncratic and untreated (control) forest represented habitat of similar value to treated forest for some taxa. Maximising conservation value while meeting the aims of fuel reduction is critical, so it is important to retain untreated patches during fuel reduction operations and provide a mosaic habitat structure suitable for a diverse suite of forest fauna. Repeat sampling is critical to track temporal trends in the responses of forest structure and fauna to fuel reduction treatment.

4.7 Western Australia trial site – Ree's Forest

University of the Sunshine Coast - Justine Edwards, Mark Brown

The University of the Sunshine Coast was awarded the contract for research services to establish the Western Australian trial site for the National Bushfire Mitigation Programme – Mechanical Fuel Load Reduction Trials. Work commenced onsite in October 2016 and final post treatment measures were

taken in December 2018. The following report summarises the undertaken works, issues particular to the Western Australian site and summarises outcomes assessed from field measurements.
WA Ree's Forest – University of Sunshine Coast, Justine Edwards and Mark Brown

4.7.1 Ree's Forest Study area

The mechanical fuel load reduction trial (MFRT) was established on land owned and managed by the state Department of Water and Environmental Regulation (DWER). The DWER are a major stakeholder in the trial and have made significant contributions to the undertaking of the works. The site, known as Rees Block (33°19'15"S, 116°12'17"E, 262 m elevation) is situated 8 km north east of the Collie townsite, on the Collie-Williams Rd (Figure 1). In addition to its proximity to a townsite, the site is bordered by mine site accommodation, a recreational facility and production plantation forest and therefore requires careful and ongoing fire control management.

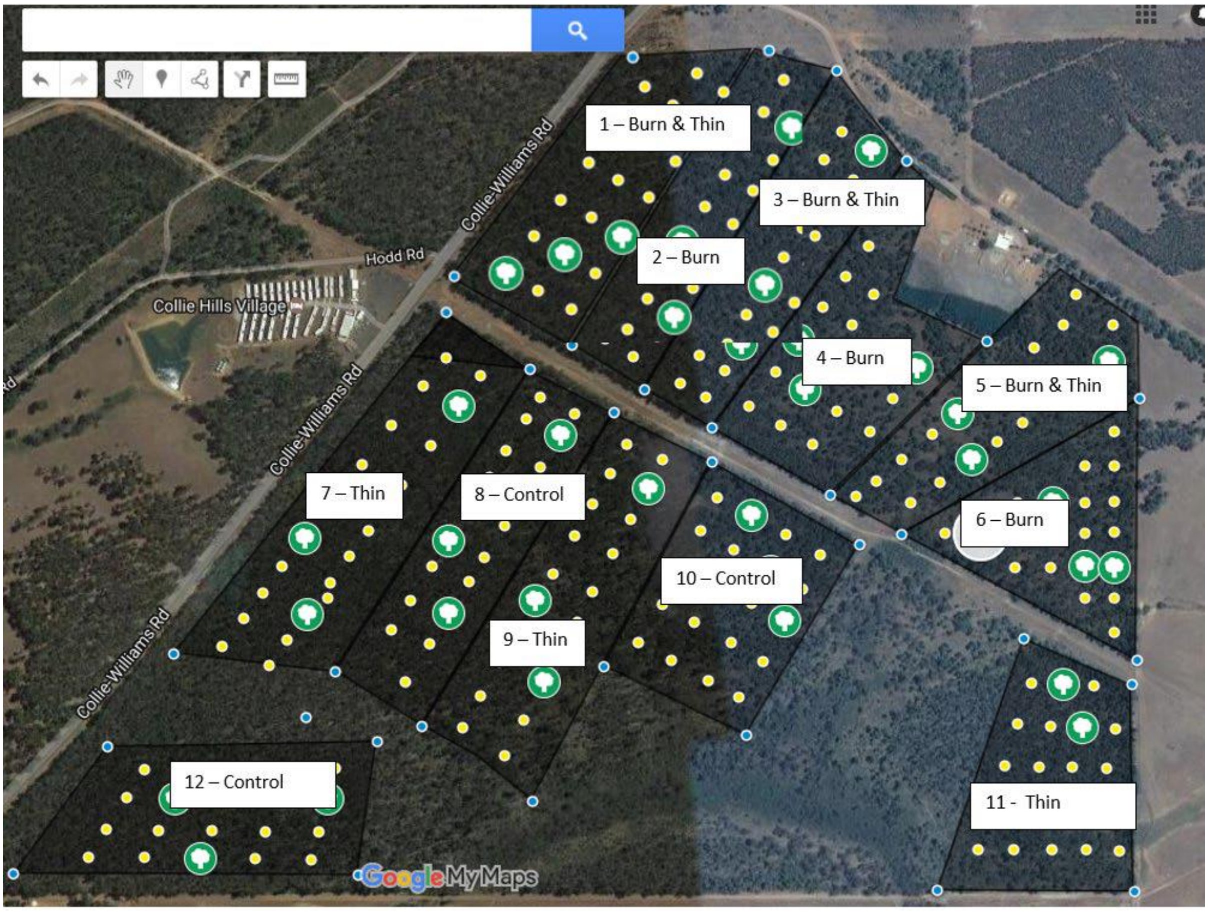

Figure 7 Location and experimental layout of Rees Block Mechanical Fuel Reduction Trial

The climate of the area is summarised in Table 7. The site has a gently undulating topography consisting of shallow ironstone gravels. The vegetation is dominated by *Eucalyptus marginata* (Jarrah) and *Corymbia callophylla* (Marri) with small patches of *E. wandoo* (wandoo). The understory is dominated by Jarrah and Marri saplings and *Xanthorrhoea australis* (grass trees). The clearing history is unknown, but the area has been heavily cut by illegal fire wood operators. This, in addition to the presence of *Phytophthora cinnamomi* (dieback), illegal recreational activities and feral pig damage has led to a generally degraded forest.

The site was last control burnt in 1993, by the Williams Road Brigade, but there are no records of fire behaviour, type etc. Prior to this, the area had not been burnt for between 28 – 35 years.

Table 7: Key climatic variables for the Collie town site

Mean maximum temperature *(°C)*	22.5
Mean minimum temperature *(°C)*	8.4
Mean annual rainfall *(mm)*	928
Mean no. of days without rain	88

4.7.2 Ree's Forest Timeline

Table 8 Timeline for MFRT activities at Rees block, Ree's Forest

Activity		Date
Biodiversity Survey	Pre – treatment	May 2016
Above Ground Biomass Course Woody Debris Soil sampling	Pre – treatment	Oct – Dec 2016
Phytophthora Assessment *Armillaria* Assessment	Pre – treatment	Dec 2016
Fuel Hazard Assessment Fuel Load Assessment	Pre – treatment	Mar – May 2017
Social Attitudes Meetings		May 2017
Mechanical Fuel Reduction		Oct – Nov 2017
Time & Motion study		Nov 2017
Control Burn		April 2018
Above Ground Biomass Course Woody Debris Soil sampling	Post treatment	Aug – Dec 2018
Biodiversity cameras Ad Hoc fauna assessments	Post treatment Control	Sept – Dec 2018
Fuel Hazard Assessment Fuel Load Assessment	Post treatment	Oct – Dec 2018
Coppice spray	Post treatment	Nov 2018
Fuel Moisture Content	Post treatment	Dec 2018

Experimental Design

The experimental site has a total area of 161 ha, with a powerline running east west through the block which splits it into a northern and southern section (Figure 7). A creek line on the southern boundary of the block excluded that area from inclusion in the trial. Within the remainder of the block, 12 plots were established to the criteria of representing the forest structure of the block and being as close to 10 ha in size each. Four treatments (Control, thin, burn, thin & burn) were established, with 3 replicates per treatment (Table 9, Figure 7).

Table 9 Ree's Forest Plot number, treatment application and plot size

Plot No.	Treatment	Area (ha)
1	Burn & Thin	9.2
2	Burn	7.36
3	Burn & Thin	8.08
4	Burn	9.44
5	Burn & Thin	8.99
6	Burn	7.63
7	Thin	12.8
8	Control	8.81
9	Thin	11.2
10	Control	9.17
11	Thin	8.88
12	Control	9.88

Within each of the 12 treatment areas, 20 circular plots were established on linear transects (Figure 7 – yellow points). Each plot is 0.04 ha in size, with a 0.004 ha sub plot at its centre point. Plot centres were marked with a metal post and GPS co-ordinates recorded. Above ground biomass, course woody debris, fuel hazard assessment, fuel load assessment and biodiversity values were assessed before and after treatments were implemented.

Mechanical fuel reduction (MFR) took place from October to November 2017. A dieback assessment (*P. cinnamomi, Armillaria* sp.) was undertaken prior to any operations on site. Due to the presence of dieback, MFR could only commence once the site was fully dry. The harvest management plan was constructed to ensure no spreading of dieback.

The clearing permit obtained for the site stipulates a final basal area of between 7 – 12 m2/ha. Best practice jarrah silviculture is a thin to 10 – 15 m2/ha (Department of Biodiversity, Conservation and Attractions) which was used as the goal. Tree marking was based on tree retention, and followed the following prescription:

1. Habitat trees were retained – any tree with a DBHOB > 70 cm, trees likely to contain hollows while still being wind sound.
2. Spacing – retention trees were selected to ensure that no artificial gaps were created, rather a natural patchy distribution was retained.
3. Biomass – larger trees were retained.
4. Form – good form (tree shape) stems were retained.
5. Species – the species distribution was maintained but where selection was possible, *E. marginata* was retained due to its potential value as a production species.

Tree marking was undertaken by a range of volunteers from the various stakeholder agencies after training from experienced Department of Biodiversity, Conservation and Attractions (DBCA) staff.
Trees were felled using a Cat Feller buncher. Full trees were extracted to roadside by a grapple skidder. Logging slash, debris, and unmerchantable trees remained where felled. Whole trees were chipped onsite, leaving heavy mulch areas, mainly due to chip overflow, at the infield chip sites.

Due to a very small climatic burn window available in 2017, and the requirement for the Mechanical Fuel Reduction to be complete prior to burning, the control burn was delayed till April 2018. The site was assessed by the Department of Fire & Emergency Services (DFES) and a DFES Full Prescribed Fire Plan (PFP) developed. The burn objective was to reduce surface and near surface fuels to less than 5 t / ha across a minimum of 90% of the trial burn area and maintain average scorch heights to less than 8 m. A cool burn was therefore planned to maximise fuel consumption and minimise damage to trees.

The majority of the thin and burn treatments were undertaken successfully. Some areas marked to thin were not ultimately harvested due to access restrictions. Unsuccessful burn areas were due to insufficient fuel loads to maintain ignition, despite continued maintenance from fire teams.

4.7.3 Ree's Forest Methodologies

Pre-treatment Biodiversity Survey
A vegetation survey was undertaken covering upper and lower slope positions by DWER. No threatened ecological communities or threatened flora or fauna were recorded. The site was identified as having potential suitability for the rare Baudins Black Cockatoo (*Calyptorhynchus baudinii*). Protection of habitat trees was therefore made the priority factor when tree marking for the fuel reduction operations.
Natural Area Desktop Assessments were undertaken for the same areas by DWER. The jarrah forest was classed as immature on the development spectrum with a woodland canopy cover.

Above Ground Biomass
Above ground biomass was assessed following the protocols provided in the Annex – EOI Detail and Background of the Expression of Interest document. Using the 20 measurement plots established for each replicate block, trees were numbered starting from 0° North. Every tree in the main plot (0.04 ha) with a DBHOB > 10 cm was tagged (metal tags to withstand fire) and the DBHOB and heights measured. Within each subplot (0.004 ha), trees with a DBHOB of < 10 cm were also measured, including the dimensions of *X. australis* if present. Tree species and status (alive / dead) was recorded. In total, 5,732 trees were measured pre-treatment. All plots were remeasured post treatment implementation.

Course Woody Debris
Course woody debris was measured using a line-intercept method. Within each replicate, plot numbers 6, 12 and 18 were assessed. Two transects were established, running North – South and East – West through the plot centre point. Course woody debris was defined as downed woody stems, standing dead trees with a DBHOB > 20 cm and stumps > 1.3 m in height with a DBHOB > 20 cm. For each piece of woody debris located on a transect, diameter was measured, a decay class attributed and hollows in stems > 75 mm assessed. Woody samples were dried at 103°C to determine moisture content and density. Volume was assessed using the water displacement method. Course woody debris was measured before and post treatment implementation.

Soil Sampling
Soil samples were taken from plots 6, 12 and 18 of each replicate (36 samples). Surface soils (0 – 10 cm) were taken with a soil corer. Samples were sent to CSBP Plant and Soil Laboratory for nutrition and soil carbon analysis. Soils were sampled before and after treatment implementation.

Disease Risk
A qualified Dieback Assessor was employed by the Department of Biodiversity, Conservation and Attractions (formally DPAW) to assess the study area for the presence of key disease risks *Phytophthora cinnamomi* and *Armillaria*. The presence of these agents was mapped and incorporated into a Dieback Management Plan and the Harvesting Plan employed by the thinning contractor.

Fuel Hazard and Fuel Load Assessment
Fuel hazard and load assessments were undertaken following the protocols provided by the CSIRO team utilising the data for Fire Behaviour Modelling. Fuel Hazard Assessments were based on the Project Vesta Fuel Assessment Field Guide and were undertaken in each of the 20 fixed circular sample

plots per replicate (240 Assessments). Fuel loads were assessed using destructive sampling. Litter samples (loose bark, twigs, fallen leaves) were sampled from a representative 0.25 m^2 quadrat for every permanent sample plot. Branch fuels (6 – 25 mm diameter) were sampled from a representative 1 m^2 quadrat for every second (even numbered) permanent sample plot. Samples were weighed on the day of collection, dried at 103°C for 48 hours or until dry weights stabilised and moisture content calculated. Fuel hazard and fuel load assessments were undertaken before and after treatment implementation. Data was forwarded to CSIRO for expert analysis.

Biodiversity Measures - fauna

Fauna species, numbers and behaviour were assessed using an extensive motion sensor camera network. The camera network was established following Western Shield Camera Trap Monitoring Protocols. As pre- and post-treatment assessments would cover different time frames and different annual seasons, the camera network was established post treatment implementation. This enabled faunal activity in the Control treatments to be compared to the Thin, Burn and Thin + Burn treatments in the same annual season. Ad hoc assessment of bird presence and activity across treatments was recorded. Ad hoc assessment of frog presence and activity in frog habitats across all treatments (where applicable) was recorded.

Fuel Moisture Content

Fuel moisture content was measured following the protocols provided by the CSIRO team utilising the data for Fire Behaviour Modelling. Moisture content was sampled in the Control and Thin treatments. Representative samples were taken at the same time of day, in close proximity to each and in speckled shade. Samples were weighed, dried at 105°C for 24 hours, reweighed and moisture content calculated. Data was forwarded to CSIRO for expert analysis.

Coppice Control

Due to Jarrah coppice sprouting in response to thinning operations, a coppice control operation was undertaken in November 2018. Bio Growth Partners undertook the operation using hand sprayers, with a mix of glyphosate 450 at 2%, Pulse penetrant added at 2 ml/L and Metsulfron at 0.1 g/L.

Summary of Outcomes

Above Ground Biomass

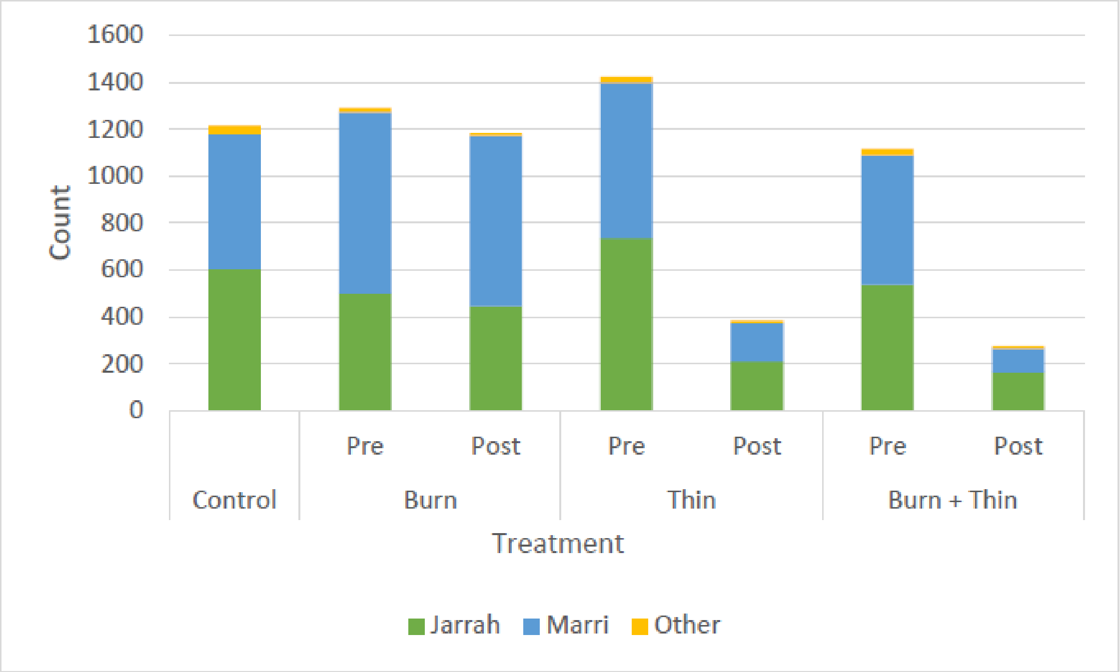

Figure 8 Ree's Forest Stem per hectare (SPH) for all stems > 10 cm DBHOB

Total SPH (all species) of stems > 10 cm DBHOB decreased for all treatments across the site. The decrease in SPH was significant for the Thin and Thin + Burn treatments. Forest composition (based on species %) did not differ for Burn and Thin treatments, with percentage values for the main overstory species remaining relatively constant. Forest composition did change in the Burn + Thin treatment, with a 11% shift from *C. calophylla* to *E. marginata.*

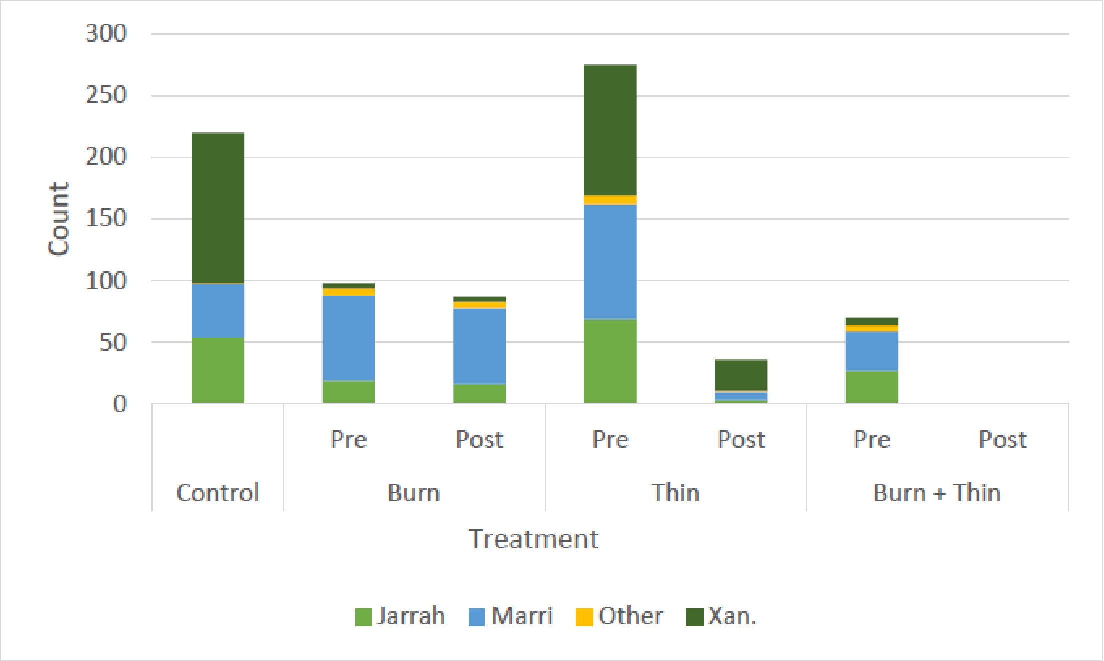

Figure 9 Ree's Forest Stems per hectare (SPH) for all stems < 10 cm DBHOB

Total SPH (all species) of stems < 10 cm DBHOB decreased for all treatments across the site. The decrease in SPH was significant for the Thin and Burn + Thin treatments. Thin and Burn + Thin also experienced the largest decrease in *X. australis*. The Burn + Thin treatment had no remaining stems of any species < 10 cm DBHOB. Forest composition (based on species %) was altered for the Thin and Burn + Thin treatments.

Table 10 Ree's Forest Above ground biomass (all stems > 10 cm DBHOB) measured pre- and post-treatment for all species, E. marginata and C. callophylla.

	Control	Burn		Thin		Burn + Thin	
		Pre T	Post T	Pre T	Post T	Pre T	Post T
All Species SPH	507	538	493	593	160	465	115
BA / ha	44	44	34	40	15	40	18
Mean Ht (m)	12.5	12.7	13.1	12.1	14.9	13	17
Mean DBHOB (cm)	25.4	25.5	24.7	23.4	30.1	26.4	39.4
E. marginata SPH	252	208	190	307	88	223	68
BA / ha	19.6	18.3	15.7	20	9.8	19.6	10.4
Mean Ht (m)	13.2	13	13.6	12.5	16.2	13.5	17.9
Mean DBHOB (cm)	26	27.9	27.5	24.6	33.5	27.6	39.4
C. callophylla SPH	239	322	304	276	68	231	43
BA / ha	13.0	25.3	18.3	12.5	4.7	19.5	6.4
Mean Ht (m)	12	12.6	12.7	11.8	13.4	12.7	16
Mean DBHOB (cm)	21.8	23.9	23	20.5	25.8	24.9	38.8

Basal area per ha (BA/ha) of stems > 10 cm DBHOB decreased for all treatments, with the greatest change seen in Thin and Burn + Thin. *C. callophylla* had the largest decrease in BA/ha, attributed to the tree marking (for retention) prescriptions employed. Tree size (height and DBHOB) was constant for the pre- and post- Burn treatment and increased for the Thin and Burn + Thin treatments. This is also considered a reflection of the fuel reduction (thinning) operation focussing on the removal of smaller inferior stems.

Table 11 Ree's Forest Above ground biomass (all stems < 10 cm DBHOB) measured pre- and post-treatment for all species, E. marginata and C. callophylla.

	Control	Burn		Thin		Burn + Thin	
All Species SPH	92	41	36	115	15	29	0
BA / ha	.14	.13	.17	.20	.01	.11	0
Mean Ht (m)	4	4.7	5	4.2	4.7	4.5	0
Mean DBHOB (cm)	6.2	6.1	6.8	5.5	5.6	6.4	0
E. marginata SPH	10	8	8	10	3	16	0
BA / ha	.06	.02	.02	.08	.01	.06	0
Mean Ht (m)	3.6	3.7	4.2	3.5	4.4	4	0
Mean DBHOB (cm)	5.3	5.5	6.1	5.2	4.5	7.2	0
C. callophylla SPH	8	29	30	14	8	19	0
BA / ha	.06	.1	.1	.1	.01	.04	0
Mean Ht (m)	4.4	5.1	5.2	4.6	4.9	5.0	0
Mean DBHOB (cm)	5.9	6.2	6.6	5.5	6.2	6	0

Basal area per ha (BA/ha) of stems < 10 cm DBHOB for all species increased slightly for the Burn and decreased significantly for the Thin and Burn + Thin treatments. The same pattern occurred for *E. marginata* and *C. callophylla* when analysed separately. The Burn + Thin removed all stems < 10 cm DBHOB from the assessment areas. There was no significant difference in tree size (height and DBHOB) in the Burn and Thin treatments pre- and post- treatment.

Course Woody Debris

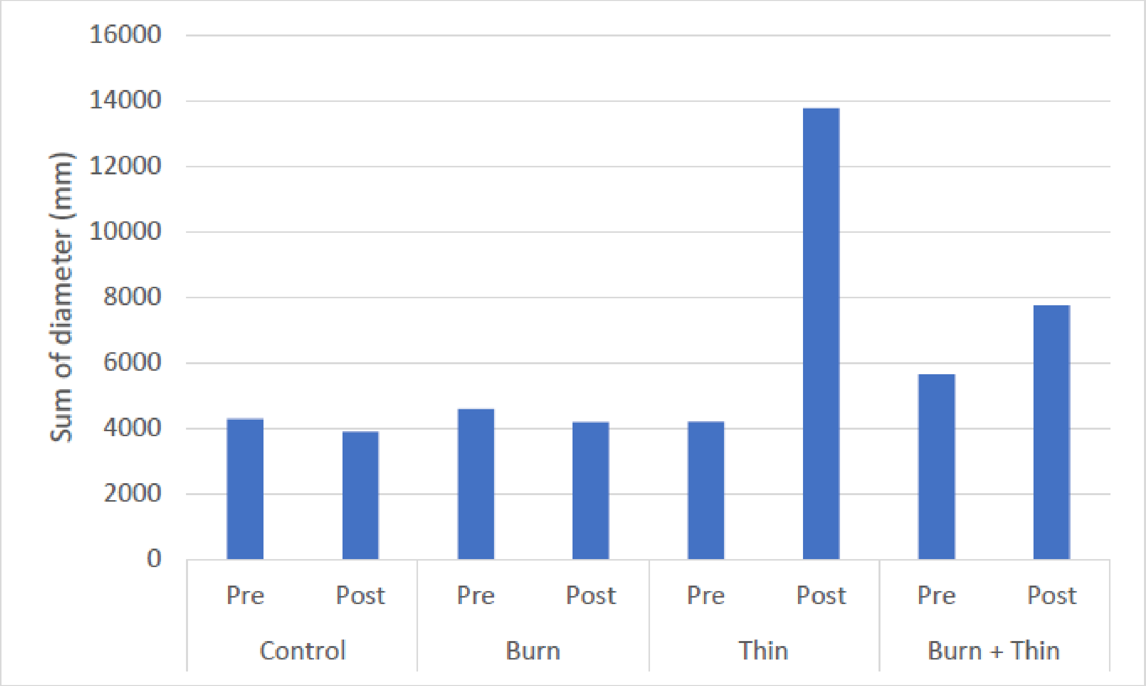

Figure 10: Ree's Forest Stem per hectare (SPH) for all stems > 10 cm DBHOB

The Thin alone treatment resulted in a significantly larger amount of 25 – 75 cm diameter course woody debris on site post treatment. This was expected due to the harvest and chip operations employed. The Burn + Thin treatment also had an increase in the small diameter class woody debris on site. These results will need to be considered in the Fire Modelling component of the data analysis.

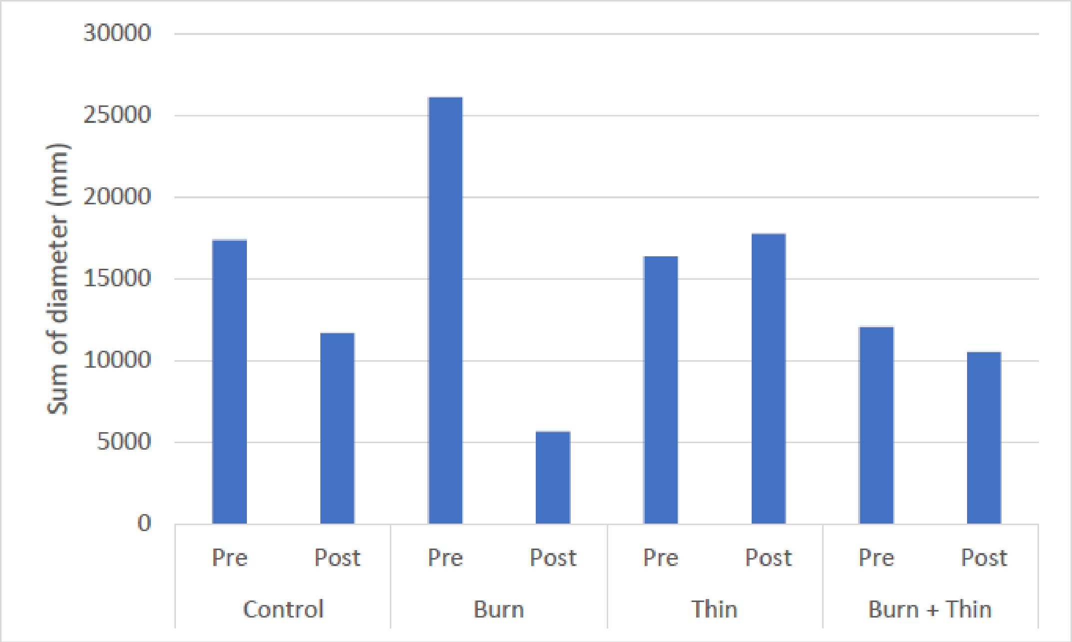

Figure 11 : Ree's Forest Summed diameters for course woody debris (>75 cm diameter size class) pre- and post-treatment.

The largest difference in course woody debris in the > 75 cm diameter size was measured in the Burn treatment. Large diameter course woody debris was reduced by 78%. Large diameter woody debris contained more hollows and a greater amount of wood to support ongoing combustion. A decrease in course woody debris in the Control treatments demonstrates the natural variation across the site.

Soil Sampling

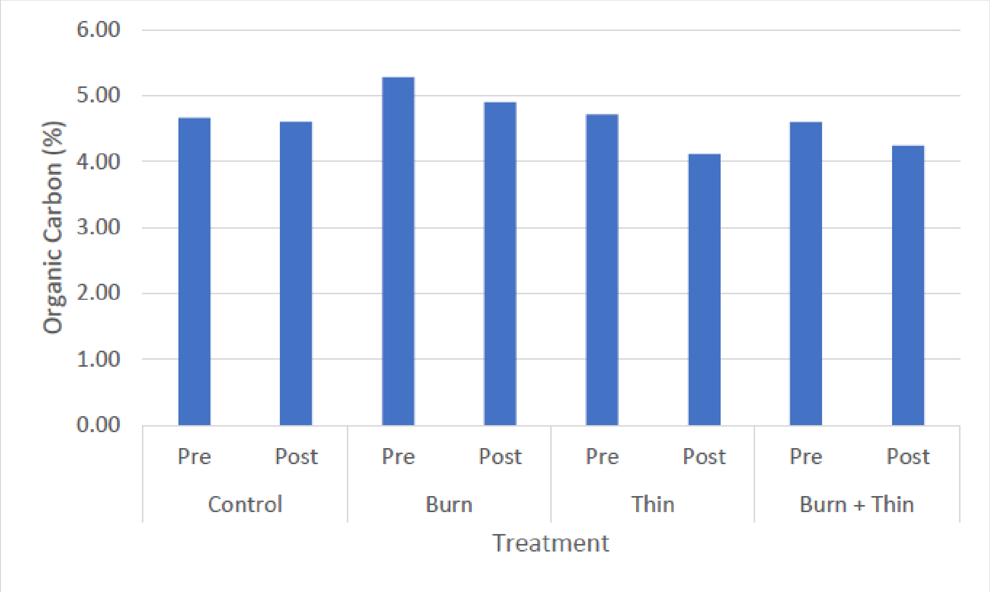

Figure 12 : Ree's Forest Soil Organic Carbon (%) assessed pre- and post-treatment.

There was a trend for soil organic carbon levels to decrease after treatment implementation, but no significant differences were measured. Long term sampling will determine if any differences exist once woody material and charcoal have degraded on site.

Fuel Hazard Assessment, Fuel Load Assessment and Fuel Moisture Content

Pre- and post- treatment measures were made for all treatments and data forwarded to CSRIO for expert modelling and analysis. Fire Behaviour Modelling results and summary graphics for Rees Block are presented in "Mechanical Fuel Load Reduction Trial Project: Fire Behaviour and Landscape Spread Analysis", Client Report No. EP192332, CSIRO.

Biodiversity Assessments

Habitat

All identified habitat trees were still standing after treatment implementation (marked for retention, no fire destruction). There was no change in the number or size of habitat hollows in standing stems. There was a trend for reduced hollows in fallen large diameter course woody debris in the Burn treatment. Post Burn and Burn + Thin treatments, 'green pick' increased and there was a trend for large grazing fauna (Kangaroos, Wallabys) to be 'grazing' rather than 'travelling' as captured by the motion camera network.

Frog Identification

Frog activity was monitored via call recordings submitted to Frog ID. The presence and activity of frogs was influenced by the amount of suitable habitat available with no impact due to surrounding treatments. Areas of frog habitat were excluded from treatment application but were adjacent to all treatment types.

Bird Identification

Bird species were abundant (c/o Geoff Cullen) across the experiment site, before and after treatment implementation. Assessments were undertaken on an ad hoc basis, but no trends were identified in behaviour or numbers based on treatment application. The exception to this trend was a short term increase in Cockatoo feeding behaviour immediately after all burn treatments, particularly on Marri ‘nuts’ exposed to fire.

Large fauna – camera network

A preliminary analysis of large fauna (primarily kangaroos, wallabies, emus, pest species (cats, rabbits, foxes)) species number and activity found no significant differences across treatment types. There was a trend for increased grazing behaviour as a result of ‘green pick’ regeneration in burnt areas. Western Brush Wallabys were observed to prefer recently thinned areas where *E. marginata* coppice provided increased shelter.

The lack of treatment impacts on fauna (preliminary analysis) may be attributed to the proximity of the treatment areas to each and their relatively small size. This resulted in a patchy network of different environment types and conditions within the expected movement range of large fauna species.

There was insufficient project time post- treatment to undertake meaningful flora assessments that would not be biased by annual seasonal differences.

5 Results

5.1 Overall Fuel loads

The different processing machines used resulted in significantly different fuel loads between the three sites, with litter fuel load at the NSW site 86% higher with mechanical only treatment compared with the pre-treatment level, in WA it was 64% higher and at the Victorian site forest fuel load increased 827% for mechanical only compared with the control. This high percentage increase in Victoria was in part due to the low level of litter load before treatment of 2.9 tonnes per hectare, while tree heads left in the forest after thinning resulted in total fuel loads of 26.6 tonnes per hectare.

Table 12 : Summary of the three site outcomes of the treatments, showing the differences and similarities between operations

Metric (means)	Burrawan SF NSW		Drummer SF Vic.		Ree's Forest WA	
	Pre-Treatment	*Post-Treatment*	*Pre-Treatment*	*Post-Treatment*	*Pre-Treatment*	*Post-Treatment*
Trees/ha mechanical only	725	372	1576	283	593	160
Trees/ha mechanical & Burn	690	352	1520	244	465	115
Basal Area m2/ha mechanical	31	17	57	23	40	15
Basal Area m2/ha mechanical & burn	29	16	56	23	40	18
Overall fuel hazard* - Control (SE) {% Change)	3.4 (0.05)	2.7 (0.07) {-21%}	3.9 (0.03)	Not measured	2.4 (0.1)	3.3 (0.13) {+36%}
Overall fuel hazard* - Burn only (SE) {% Change)	3.6 (0.07)	1.4 (0.08) {-61%}	4 (0.02)	3.9 (0.09) {-1%}	2.9 (0.09)	2.1 (0.13) {-28%}
Overall fuel hazard* - Mechanical (SE) {% Change)	3.5 (0.07)	2.3 (0.11) {-34%}	4 (0)	(0) {0%}	2.2 (0.1)	3.6 (0.15) {+65%}
Overall fuel hazard* - Mechanical & burn (SE) {% Change)	3.6 (0.05)	1.7 (0.11) {-55%}	4 (0.02)	2.3 (0.41) {-42%}	2.9 (0.09)	1.7 (0.12) {-41%}
Litter~ Fuel load t/ha- Control (SE) {% Change)	14.5 (0.3)		3.1 (0.19)	Not measured	3.2 (0.04)	2.0 (0.03) {-37%}
Litter~ Fuel load t/ha- Burn only (SE) {% Change)	15.6 (-2.1)	12 (-0.3) {-23%}	3.0 (0.17)	0.3 (0.09) {-90%}	5.8 (0.07)	1.8 (0.02) {-67%}
Litter~ Fuel load t/ha- Mechanical (SE) {% Change)	13.8 (-0.5)	25.6 (-1.6) {86%}	2.9 (0.19)	26.6 (3.64) {827%}	3.6 (0.05)	3.3 (0.05) {-8%}
Litter~ Fuel load t/ha- Mechanical & burn (SE) {% Change)	15 (-1)	11.2 (-2) {-25%}	3.1 (0.16)	20 (2.33) {553%}	6.1 (0.05)	2.3 (0.03) {-64%}

* Victorian Overall Fuel Hazard Guide 4th Ed.1=Low, 2=Moderate, 3=High, 3.5=Very High, 4=Extreme

~ NSW = 1 hour fuels, Vic. = Top litter, WA = Fine Fuel Load (litter and Twig)

The WA feller-buncher with roadside chipping resulted low fuel loads after treatment comparative to the other sites, with all treatments and the control seeing a drop of fuel loads. The WA drop of 31% in fuel loads in the control treatments suggests that the mechanical only treatment may have increased fuel loads rather than having an 8% drop. The proportion of twig to leaf litter increased in the mechanical only treatment.

For litter fuel loads in burn only treatments, NSW saw a drop of 23% to 12 tonnes per hectare, WA a 43% drop to 1.8 tonnes per hectare whilst in Victoria there was a 90% drop to 0.3 tonnes per hectare.

5.2 Hazard ratings

The fuel hazard scores[28] for the mechanical only treatment in New South Wales saw a 34% drop a changing rating from 'Very High' to 'Moderate/High', in Victoria a zero percent change whilst in WA a 65% increase in overall fuel hazard score changing rating from 'Moderate/High' to 'Very High/Extreme'.

When mechanical treatment was combined with burning the overall fuel hazard score decreased by 55% in New South Wales (changing from 'Very High' to 'Low/Moderate'), 42% in Victoria (changing from 'Very High' to 'Low/Moderate'), and 41% in WA (changing from 'High' to 'Low/Moderate').

For fuel hazard scores the burn only treatments in NSW saw a 61% drop (changing from 'Very High' to 'Low/Moderate'), in Victoria at 1% drop and WA a 28% drop (changing from 'High' to 'Moderate/High') compared to pre-treatment scores.

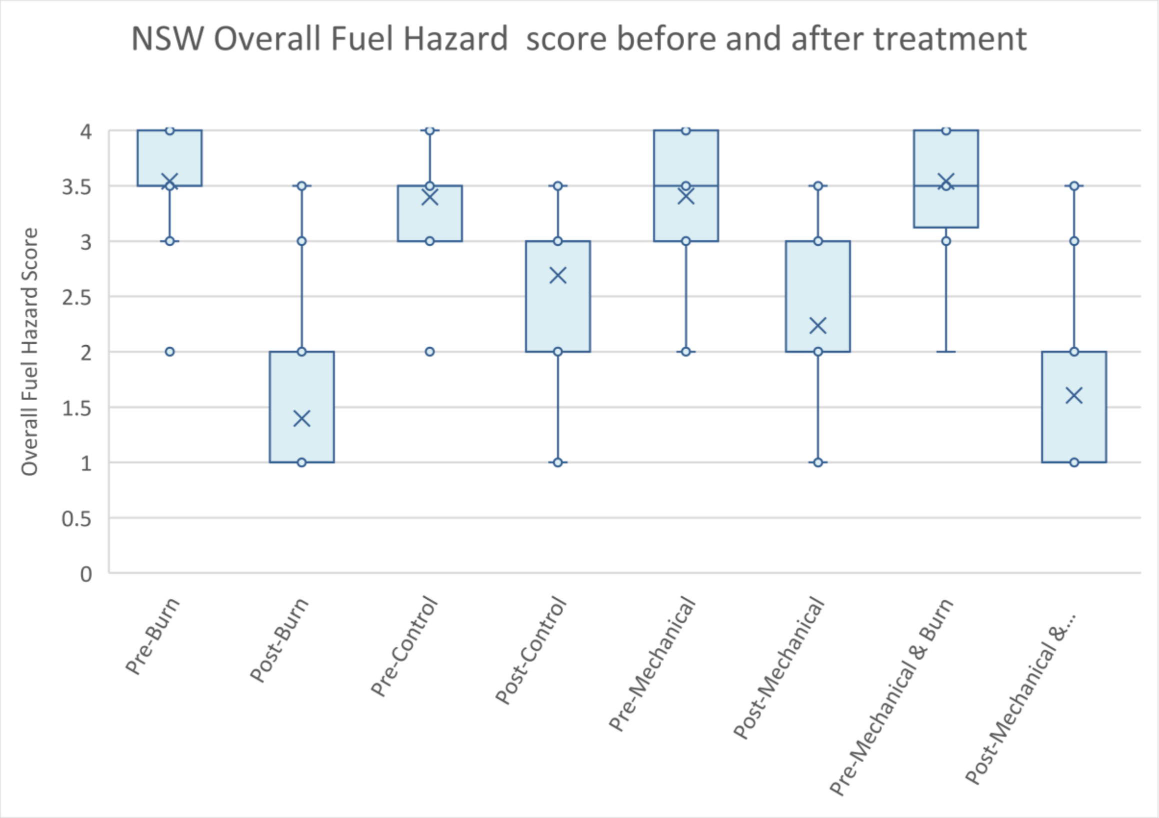

Figure 13 Burrawan State Forest Overall Fuel Hazard Scores before and after treatment

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[28] Victorian Overall fuel hazard assessment guide 4th edition July 2010 Fire and adaptive management, report no. 82 By Francis Hines, Kevin G Tolhurst, Andrew AG Wilson and Gregory J McCarthy

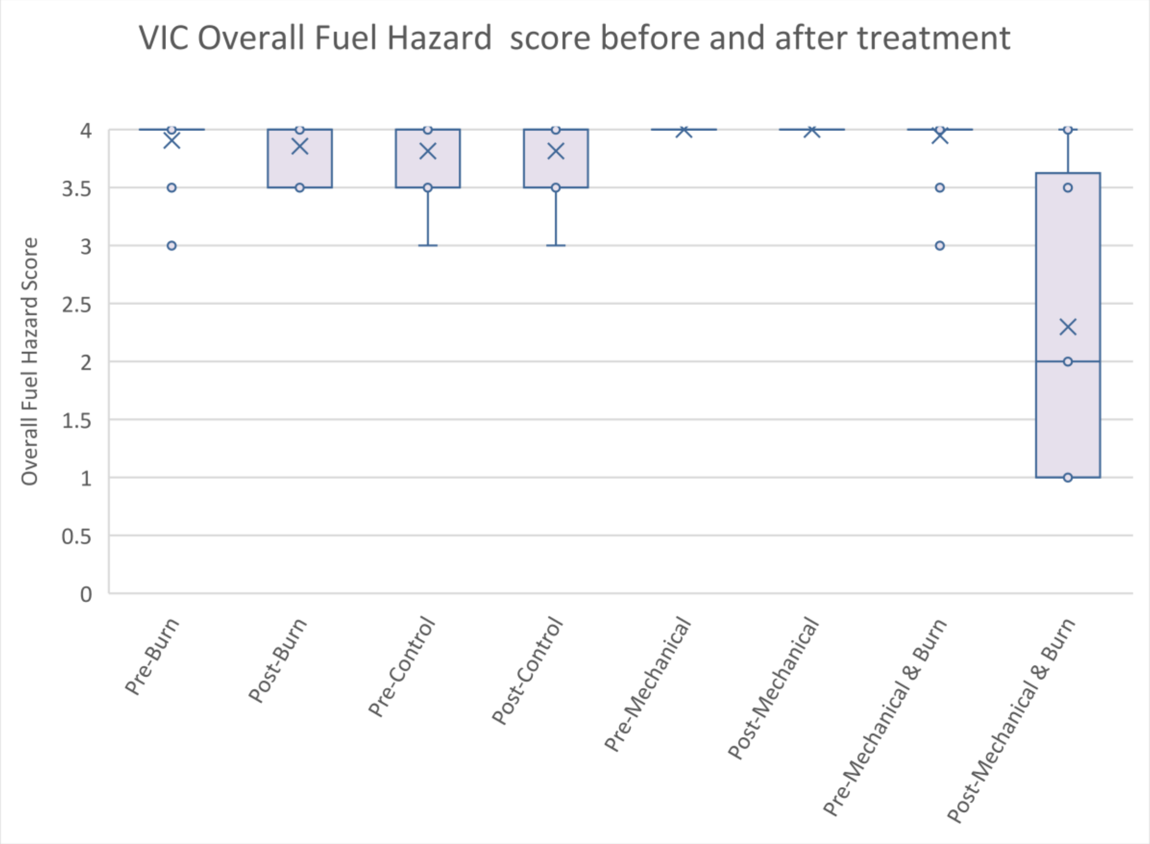

Figure 14 Drummer State Forest Overall Fuel Hazard Scores before and after treatment

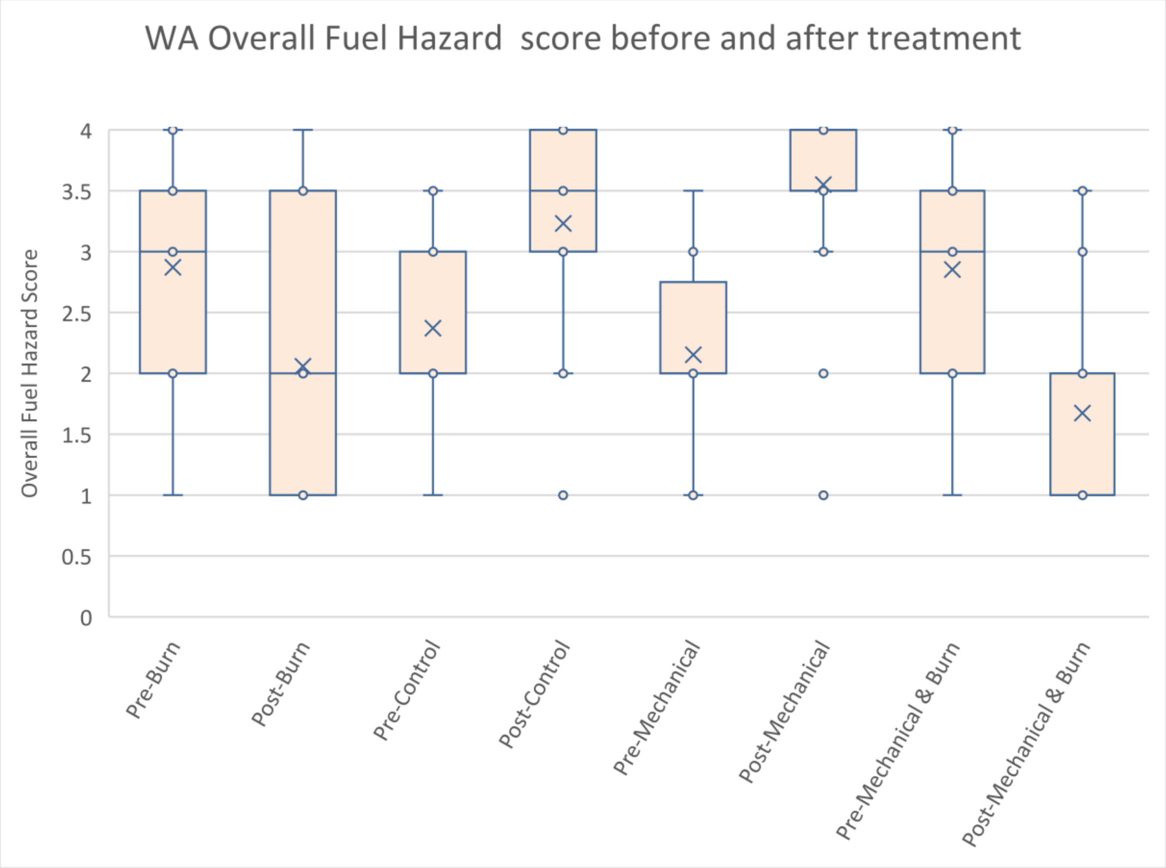

Figure 15 Ree's Forest Overall Fuel Hazard Scores before and after treatment

5.3 University of the Sunshine Coast were commissioned to report on the trial site machinery productivity. Through AFORA, Dr. Mauricio Acuna, Dr. Glen Murphy, Rick Mitchell undertook the work

5.3.1 Editor comment

This report highlights again the fundamental challenge in the way mechanical fuel reduction is planned, managed and reported on.

Traditional forestry assessments of machinery productivity assess basal area removal, volumes/DBH of trees cut and cost per m^3 or tonne of material or product removed. Volume of timber produced per hour and cost per tonne of wood sold is not the driver of these mechanical fuel load reduction operations.

Operational plans for mechanical fuel load reduction needs to be based on fuel removal objectives, including the material that cannot be categorised by DBH or volume per stem. The cost of the operations needs to be assessed as a cost per hectare treated with segregation or categorisation of the operation based on the intensity of removal and with overall change in fuel load before and after the operations.

Unfortunately, this traditional forestry type study looked at cost per cubic meter processed, future studies need to ensure the operations are driven and measured around the objective of reducing fuel load and fire risk such as cost per hectare treated for reducing fuel load and fire risk.

5.3.2 Report authors reporting

It was found that on average, the productivity of the cut to length harvester/processor in trees per productive machine hour (PMH) was only 6.0% higher in NSW than in Vic. (54.4 versus 51.3 trees per productive machine hour). However, a big productivity difference in m^3 per productive machine hour was obtained between NSW and Vic. (13.0 versus 6.4 m^3 per productive machine hour). The productivity of the whole tree feller buncher in WA (on a m^3 per productive machine hour basis) was 1.05 and 2.14 times higher than those of the harvester/processor in NSW and VIC, respectively.

A large percentage of the cycle time of harvester/processors was explained by their felling and processing times, which in turn were associated with tree diameter, piece size, and operator experience. As expected, processing was the largest single work element contributing to cycle times, accounting for about ~45% in the NSW plots and ~65% in the Vic. plots. In the case of the feller buncher in WA, most of the cycle time was explained by cutting and swing to bunch times, which accounted for 50% and 20% of the cycle time, respectively.

Using regression models, in NSW, a productivity of 13.6 m^3 per productive machine hour was predicted for the mean DBHOB of 25.3 cm. The predicted productivity increases at a higher rate in the DBHOB range of 20 and 50 cm, passing from 8.9 m^3 per productive machine hour to 32.2 m^3 per productive machine hour (rate equal to 0.77 m^3 per cm).

In the case of VIC, the productivities predicted for the harvester/processor were lower than those obtained in NSW. For a mean DBHOB of 19.5 cm, the predicted productivity was 9.2 m^3 per productive machine hour in Plots 1 and 2 and only 5.5 m^3 per productive machine hour in Plot 3.

In the case of the feller buncher in WA, a productivity of 13.7 m^3 per productive machine hour was predicted for the mean DBHOB of 15.3 cm. The predicted productivity ranged from 1.4 m^3 per productive machine hour (DBHOB of 10 cm) to 71.3 m^3 per productive machine hour (DBHOB of 40 cm), with a rate equal to 2.33 m^3 per cm.

Unit costs for the harvester/processor calculated in the Vic. plots were more than twice as big as those computed for the NSW plots (average of $37.6 per productive machine hour in Vic. versus $17.8 per

productive machine hour in NSW). The average unit cost of the feller buncher in WA was $16.7 per productive machine hour for an average DBHOB of 15.3 cm.
Except for Plot 3 in VIC, the cost curves for the harvester/processor exhibit the same shape and magnitude in NSW and VIC. The costs exceed the $25 per tonne when trees of a DBHOB of 20 cm or less are harvested. In the case of WA, the inflexion point occurs at a DBHOB of 15 cm with a harvesting cost of $14 per tonne and reaches about $170 per tonne for a DBHOB of 10 cm.

Total costs for the cut-to-length (CTL) system (including harvesting, extraction, transport, mobilisation, planning/administration) calculated in Plots 1 and 2 of Vic. were very similar to those computed for the NSW plots. For a mean DBHOB <15 cm, total costs ranged between about $70/tonne (DBH = 15 cm and transport distance < 50 km) and about $212/tonne (DBH = 10 cm and transport distance >150 km). For a DBHOB > 15 cm, the costs ranged between about $20/tonne (DBHOB = 50 cm and transport distance < 50 km) and about $70/tonne (DBHOB = 20 cm and transport distance > 150 km).

Total costs for the full tree (FT) system (including harvesting, extraction, processing, transport, mobilisation, planning/administration) calculated in the WA plots were lower than those computed for the cut to length systems in the NSW and Vic. plots. In WA, for a mean DBHOB <15 cm, total costs ranged between about $50/tonne (DBHOB = 15 cm and transport distance < 50 km) and about $280/tonne (DBHOB = 10 cm and transport distance >150 km). For DBHOB > 15 cm, the costs ranged between about $20/tonne (DBHOB = 50 cm and transport distance < 50 km) and about $60/tonne (DBHOB = 20 cm and transport distance > 150 km).

The results of this study provide useful information for potential managers applying MFLR and confirm that the selection of the harvest system is critical in this type of operations. The selection of the right equipment is dictated by the initial site conditions (e.g. tree size, forest type, understory type/density), the required fuel reduction objectives, and if/how the resulting material will be used after treatment, among other aspects.

The results clearly show that in thinning operations with small trees (DBHOB <15-20 cm), and reduced extraction distances (<250 m), the use of a full tree harvesting system is more cost-effective than a cut to length system. When trees exceed a DBHOB of 25 cm, the cost differential between full tree and cut to length systems is very small, since, with trees of this size, the harvester/processor can reach its maximum productivity. Likewise, the productivity of a forwarder is higher than that of a skidder when the extraction distance exceeds 300-400 m.

For small trees, the use of small-scale harvesting equipment, as opposed to conventional large-size equipment, might make the operations more cost-effective, due to the much lower hourly costs (including ownership and operational costs), and the reduced mobilisation costs associated with small equipment.

FIRC/USC, Private Forests Tasmania (PFT), and the Australian Forest Growers Association (AFG) are working collaboratively on a National Institute for Forest Products Innovation (NIFPI) project titled “Optimising machinery configurations for profitable harvesting of small-scale plantations” which will provide guidelines and a web-based decision support tool (DSS) to effectively select harvesting equipment configurations for smaller, more dispersed woodlots. It is believed that these guidelines can also be applied in mechanical fuel load reduction operations, so it is suggested that further studies of these harvesting machines should be conducted soon in such conditions/operations.

5.4 Fire behaviour and landscape spread analysis - CSIRO

This component of the Mechanical Fuel Load Reduction trial project, undertaken by CSIRO's Andrew L. Sullivan, Matt P. Plucinski and Will Swedosh, focused on analysing changes in vegetation structure, arrangement and amount (as quantified by standard fuel attributes) as a result of fuel modification treatments and the resultant likely effect on fire potential as defined by a set of fire behaviour metrics. Calculated fire behaviour metrics were then extended to quantify changes in fire spread over the landscape for the purpose of supplying fire propagation maps for the Benefit Cost Analysis conducted by GHD.

Process - CSIRO

- Quantification and assessment of the effect of fuel modification treatments on fuel attributes critical for determining fire behaviour were undertaken by the trial participants at each site according to detailed methodologies developed for this purpose. These fuel attributes were surface fuel hazard score, surface fuel load, near-surface fuel hazard score, near-surface fuel height, elevated fuel hazard score and bark fuel hazard score.
- Additional measurements of effect of fuel modification treatments at the NSW site were undertaken by CSIRO to quantify second order (indirect) effects on wind and fuel moisture on fire behaviour metrics.
- Fire behaviour metrics assessed in the study are fire rate of forward spread, fireline intensity, headfire flame height, and maximum spotting distance.
- The Dry Eucalypt Forest Fire Model (DEFFM, Cheney *et al.* 2012) was used to calculate fire behaviour metrics. Fireline intensity was calculated using the model of Byram (1959) and a heat yield value of 18,600 kJ/kg.
- Fire behaviour findings were applied at the landscape scale using the Spark wildfire spread simulation framework (Miller *et al.* 2015).

Results - CSIRO

- Pre-treatment fuel attributes at each site were largely consistent. A minor degree of variability was observed across and between replicates at all sites, with variations possibly due to differences in climatology, forest type, site productivity, topography, geology and fire history.
- Application of fuel treatments at each site was inconsistent across and between replicates with some replicates not receiving or only receiving incomplete burn treatments due to unsuitable weather.
- Quality of post-treatment fuel attribute assessments was highly variable between and across sites, with a range of variability in the consistency of data collection. These were possibly due to differences in the application of fuel assessment methodologies, changes in assessment staff, difficulties in correctly identifying particular fuel attributes following treatment, differences in the length of time between treatment and assessment, and seasonal variation in vegetation growth.
- Treatment effects on fuel attributes were consistent at each site but variable between sites as a result of differences in treatment methodologies, site productivity and forest type.
- Fuel attributes for each site were conflated and changes relative to each site's control were calculated. Table 13 summarises the median changes observed in fuel attributes from all three sites.
- Fuel attributes for each site were combined with weather scenarios derived from an analysis of historical weather from the closest automatic weather station at each site and used to model likely changes in fire behaviour as a result of fuel treatments.

Table 13 Summary of changes in fuel attributes that affect fire behaviour at all three study sites. Changes are expressed as the average percentage change from pre-treatment conditions. Changes that reduce fire behaviour are coloured green, while that increase fire behaviour are coloured red.

Treatment	Surface Fuel Hazard Score	Near-surface Height	Near-surface Hazard Score	Elevated Fuel Hazard Score	Bark Fuel Hazard Score	Surface litter-load
Mechanical-only	-14.3	26.8	15.5	-66.7	0.0	75.4
Burn only	-66.7	-50.0	-66.7	-50.0	-50.0	-67.1
Mechanical and burn	-66.7	-50.0	-66.7	-66.7	-66.7	-63.3

- Weather scenarios consisted of representative weather for each of five fire danger rating classes (Extreme, Severe, Very High, High and Moderate). No weather was recorded at the sites that resulted in Catastrophic fire danger.
- The fire behaviour knowledge base Amicus (Plucinski *et al.* 2017) was used to model the effect of fuel attribute changes and weather scenarios for each site utilising the DEFFM.
- Fire behaviour metrics for each site were conflated and changes relative to each site's control were calculated.

Table 14 Summary of percent changes in modelled fire behaviour as an average across all three study sites. Changes that reduce fire behaviour are coloured green, while that increase fire behaviour are coloured red.

Treatment	Fire Danger Rating	Rate of spread (m/hr)	Flame height (m)	Intensity (kW/m)	Maximum spotting distance (m)
Mechanical-only	Extreme	9.69	-14.90	326.67	-48.33
	Moderate	25.62	3.44	231.63	18.07
Burn-only	Extreme	-80.04	-73.31	-85.47	-100
	Moderate	-75.94	-70.98	-85.80	-100
Mechanical and burn	Extreme	-80.04	-73.31	-87.02	-100
	Moderate	-74.23	-68.83	-82.08	-100

- Measurements of wind speed and surface fine dead fuel moisture content under the canopy at a mechanically treated plot and adjacent control were made over a two-day period at the NSW site to quantify likely second order (indirect) impacts of fuel treatments that would further influence fire behaviour on top of first order (direct) impacts of changes in fuel attributes.
- It was found that median wind speed at 2-m under the canopy at the control plot was 41% of that in the mechanically treated plot. Similarly, fuel moisture content was 17% higher in the control plot than the mechanically treated plot.

- The effect of these changes in wind speed and fuel moisture resulted in an increase in modelled rate of spread by a factor of three in the mechanically treated plot compared with the control plot.
- Changes in fuel attributes determined for all three sites were combined into absolute fuel attribute values for the purpose of enabling landscape-scale fire spread simulations. The fuel attributes for the control were assumed to be those recommended for long unburnt (> 12 years since last fire) dry eucalypt fire. The percent change in fuel attributes for each treatment were then applied to these values.

Table 15 Fuel attributes that affect fire behaviour for all treatments and control for landscape fire spread simulation. Percent change from control values shown in brackets. Changes that reduce fire behaviour are coloured green, while that increase fire behaviour are coloured red.

Treatment	SFHS	NS-height (cm)	NSFHS	Litter load (t/ha)
Control	3.5	25	3	12.5
Mechanical-only	3 (-14.3%)	31.7 (26.8%)	3.5 (15.5%)	21.9 (75.4%)
Burn-only	1.2 (-66.7%)	12.5 (-50.0%)	1 (-66.7%)	4.1 (-67.1%)
Mechanical and burn	1.2 (-66.7%)	12.5 (-50.0%)	1 (-66.7%)	4.6 (-63.3%)

- A hypothetical landscape was constructed in which the landscape-scale fire spread simulations were conducted.
- Fuel treatment was restricted to an approximately 700 ha region to the north-west of a township under threat.
- Median fire weather scenarios from a collated set from all three sites were selected for each fire danger rating class. Grasslands were assumed to be fully cured and to carry 2 t/ha (representative of late summer in Australia).
- The Spark wildfire spread simulation framework was then used to conduct 60 landscape fire spread simulations for three different ignition locations, five different weather scenarios and four different fuel treatment scenarios.
- Simulation results indicate of the Control and Mechanical-only treatment were very similar, with only a slight increase in fireline intensity in the fuel treatment area.
- Simulation results of the Burn-only and Mechanical and burn treatments were very similar, with burn areas and fireline intensities (in the fuel treatment area) much less than the Control and Mechanical-only treatments.
- Analysis of all results (considering first order effects only) show that Mechanical-only fuel treatment results in fire behaviour and landscape fire spread that is marginally worse than the Control with no treatment, as a result of treatment debris on the forest floor increasing fuel hazard attributes and surface fuel loads and thus fire spread and behaviour.

5.5 Benefit cost analysis - GHD

Seamus Hoban and Paul de Mar of GHD evaluated the economic merit of adopting mechanical fuel reduction (MFR) techniques to reduce fire impacts. The study outlined the estimated net societal benefits and costs associated with the adoption of mechanical fuel reduction techniques, as compared to the current methods of fuel reduction, primarily focused on prescribed fire. Mechanical fuel reduction in combination with prescribed fire was also evaluated.

5.5.1 Scope - GHD

This study seeks to quantify the relative economic impacts of applying MFR within a particular location and situation. Specifically, the study considers how different treatments applied to a 660 ha forested area outside a rural township, may impact on fire behaviour and therefore economic loss. The area chosen for the fire modelling is an actual landscape, which represents a likely situation where MFR might be considered suitable if adopted by Australian fire agencies and land managers in the future. To avoid impacting on local residents the location used for this modelling has been obscured.

The study considered the economic impact under 60 simulated fire events, representing variations in:

- Ignition points: 1km, 4km, 10km from township
- Fire Danger Rating (FDR): Moderate, High, Very High, Severe, and Extreme.
- Treatments within the 660 ha treatment area:
  - control = no treatment
  - MFR
  - prescribed fire
  - MRF + prescribed fire

Fire damage was calculated based on areas of different land types burnt, with fire intensity used to estimate the probability of dwellings being lost. Benefits were calculated as net savings in fire damage and suppression costs, as compared to the control, while costs were calculated as net increases in treatment costs as compared to the control.

Some key limitations from this project include:

- The study only considers the results within a single location, albeit with variations in ignition points and FDR. In reality the economic value from using MFR may vary significantly due to variations in treatment costs (MFR vs prescribed fire), fire suppression costs, asset value and fire behaviour.
- The study relies on the outputs from MFR trials conducted in three states. The outputs from these 1 ha trials were extrapolated and applied to a 660 ha treatment area. The fuel loads from this trial were adopted in the fire behaviour modelling, while the MFR machine productivity and costs as well as wood yields were adopted in this economic analysis.
- Limitations in the MFR trials, such as the non-removal of woody debris and surface fuels following treatment at two of the sites, having a direct impact on the CSIRO fire modelling and consequential cost-benefit analysis.
- Damage costs from adverse smoke impacts from the use of prescribed burning have not been included in the analysis, which previously have been shown to be quite a significant cost (Deloitte Access Economics 2014).
- The study relies on the outputs from the CSIRO's Spark Fire Model, which may vary from actual outcomes.
- Furthermore, the landscape fire modelling did not consider the impact of time since treatment i.e. the reduced effectiveness of MFR and prescribed fire in the years following treatment as the vegetation. In order to evaluate the net costs and benefits over time (20 years), this study has assumed that prescribed fire is required to be carried out on the trial

site every 10 years and MFR every 20 years, in order to broadly maintain the fuel loads achieved in the trials and assumed in the landscape modelling. Accordingly, treatment costs were annualised and spread equally across these time periods. Similarly, the costs from fire events were annualised based on an assumption of these events occurring every 30 years.
- For simplicity the modelling of economic costs from the simulated fire events has been limited to the impact on land and dwellings, with consideration of impact on environmental services or potential benefits arising from government, community or insurance coverage.
- The landscape fire modelling and subsequent calculations of treatment, fire damage and fire suppression costs calculations provide an economic assessment of a single fire event at a single point in time. However, it is the role of a BCA to assess benefits and costs over time (20 years) and discount to present day values.

Assumptions

GHD has applied several key assumptions outlined throughput this report, including:

- A flat rate for fire damage costs to different asset classes (different land use classes and houses), based on published estimates and GHD experience in assessing fire damage from previous fire events.
- Probability of houses being lost based on fire intensity within 100m radius.
- Treatment costs based on data from MFR trials and input from fire agencies
- Fire suppression/emergency response based on published estimates from previous fire events
- Fire events similar to those simulated in the landscape fire modelling were assumed to be one in 30 year events, with damage and suppression costs annualised over this period.
- In order to broadly maintain the fuel loads achieved in the trials and assumed in the landscape modelling, it was assumed that prescribed fire is required to be carried out on the trial site every 10 years and MFR every 20 years, with treatment costs annualised over these periods.
- The analysis has not sought to quantify impacts associated with environmental outcomes (including climate change), health impacts (including smoke related impacts, injuries, mental health impacts or fatalities) or impacts on local economies (including businesses operations or government services).

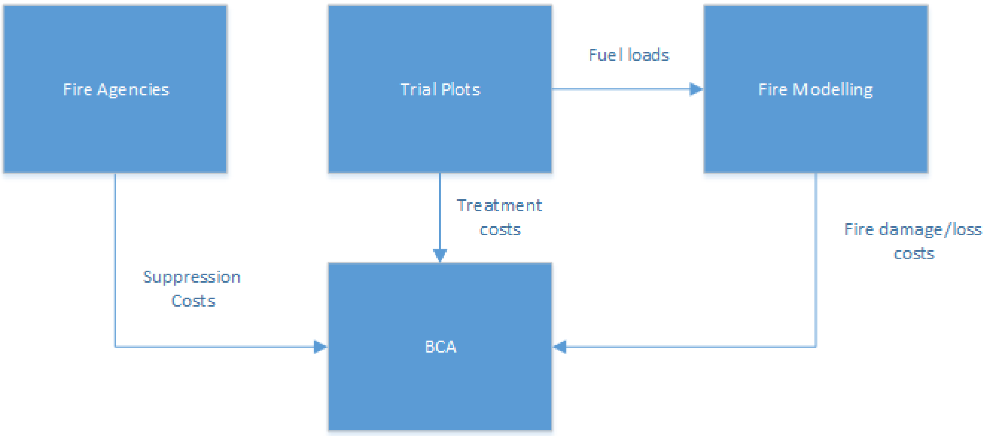

Figure 16 Summary of the BCA methodology

5.5.2 Fire modelling results - GHD

Table 16 below shows the areas burnt under each of the 60 simulations and the marginal change in areas burnt from treatments 1, 2 and 3 when compared to treatment 0 (control). The results show a significant variation in areas burnt, particularly based on weather conditions.

Treatment 1 (mechanical fuel reduction) resulted in a marginally higher areas burnt than the control. This may be explained by a net increase in ground fuel (limbs and leaves) left behind following mechanical harvesting. Treatment 2 (prescribed fire) resulted in a significant reduction in area burnt across most simulations. Treatment 3 (mechanical fuel reduction and prescribed fire) producing very similar results to Treatment 2, though areas burnt were marginally higher across most simulations. Again, this could be viewed as counterintuitive, given the removal of trees and therefore fuel from the landscape.

Table 16 Modelled Area burnt (ha)

		Areas burnt (ha)				Marginal change in areas burnt from control (no treatment)		
Ignition point km	Fire Danger Rating[29]	0. Control	1. Mechanical	2. Prescribed Burn	3. Mechanical and Prescribed burn	1. Mechanical	2. Prescribed Burn	3. Mechanical and Prescribed burn
10	1	840	840	840	840	0.0%	0.0%	0.0%
10	2	1,986	1,986	1,986	1,986	0.0%	0.0%	0.0%
10	3	4,208	4,242	3,842	3,843	0.8%	-8.7%	-8.7%
10	4	9,821	9,875	8,972	8,994	0.6%	-8.6%	-8.4%
10	5	18,952	18,995	17,377	17,402	0.2%	-8.3%	-8.2%
4	1	620	637	487	487	2.7%	-21.6%	-21.6%
4	2	1,691	1,768	1,056	1,058	4.6%	-37.5%	-37.4%
4	3	2,421	2,705	1,332	1,345	11.7%	-45.0%	-44.5%
4	4	8,043	8,141	6,664	6,689	1.2%	-17.1%	-16.8%
4	5	14,598	14,618	13,584	13,611	0.1%	-6.9%	-6.8%
1	1	325	431	10	10	32.5%	-96.8%	-96.8%
1	2	506	721	13	13	42.4%	-97.4%	-97.4%
1	3	1,248	1,359	38	42	8.9%	-97.0%	-96.7%
1	4	3,664	3,997	830	834	9.1%	-77.3%	-77.2%
1	5	11,164	11,340	5,971	5,972	1.6%	-46.5%	-46.5%
Average		**5,339**	**5,444**	**4,200**	**4,208**	**7.8%**	**-37.9%**	**-37.8%**

Table 17 on the next page presents the proportion of areas burnt which experienced fire intensity of above 1,500mW/h (i.e. medium to high rating). The results generally follow a similar pattern as above, with treatment 1 (mechanical fuel reduction) producing typically higher fire intensity than the control, while treatments 2 and 3 (involving prescribed fire) typically producing less fire intensity.

Table 17 Average fire intensity (% rated medium or high i.e above 1,500mW/h)

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[29] 1. Moderate FDR, 2. High FRD, 3. Very High FDR, 4 Severe FDR, 5 Extreme FDR

		Areas burnt (ha)				Marginal change in areas burnt from control (no treatment)		
Ignition km	FDR[19]	0. Control	1. Mechanical	2. Prescribed Burn	3. Mechanical and Prescribed burn	1. Mechanical	2. Prescribed Burn	3. Mechanical and Prescribed burn
10	1	47%	47%	47%	47%	0.0%	0.0%	0.0%
10	2	71%	71%	71%	71%	0.0%	0.0%	0.0%
10	3	81%	83%	83%	83%	1.3%	1.4%	1.4%
10	4	66%	66%	63%	63%	-0.1%	-2.4%	-2.6%
10	5	73%	73%	72%	72%	0.3%	-0.7%	-0.8%
4	1	53%	63%	55%	55%	10.3%	1.8%	1.8%
4	2	65%	65%	58%	58%	-0.2%	-7.2%	-7.3%
4	3	73%	69%	74%	74%	-4.3%	1.5%	0.9%
4	4	51%	51%	44%	44%	0.1%	-6.9%	-7.1%
4	5	74%	74%	75%	75%	0.6%	1.2%	1.1%
1	1	42%	62%	62%	62%	20.3%	19.9%	19.9%
1	2	39%	40%	80%	80%	0.7%	40.5%	40.5%
1	3	56%	58%	37%	34%	1.8%	-18.6%	-22.1%
1	4	38%	45%	26%	26%	6.7%	-11.8%	-11.9%
1	5	72%	74%	65%	65%	1.5%	-7.0%	-7.1%
Average		**60%**	**63%**	**61%**	**60%**	**3%**	**1%**	**0%**

5.5.3 Benefit Cost Analysis results - GHD

This section outlines the results of a benefit cost analysis, with costs and benefits modelled over a 20 year period and discounted to current day amounts.

This analysis takes into account the longer term benefits of fuel reduction, which are spread across multiple years before requiring re-treatment.

Similarly, this analysis recognises that fire poses an ongoing risk. Therefore, rather than modelling the impact of a single fire event within the 20 year timeframe, the analysis factors in annualised costs taking into account the assumed risk of fire events. In this case we have assumed that fire in this region poses a one in 40 year risk, therefore the annualised cost is calculated at fire cost divided by 40. Note this analysis applies the same assumptions around treatment costs, fire damage costs and emergency response costs as outlined earlier in this report.

Table 18 presents the discounted cost to applying the treatments over a 20 year period.

Table 18 Present value of treatment costs ($M)

		Treatment Cost			
Ignition	FDR	0 C	1 M	2 PB	3 M+PB
All	All	$0.0	$4.5	$0.1	$2.51

Table 19 below presents the discounted value of fire costs, including damage and emergency response, over a 20 year period.

Table 19 Present value of fire damage and emergency response costs ($M)

		Net Cost				Change in net cost, relative to control		
Ignition	FDR	0 C	1 M	2 PB	3 M+PB	1 M	2 PB	3 M+PB
10	1	$1	$1	$1	$1	0%	0%	0%
10	2	$2	$2	$2	$2	0%	0%	0%
10	3	$10	$10	$8	$9	4%	-13%	-11%
10	4	$64	$70	$35	$36	8%	-45%	-45%
10	5	$112	$116	$84	$84	4%	-25%	-25%
4	1	$0	$0	$0	$0	14%	-20%	-20%
4	2	$30	$37	$9	$9	21%	-71%	-71%
4	3	$31	$36	$11	$11	17%	-65%	-65%
4	4	$78	$82	$54	$54	5%	-31%	-31%
4	5	$112	$114	$82	$83	2%	-26%	-26%
1	1	$9	$27	$0	$0	207%	-100%	-100%
1	2	$16	$30	$0	$0	90%	-99%	-99%
1	3	$35	$37	$2	$2	6%	-96%	-96%
1	4	$59	$62	$10	$10	6%	-83%	-83%
1	5	$78	$84	$53	$53	7%	-32%	-32%
Average cost weighted to FDR probability		**$10.6**	**$16.9**	**$2.3**	**$2.3**	**$6.3**	**-$8.2**	**-$8.2**

Table 20 presents the marginal benefits of the three fuel reduction treatments compared to the control treatment.

Table 20 Marginal benefits and marginal costs

		Marginal Benefits (Change in fire damage and emergency response costs compared to Control) ($M)			Marginal Cost (Change in treatment costs compared to the Control) ($M)		
Ignition	FDR	1 M	2 PB	3 M+PB	1 M	2 PB	3 M+PB
Average cost weighted to FDR probability		**-$5**	**$19.02**	**$18.93**	**$4.46**	**$0.05**	**$2.51**

Table 21 presents the Net Present Value (NPV) i.e., the marginal benefits minus marginal costs, and Benefit Cost Ratio (BCR) i.e. the marginal benefits divided by the marginal costs, for each simulation

Table 21 NPV and BCR

		NPV			BCR		
Ignition	FDR	1 M	2 PB	3 M+PB	1 M	2 PB	3 M+PB
Average		**-$9.23**	**$18.96**	**$16.42**	**-1.1**	**353.5**	**7.6**

The results show that treatment 2 (prescribed fire) delivered the greatest economic return with treatment costs on average delivering a 353 fold return on investment. The application of treatment 3 (mechanical fuel reduction and prescribed fire) delivered a lower economic return (7.6 fold), while the application of treatment 1 (mechanical fuel reduction alone) delivered a net economic loss compared to the control, due to both the higher fire costs and higher treatment costs.

Editor -The results on the net societal benefits should be interpreted with some caution in terms of their relative comparability and applicability into the future, given the limitations for two of the sites with the mechanical only treatments not removing tree heads and woody debris. Where this biomass material is removed, this could change the results substantially depending on the treatment costs and impact on reduced fire probability. Other potential costs such as health costs from smoke were also not included.

5.5.4 Sensitivity analysis - GHD

The sensitivity of the above BCR's were tested in terms of changes to key variables. The results show minimal change in the results.

Table 22 Sensitivity of BCR results to changes in variables

	1	2	3
Baseline BCR	**-1.1**	**353.5**	**7.6**
Damage valuations +20%	-1.1	360	7.7
Damage valuations -20%	-1.1	347	7.4
MFR treatment cost + 20%	-0.9	353	6.3
MFR treatment cost - 20%	-1.3	353	9.4
Emergency response costs + 20%	-1.1	354	7.6
Emergency response costs - 20%	-1.1	353	7.5
Value of product harvested in mechanical fuel reduction + 50%	-1.3	353	9.0
Value of product harvested in mechanical fuel reduction - 50%	-0.9	353	6.5
Discount rate = 4%	-1.1	368	9.4
Discount rate = 10%	-1.0	335	6.3

5.6 Social acceptance - University of Canberra

Jacki Schirmer, Mel Mylek, Helena Clayton at the University of Canberra were commissioned to examine the social acceptability of MFLR (‘social acceptability study’). The objectives of the social acceptability study were to identify the extent to which using MFLR is considered acceptable by different people and groups, and to understand key factors that influence social acceptability of using mechanical fuel load reduction. While multiple studies have examined the social acceptability of various natural resource management practices, relatively little has examined acceptability of MFLR.

Social acceptability of MFLR

While multiple studies have examined the social acceptability of various natural resource management practices, relatively little has examined acceptability of MFLR. From available work relevant to MFLR (including studies examining acceptability of MFLR, of controlled burning, and more broadly of natural resource management practices), several key factors were identified that are likely to influence the social acceptability of MFLR. These include:

- Geographic and socio-demographic characteristics (e.g. a person’s gender, age or the location in which they live)
- A person’s perceptions of
    - the problem being addressed (e.g. bushfire risk)
    - the effectiveness of proposed actions (does MFLR reduce bushfire risk in a given situation)
    - the benefits and costs of a proposed action (what positive and negative outcomes does a person believe will result from use of MFLR)
- The way the proposed action is designed and implemented (is MFLR being conducted in appropriate ways)
- Governance (who is making decisions about MFLR and how)
- Values and norms relevant to the action (for example about the relative priority of protecting the environment versus reducing bushfire risk), and
- Past experiences.

Acceptability of MFLR

Social acceptance of an action is something that can change over time, and which will depend on how that action is designed, implemented and managed. This means that the survey data collected in this project assessed initial views about the social acceptability of MFLR. As MFLR is a relatively new practice in Australia, currently implemented in relatively small areas typically close to built infrastructure, these initial views provide an indication of the ‘starting position’ of acceptability – whether members of the community and members of different stakeholder groups are starting with a relatively positive or negative perception of MFLR – but are likely to change as people are exposed to information on MFLR. Stakeholder interview/workshop data provides a useful indicator of the factors that will influence how attitudes to MFLR change if it is more widely implemented.

In the survey of Australians, 50% of rural and regional Australians and 42% of people living in major cities felt MFLR was acceptable to some degree, less than the 76% of both groups who felt controlled burning was an acceptable practice in their local area. Close to one-third (30%) of rural and regional Australians, and 32% of major city residents, felt MFLR was unacceptable, compared to 10% and 8% of rural/regional and urban residents who found controlled burning unacceptable. The remainder were neutral or ‘unsure’. Very few people felt they would not support MFLR under any circumstances (13%), and 62% of rural/regional and 57% of major city residents agreed that they *might* support MFLR depending on how it was done, higher than the proportion who support the idea of MFLR more generally. This suggests that initial views about MFLR, while more positive than negative, are highly subject to change depending on the types of information and views they are exposed to about MFLR.

People living in cities were less likely to find MFLR acceptable than those living in more rural and remote regions. People were significantly more likely to find MFLR acceptable if they were male, earned higher household income, had lower levels of formal education, and were employed in wood-related industries.

In stakeholder workshops and interviews, similar to the survey findings, almost all participants stated that they would support MFLR under some circumstances. However, the large majority also indicated they would oppose the use of MFLR in some (or many) circumstances. These circumstances, and factors that influenced levels of support for MFLR under different circumstances, were explored in detail.

Factors influencing acceptability of MFLR

Seven key factors were explored when examining the circumstances in which people would find MFLR more or less acceptable: perceived need for MFLR, perceived effectiveness of MFLR, perceived benefits and costs, how MFLR is designed and implemented, how MFLR is governed, values and norms, and past experiences.

Perceived need

The extent to which a person finds MFLR acceptable is likely to be influenced by whether they believe there is a problem that requires action – in this case, a need to reduce fuel loads in order to reduce bushfire risk. More than half of rural and regional Australians (54%) and urban Australians (55%) felt that they lived in an area with high bushfire risk. Fewer - 36% of rural and regional Australians and 39% of urban Australians – were specifically worried about the potential impact of bushfires on their property or business. When asked whether fuel loads were too high in their local region, around one-third agreed (36% of rural/regional residents and 31% of major city residents), 32% of both groups disagreed, and many were unsure (17% of rural/regional and 24% of major city residents). Similarly, when asked whether it was difficult to get enough controlled burning done in their region, 30-40% of people were unsure, while around one-third agreed. If a person felt there was high bushfire risk in their region, were worried about impacts of bushfires, felt fuel loads were too high, and/or felt it was difficult to get enough controlled burning, they were significantly more likely to feel that MFLR is acceptable.

In workshops and interviews, while all attendees agreed on a need to manage bushfire risk in the landscape, they often differed substantially in their views on the most appropriate methods of reducing this risk, and about the circumstances in which they felt there was a legitimate need for MFLR as part of bushfire risk reduction strategies in different circumstances. In particular, many felt that MFLR was needed only in specific circumstances, and some felt that investment in fuel reduction efforts in general was inappropriately high due to reactionary approaches to bushfire management and negative social norms about fire in the landscape. The location or scale at which MFLR is implemented was a key consideration in assessing perceived need. A need for MFLR was most commonly identified as occurring in specific, small-scale areas to address specific risks, particularly near assets such as built infrastructure or plantations, and in situations where other bushfire risk reduction strategies were not feasible. Fewer felt there was a need for MFLR at larger landscape scales.

Perceived effectiveness

The extent to which a person feels that MFLR will be effective in reducing risk of damage from bushfires through reducing fuel load and/or fuel structure will also influence perceived acceptability of MFLR. This topic was discussed in stakeholder workshops and interviews. Many stakeholders felt that MFLR could be effective in specific situations, specifically where there was evidence it might reduce speed or spread of fire near built infrastructure. Many did not feel it would be effective at larger landscape scales. It was typically viewed as effective if it formed part of an integrated toolbox of strategies that were used together to reduce risk of bushfire damage. Multiple questions were asked about effectiveness of MFLR by stakeholders who wanted these questions to be answered by the trials or other processes. These questions included what types and structures of fuels should be removed for greatest effectiveness; how long fuel reduction would be effective, whether there would be rapid regrowth of vegetation and of fire risk; and how often MFLR treatment might be needed in different forest types. More broadly, some stakeholders felt that effectiveness needed to be assessed with consideration for the relative environmental impacts of MFLR versus other fuel reduction strategies that might have similar effectiveness in reducing fuel loads.

Perceived benefits and costs

A person's beliefs about the benefits and costs associated with the implementation of a natural resource management practice influence how acceptable they find that practice. The survey asked about perceptions of impacts of MFLR and controlled burning on three key areas: forest and vegetation health; animal and bird populations; and human health and impacts. Around one-third of respondents were unsure, selecting 'don't know' in response to these questions. Around one-quarter felt MFLR would be good for forest and vegetation health while a similar proportion felt it would have negative impacts; controlled burning, meanwhile, was considered positive for forest/vegetation health by 67% of both rural/regional and major city residents. When asked if MFLR is likely to harm animal and bird populations, 44% of rural/regional and major city residents agreed, and 20% of rural/regional and 18% of major city residents agreed. Controlled burning was viewed as slightly less likely to harm animal and bird populations. People were more likely to worry about the impacts of controlled burning on human health compared to MFLR: 24% of rural and regional residents and 25% of major city residents agreed that they worry about the effects MFLR could have on human health, compared to 39% of both groups who worried about health effects of smoke from controlled burning. There was a strong association between overall views about acceptability of MFLR and perceptions of its benefits and costs.

In stakeholder workshops and interviews, potential benefits of MFLR were more commonly discussed by representatives involved in bushfire management and forest management, while concerns about negative impacts (costs) were more commonly discussed by representatives of ENGOs and NRM organisations. Impacts of MFLR for environmental health, bushfire risk, cost effectiveness, commercial sale of timber, the forest industry, other industries, human health, and landscape aesthetics were discussed.

When discussing environmental impacts, multiple topics were discussed. One of the most common was concern about potential for loss of biodiversity when vegetation was removed in MFLR, although a small number discussed situations in which MFLR could assist regeneration of specific species or protect important habitats with high vulnerability to damage from fire. Potential impacts on forest structure were also discussed: some felt that MFLR had potential to help restore some forest structures that were under-represented in the forest estate, while others were concerned that in long-term repeated application of MFLR to a given area would change stand structure in negative ways, including potential loss of particular layers of understory and/or age classes of trees. MFLR was also viewed as needing to be carefully managed to reduce potential for spread of invasive weeds, while providing potential avenues for managing large woody weeds such as pine wildings. Concerns about potential impacts of use of machinery on soil health, particularly soil compaction, as well as concerns about impacts of clearing groundcover vegetation on soil health, were also raised.

One of the most commonly cited potential benefits of MFLR was the ability to increase the toolbox of options fire managers have for reducing bushfire risk, particularly by providing an option that could be applied in situations in which controlled burning is not an option, or in situations where MFLR might enable subsequent re-introduction of controlled burning (for example in areas of NSW forest affected by bell-miner associated dieback). Others spoke more specifically about the trials, feeling they provided some insight into whether use of MFLR could be extended beyond current uses that often focus on slashing and mowing of grasses, to the mechanical removal of other layers of vegetation.

The financial cost of MFLR, and how cost effective it is compared to other fuel reduction strategies, was raised by several participants. Many felt that MFLR would not be cost effective compared to controlled burning in situations where both were feasible options, with this contributing to the commonly held view that MFLR was appropriate as a tool to be used where other options were not feasible, but not generally in competition with them, although some argued MFLR would be cost effective if conducted at large scales that reduced the fixed costs of floating machinery to individual sites.

Closely related to discussions of cost effectiveness were discussions about the commercial sale of timber removed during MFLR. This was a key issue in most focus groups and interviews, with some feeling that any commercial sale of removed materials would result in substantial problems, while others felt this was one of the potential benefits of MFLR compared to other fire control methods. Some stakeholders – predominantly some of those involved in managing forests for timber production – felt that commercial sale of removed timber could make MFLR cost effective. However, this was often reliant on achieving a scale and volume sufficient to support an industry, something which raised significant concerns for other stakeholders. Stakeholders from ENGO groups, and some NRM representatives, were generally actively opposed to commercial sale of material removed using MFLR, viewing this as 'logging by stealth' that, even if done with good intentions, would result in perverse outcomes due to commercial interests becoming a driver of decision making, rather than considerations of bushfire risk reduction.

Other benefits and costs were discussed by fewer people: some forest industry representatives felt it could provide new silvicultural options in forest areas managed for timber production; potential benefits for grape growers compared to use of controlled burning were also identified; a need to understand impacts on pollen production and apiarists was identified; MFLR was identified as potentially better for human health than controlled burning due to reducing health impacts from smoke; and the need to manage appropriately for animal welfare impacts was also raised.

Design and implementation

The way MFLR is designed and implemented will influence the extent to which it is viewed as acceptable. This was predominantly examined in stakeholder interviews and workshops, where the most common topics raised related to:

- the locations in which MFLR is applied: most stakeholders supported use in locations near specific at-risk infrastructure such as buildings but often not in other locations
- scale of implementation: most stakeholders supported smaller-scale application of MFLR, but many would not support large-scale application
- frequency of application, type of vegetation removed, and machinery used: these aspects of design would influence about effectiveness of MFLR and potential environmental impacts, and stakeholders often wanted more information about how best to design these aspects
- use of removed material: several stakeholders felt that commercial sale of removed material was unacceptable; others supported it. Almost half (49.6%) of rural and regional Australians, and 44.1% of major city residents, would support sale of timber removed in MFLR, while 20% would not support it and many (21.2% of rural/regional and 27.2% of urban Australians) were unsure.
- integration of MFLR with other actions to manage bushfire risk: MFLR was in general viewed as more acceptable if undertaken as part of an integrated strategy to manage bushfire risk that involved multiple actions, rather than being undertaken separate to broader bushfire management action.

A common over-riding theme was a need for clear guidance on when MFLR was and wasn't an appropriate action to implement, and for clarity about the guiding objectives that would be used to determine this. Stakeholders often expressed a desire for this type of guidance to be provided as an outcome of the MFLR trials.

Governance

The way MFLR is governed – in other words, the processes by which decisions are made about whether, when, where and how MFLR will be undertaken, and the organisations that make these decisions – will influence the extent to which a person finds MFLR acceptable.

In the survey, questions about governance focused on understanding the extent to which different organisations would be trusted to make decisions about MFLR, as this is a key indicator of the extent to which there is likely to be social acceptance of these decisions. The group most trusted to undertake both MFLR and controlled burning was rural and volunteer fire brigades, with 59% of rural/regional and 53% of urban Australians having high trust in this group to undertake MFLR, while 80% of both rural/regional and urban Australians had high trust in this group to undertake controlled burning. National Park managers were the next most trusted group: 53% of rural/regional and 56% of major city residents trusted them to undertake MFLR. Government-owned forestry agencies/businesses were trusted by fewer: around two in five people trusted these agencies to undertake MFLR. Farmers and private forestry companies/logging contractors were less commonly trusted to undertake MFLR.

When stakeholders discussed governance, acceptability of MFLR was contingent upon trust that agencies involved were trustworthy based on past experience, had the skills and knowledge required to manage for both bushfire mitigation and ecological aspects of forest management, and did not have conflicts of interest. Forestry agencies had low trust from ENGO stakeholders, and sometimes other stakeholders, due to both a legacy of conflict about forest management, and concern that these agencies would have conflicts of interest when making decisions about MFLR, between bushfire risk reduction and making commercial return. Fire management organisations and agencies were more widely trusted to make decisions about MFLR. Some stakeholders suggested that rather than having single organisations responsible for all or the majority of decision making about MFLR, or more broadly about fire risk management, it was better to have governance arrangements in which multiple stakeholders shared responsibility for decision making. This was viewed as ensuring that different interests were considered and needed to be satisfied in decision making and reducing the risk of decision making being biased to particular interests.

To be acceptable to most stakeholders, governance systems for MFLR should be designed to be integrated with decision making about bushfire risk reduction more generally. They should provide space for evidence-based decision making and require appropriate environmental and animal welfare assessment prior to MFLR, training of operators, monitoring and assessment of outcomes, and accountability for outcomes. Any sale of materials should be managed in ways that ensure commercial imperatives do not become a driver of decisions about when and where MFLR will be used. Ideally, clear guides or codes of practice should be developed to govern on-ground practices and this should occur in a legislative and regulatory environment that places appropriate conditions on when, where and how MFLR occurs, while also enabling it to be undertaken where it is appropriate rather than placing tenure-based restrictions on when and where it can occur. More broadly, a need for long-term and stable political support for bushfire risk reduction was identified, with concern that specific practices such as MFLR might be promoted in the short-term rather than longer term investment in an integrated set of bushfire risk reduction strategies.

Values and norms

A person's values and norms – deeply held beliefs, and expectations about acceptable behaviour, which guide a person in determining what they believe to be right or wrong – will influence the extent to which they believe MFLR is an acceptable practice.

Survey participants were asked the extent to which they found a number of activities acceptable or unacceptable, including MFLR and controlled burning. People were significantly *more* likely to find MFLR acceptable if they also felt that (i) logging native forest for wood production, (ii) open-cut mining and (iii) growing genetically modified crops was acceptable. This suggests that if a person believes that humans are capable of successfully harvesting, mining or manipulating natural resources without causing significant harm, they are more likely to support MFLR. People were significantly *less* likely to find MFLR acceptable if they felt it was acceptable to (i) plant trees on good agricultural land for environmental purposes, and/or (ii) implement regulations that restrict farmers from clearing native vegetation, and if they felt there were significant environmental degradation problems in their local area. These results suggest that those who value environmental attributes above human use attributes of resources are less likely to support MFLR.

In workshops and interviews, values were examined by analysing the criteria that different stakeholders prioritised when describing whether they would or would not support the use of MFLR in different circumstances. There was in workshops and interviews a clear distinction between two types of values that underpinned arguments made about the acceptability or unacceptability of MFLR. On one hand, many ENGOs representatives and some NRM representatives viewed environmental protection as occurring when human intervention is reduced or removed, rather than when it is increased. For these stakeholders, optimal fire risk reduction was more likely to occur through use of natural processes or of processes that closely mimic natural processes, with MFLR not generally viewed as doing this. On the other hand, members of the forest industry, and to a lesser extent stakeholders involved in fire management, felt that human intervention was an appropriate means to achieve desired outcomes in forest areas, whether those desired outcomes be environmental enhancement, reduced fire risk, or others. The values held by this group include high trust in humans being able to achieve positive outcomes through direct intervention in nature, and also a sense of moral obligation for human intervention to achieve these outcomes, with a strong belief that without intervention, there may be damage to forest health. While not all stakeholders fit the extreme ends of this spectrum of values, the findings do suggest high potential for social conflict about the use of MFLR if it is applied on a large scale, given the reasonably high polarisation between these differing values.

Past experiences

Acceptability of different land management practices can be influenced by positive and negative past experiences with that practice, as well as by having no prior experience by which to judge the practice. This was explored in the survey, by asking about past experience of bushfire. Survey respondents who had been more severely affected by a bushfire in the last 10 years were significantly more likely to find MFLR acceptable.

Information needs and access

Survey participants were asked how they prefer to access information about natural resource management. Their preferences varied, although the three most preferred ways of accessing information were typically (i) information provided via websites, (ii) being sent occasional emails, and (iii) information on television. The variance in preferences beyond this, for examples for information in local newspapers versus Twitter, highlights that any information sharing about MFLR as a practice needs to use more than one information delivery method to successfully reach different groups.

Stakeholders identified a wide range of information needs about MFLR, examined throughout this report. In particular, they sought information on the effectiveness of MFLR for reducing bushfire risk; impacts on biodiversity and environmental health more generally; cost effectiveness; and specific guidance on appropriate use of MFLR in differing contexts. Ideally, this would be situated in information about addressing bushfire risk more generally, enabling better identification of when and in what circumstances MFLR was appropriate compared to other strategies for addressing bushfire risk.

Overall, while most stakeholders agreed that trials of MFLR were a useful action to invest in, and many supported the specific trials undertaken in this study, many felt that on their own these trials would not be sufficient to answer the question of whether, when, and under what circumstances MFLR is an appropriate method to use to reduce bushfire risk. Several specifically identified a need for longer term funding for trials, particularly an extension of time for monitoring of the three sites, and ideally funding for longer term experiments with MFLR applied at differing temporal scales and with a wider range of vegetation removal designs, to better understand the implications of variations in design. Some also felt a wider range of case study sites was needed, and that a broader range of environmental attributes should be monitored at each site.

5.7 Post-wildfire Evaluation of the East Gippsland Mechanical Fuel Load Reduction Trial - University of Melbourne

Chris Weston and Luba Volkova, of the University of Melbourne Forest Ecology and Silviculture research group, set out to discover if the previously applied fuel treatments resulted in lower severity and intensity of the bushfire when other reasons for severity and intensity variation are removed, such as weather effects, wind direction changes and fire-fighting efforts.

5.7.1 Wildfire Trial site summary - UoM

Observed fire severity in relation to previous treatments

Observed fire severity was greatest in thinned only sites, where the mean fire severity score was 3.9 (Table 23), closely followed by the control (untreated) forest at fire severity 3.5. Treatments comprising a combination of thinning and high intensity prescribed fire applied in block 3 did not ignite in the wildfire and recorded a fire severity score of 1.0, or unburnt (Table 23). The prescribed burn in Block 2, applied in late May 2018, was far less intense than the burn in Block 3, with more fuels remaining in the Block 2 treatment, resulting in a fire severity rating of 1.9 (Table 23), with the wildfire mainly consuming understorey fuels at this site. Further evidence in support of these results was observed in fire scars extending to overstorey tree canopy in thinned plots while fire scars were only a few meters high in thinned and burnt plots.

Table 23. Listing of fuel modification treatments as planned and as implemented, overall fuel hazard score, canopy cover (%) and fire behaviour parameters, Drummer State Forest

Block	Treatment received	OFHS before wildfire	Canopy cover, %	Fire severity score	Fuel consumed, Mg ha^{-1}	Predicted rate of spread, m h^{-1}	Estimated Fireline intensity, kW m^{-1}
1	Thinned	3.3	27±1.8	4.1±0.2	58.0±6.3	53	671
1	Thinned	4.0	22±1.2	4.9±0.1	130.3±12.8	53	1041
1	Untreated	3.9	441.8	4.1±0.2	17.5±2.4	53	55
1	Untreated	4.0	38±1.4	3.6±0.2	15.8±1.8	53	47
2	Thinned	3.9	20±1.7	4.0±0.2	72.8±12.1	53	520
2	Thinned low fire	1.0	25±1.3	1.0±0	0.6±0.6	53	367
2	Burnt low fire	1.9	43±1.9	2.9±0.2	23.8±2.2	53	41
2	Untreated	3.8	42±1.4	4.0±0.2	15.6±2.4	53	101
3	Thinned	3.6	24±1.6	2.5±0.1	44.7±7.6	53	342
3	Thinned high fire	1.0	25±2.7	1.0±0	0	53	290
3	Burnt high fire	1.0	41±0.9	1.0±0	0	53	14
3	Untreated	3.8	44±0.7	2.4±0.1	19.1±2.2	53	99

Values are mean, n=20, ± is the standard error of the mean

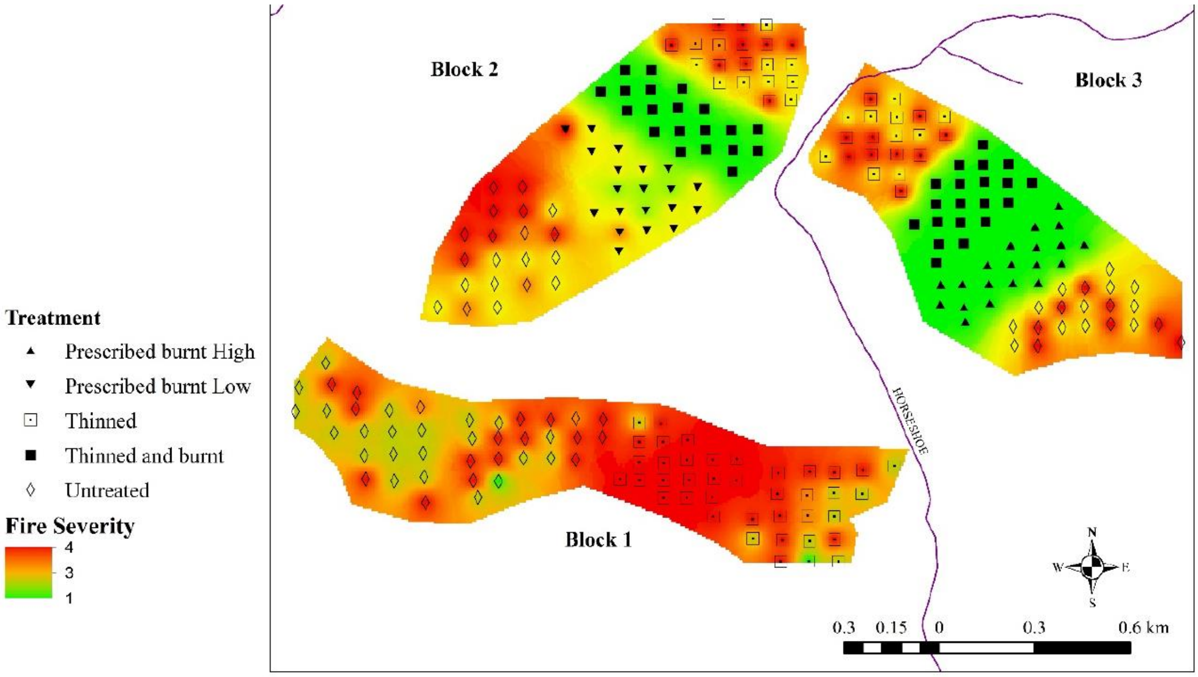

Figure 17 Map of on-ground measurements of fire severity resulting from the Black Summer wildfires of Jan 2020, Drummer State Forest

The peak in fire weather occurred in the days prior to the arrival of the fire at the Cann River fuel reduction trial area, in the early hours of 5 January 2020, from about midnight. A fire line-scan taken at 0240 on 5 January indicates two main fire fronts, one on the western boundary of the trial plots, and one on the eastern boundary. Weather records from Orbost suggest 5-10 km/h west-southwest winds at this time, consistent with the deeper fire-front on the western edge of the trial. The line-scan indicates a narrower fire on the eastern edge, consistent with a backing fire from the east burning down into the trial area from the elevated eastern flanks of Mt Drummer.

The forest fire danger index (FFDI mean) averaged over the week preceding was 9.2 (VicClim Estimates for trial location) while the FFDI averaged 2.8 (VicClim) over the week starting January 4. Under these conditions the *Amicus* fire spread model predicts that fire was spreading slowly, at no more than 53 meters per hour, and with estimated fire-line intensities not exceeding those recommended for prescribed fire (range 47–1000 kW m-1, Table 23).

The wildfire entered the trial plots early on 5 January 2020 and had burnt through the trial area by 10 January 2020. Dashed lines indicate FFDI ratings: 0-4 (low); 5-11 moderate; 12-23 (high); 24-49 (very high) and 50+ (extreme).

Predicting wildfire severity from fuel hazard scores

The fire severity recorded at each plot correlated strongly with scores for both near-surface fuel hazard (77%) and overall fuel hazard (73%; P<0.001, Table 24). Predicted means for fire severity score were highest in thinned sites (3.86) followed by the untreated sites (3.5, Table 25). Because overall fuel hazard strongly correlated with wildfire severity, an OFHS of 1 (low) may be regarded as a management target for reducing wildfire spread under low FFDI conditions.

Table 24 The proportion of the variance in fire severity score (240 plots) that is predictable from the fuel hazard score (r2), the level of significance (p value) and the Akaike Information Criterion (AIC), Drummer State Forest

Predictor	r^2	p value	AIC
Near-surface fuel hazard score	0.7678	<0.001	32.1
Surface fuel hazard score	0.7401	<0.001	33.4
Bark fuel hazard score	0.7487	<0.001	33.0
OFHS	0.7275	<0.001	34.1

Table 25. Effect of treatments on fire severity, Drummer State Forest

Treatment	Predicted mean for fire severity score	Sign
Thinned and Burnt	1.0^a	P>0.001
Burnt	1.95^b	
Untreated	3.5^c	
Thinned	3.86^d	

Values are predicted means of fire severity score based on 240 data points. Different letters indicate significant difference between the treatments.

All 40 thinned + burnt fuel reduced plots were not ignited by the wildfire along with 20 un-thinned plots burnt in May 2018 in a high intensity fuel reduction burn. All the evidence suggests that under fairly mild wildfire conditions (FFDImax. < 4) prescribed fire, either with or without thinning, was effective in limiting the spread of the wildfire, while thinning without burning to reduce residues resulted in more severe wildfire impacts relative to un-treated forest.

6 Mechanical Fuel Load Reduction Trials Conclusions

6.1 Participant conclusions

6.1.1 Victorian Site, Drummer State Forest, Conclusion by Scott Arnold VicForests

VicForests believes that mechanical fuel reduction is a viable option for fire management in regrowth forests in Victoria. DELWP is already introducing mechanical treatment into its annual fire risk mitigation plans.

The urban interface with forested land tenures is an example of areas where the treatment is most suitable. In those areas the consequence of a planned burn escaping is significant, and that risk can be eliminated by applying mechanical treatment.

Under State Forest tenure treatments could include the sale of merchantable material (where suitable markets exist) or could be done as a fall to waste operation. In other land tenures, such as National Parks, falling to waste would be the only option. Falling to waste would increase the elevated and near surface fuels.

Aside from the obvious safety benefits, the greatest strength of mechanical treatment is its independence from prevailing weather conditions or seasonal constraints. The results of the Drummer SF trial highlight the difficulty in planning and executing burning operations. By contrast, the mechanical treatments were planned and executed with a great deal of certainty.

Other benefits of mechanical treatment include:

- the creation of access infrastructure which may assist in the suppression of future bush fires,
- elimination of community issues with smoke (wine taint, health impacts on those with respiratory conditions, social amenity),
- the maintenance of tolerable fire intervals for fire sensitive flora,
- a reduced impact on floristic diversity in treated areas.

Given the relatively low levels of community concern arising from the public consultation session held in Orbost, VicForests would not anticipate broad-based opposition to the application of mechanical treatments.

On the basis of the wide range of benefits, potential for costs to be offset by sale of material and a general acceptance from communities VicForests would support the expansion of mechanical fuel treatments in Victoria.

6.1.2 NSW Site, Burrawan State Forest, Conclusions by Mark Dury, Forestry Corporation NSW

The Burrawan trial site well represents ~100,000 ha of State Forest between Grafton and Taree on the Mid North Coast in terms of forest type, structure, proximity to community and ability to mechanically treat with commercial thinning.

The fire attributes of the site are representative of a many forests up and down the coast of NSW where fire history has changed from regular low intensity burning to increasing fire exclusion and subsequent wildfire driven fire regime. In the absence of low intensity fire and following intensive fire these forests tend to rapidly develop a dense shrub understorey and become increasingly difficult to treat with low intensity burning. The results in terms of fire risk mitigation identified by the CSIRO modelling from the site are applicable to this wider array of forests.

6.1.2.9 Cost Drivers and Scalability

6.1.2.9.1 Environmental approvals

The Burrawan site was relatively low cost to plan for both treatment and burning due to having environmental approvals in place via the Integrated Forestry Operations Approval (IFOA). Getting environmental approvals for mechanical treatment outside of that permitted under the BFEAC on private or council owned land may be prohibitive, especially for small sites. In the long run a code of practice approach to facilitate mechanical treatment would be important to manage costs.

6.1.2.9.2 Location and size

Substantial costs are associated with floating equipment to sites. For small sites the per hectare costs of getting gear there may be very substantial. The larger the site the greater the economy of scale. The proximity of sites to local communities and type of equipment are important considerations. Traditional tracked timber harvesting equipment and log trucks may not be suited to peri-urban environments. For mechanical treatment to be realistic close to communities, availability of appropriately sized equipment will be necessary. Similarly, local markets for the residues from thinning will be crucial to offset costs of undertaking mechanical treatments.

6.1.2.9.3 Improved Markets and would increase applicability

From a State forest managers perspective mechanical thinning is a cost effective and important silvicultural strategy subject to market availability. Lager and more widespread residue markets would make mechanical thinning affordable over a broader area and be more efficient if a greater proportion of the residue could be sold rather than burnt on site. A wider array of commercial markets may make thinning a more realistic option off state forest estate. The marketability at Burrawan of a range of timber products funded the mechanical treatment. In less commercial or younger aged class forests where residue markets (pulp wood, fibreboard, biofuel etc) are the only realistic merchantable products.

6.1.2.9.4 Mechanical Treatment makes ongoing burning easier.

The thinning treatment makes reintroduction of fire into these sites more practical and cheaper. The CSIRO wind results were consistent without experience in conducting burning at the site. It is clear the more open canopies will increase the window for low intensity burning. One harvest treatment with follow-up burning may be sufficient to maintain the sites in a condition suitable for low intensity fire on an ongoing basis.

6.1.2.10 Smoke

It is increasingly evident that smoke management is an important consideration for fuel management. The results from this study identified the best fuel reduction comes from the combination of mechanical treatment and subsequent burning. On the state forest estate, the increased ability to burn following mechanical treatments along with its relatively low cost and being less proximate to towns (generally) means that a mechanical treatment and follow up burning are the likely preference.

In areas immediately proximate to communities, where fire risk is greatest and mitigation most important, there is potential that an initial mechanical treatment of long untreated sites, follow-up burning and then lower cost mechanical only treatment on an ongoing basis to maintain open understorey structure may be applicable. Sites with heavy understorey and large trees will be expensive to treat mechanically but will produce the most potential volume of residue. Regular follow-up treatment with smaller equipment may be cost effective and maintaining open structures. With this approach you may generate an initial one-off smoke concern, but you can reduce future burns and smoke issues with follow-up mechanical treatments.

6.1.2.11 Community Concerns

Community concern about new approaches to fuel management are inevitable. There is already a wide range of views around the benefits of fuel management, trade-offs between environmental and social values and concerns about ‘electricity from forests’ both from community and researchers. Improved awareness around the benefits from fuel management activities is important as is addressing concerns around mechanical treatments. The CSIRO modelling shows substantial risk mitigation for communities from burning treatments. This could be cast through a lens of benefits for fire-fighter, community and wildfire safety. Fuel management treatments have potential to have much smaller fires at lower intensities than unmanaged landscapes which must have benefits for all the values the community cares about. More work and more effective messaging are crucial to building support for fuel management, including mechanical fuel treatments.

6.1.3 WA Site, Ree’s Forest, Conclusions by Justine Edwards and Mark Brown, University of Sunshine Coast

The Western Australian trial site was established in an area dominated by *Eucalyptus marginata* and *Corymbia callophylla*. Control, Burn, Thin and Burn + Thin treatments were replicated across the site. Total stems per hectare (for all overstory species) ranged from 1,116 – 1,423 SPH pre- treatment and were reduced to 1,183, 385 and 276 SPH for the Burn, Thin and Burn + Thin treatments respectively. Overstory basal area ranged from 40 – 44 m2/ha pre- treatment and were reduced to 34, 15 and 18 m2/ha for the Burn, Thin and Burn + Thin treatments respectively.

Course woody debris increased significantly in the 25 – 75 cm diameter size class post the Thin treatment. Course woody debris in the > 75 cm diameter size class decreased significantly in the Burn treatment. Above ground biomass, course woody debris data and measures of Fuel Hazard, Fuel Load and Fuel Moisture Content were measured for all treatments pre- and post- treatment. This data was supplied to CSIRO for analysis and modelling and is reported elsewhere.

Soil carbon (Organic Carbon %) was measured pre- and post- treatments with no significant change occurring.

Biodiversity assessments including habitat rating, frog monitoring, bird monitoring and large fauna monitoring was undertaken. Trends existed for some short-term behavioural change in feed and sheltering behaviour.

Key issues for fuel management in the Western Australian environment were identified as the management of *Phytophthora cinnamomi* spread, the management of *E. marginata* coppice and protection of *Xanthorrhoea australis* trees.

The long-term impacts of fuel adaption strategies, including the impacts on forest structure, biodiversity measures and effectiveness of treatments in reducing fire risk require further study. The role of spatial impacts (treatment size, treatment allocation spread in the environment) warrants further investigation.

6.1.4 Fire Modelling Conclusions by Andrew Sullivan, Matt Plucinski CSIRO

- Within the constraints of this study, mechanical-only treatment does not reduce fuel hazard attributes or surface fuel loads and may increase them. This results in fire behaviour that is the same or slightly more intense than in the control (no treatment).

- Furthermore, prescribed fire (either by itself (Burn-only) or in conjunction with mechanical treatment (Mechanical and burn)) results in much reduced fuel hazard which subsequently leads to reductions in fire spread and behaviour.

- The results of the fire behaviour modelling (both at site scale and landscape scale) need to be validated against actual burning experiments in fuels of different treatments.

- The effects of time since treatment were not studied in this project. It is possible that fuel hazard attributes could change over time since treatment that would change the results of this study, as suggested from studies in other forest types.

- Further research is required to quantify effects of time since fuel treatment on fuel attributes and fire behaviour.

6.1.5 Benefit Cost Conclusions by Paul de Mar, Seamus Hoban, GHD

This study found prescribed fire to be the most preferred option for reducing fuel loads and hence reducing fire risk to nearby assets. Prescribed fire is relatively inexpensive ($48 per ha in the modelled scenario) and if undertaken at regular intervals, offers an effective means of removing fuel loads.

The use of mechanical fuel reduction in isolation (treatment 1) is significantly more expensive to undertake (net cost of $3,975 per ha in the modelled scenario, accounting for an estimated $1,275 in revenue from wood products sold). Due to the assumed increase in ground litter left behind following mechanical treatment, this treatment also resulted in increased fire damage and therefore costs compared to the control. Based on these results the use of mechanical fuel reduction alone, in this way, is not economically justified.

The application of mechanical fuel reduction followed by periodical fuel reduction burning (treatment 3) delivered a net economic benefit compared to the control, however due to the higher treatment costs, this return was not as high as prescribed fire alone (treatment 2). These results suggest that mechanical fuel reduction treatments may be an economically viable option for treating areas which cannot be treated with prescribed fire in their current state, for example due to the thickness and fuel load of the vegetation. Once treated these areas could be bought into a traditional prescribed fire regime. If not treated by mechanical fuel reduction, it is not safe to apply prescribed fire, and therefore the adjacent area remains exposed to the highest level of economic loss. Accordingly, in such a scenario, mechanical fuel reduction is an essential enabler of adopting the most effective treatment regime.

It should be stressed that the results of this study relate only to a particular situation, therefore care is needed in interpreting these results for other situations. The suitability and economic returns from treatment options will vary, in particular depending on:

- the value of the assets you are trying to protect;
- the prevailing fire risk within the region; and
- the value of the harvested product relative to the costs.

6.1.6 Social Acceptance Conclusions by Jacki Schirmer & Mel Mylek, University of Canberra

This study examined whether and under what circumstances MFLR would be supported as a practice used to reduce bushfire risk. MFLR is not generally considered to be in and of itself an unacceptable practice: most people would support MFLR if they felt it was being undertaken in the right way. This means there is potential to develop forms of MFLR that have widespread stakeholder and community support. However, while MFLR is considered acceptable in principle by many people, that acceptance is highly conditional on how MFLR is applied. This means that some forms of MFLR would have high levels of social acceptance, while other forms would be highly likely to attract high levels of opposition and active protest. To be viewed as an acceptable practice, the concerns of stakeholders about particular aspects of the practice – particularly potential environmental impacts, effectiveness in reducing fuel loads and fire spread, and frequency of application required – need to be adequately addressed. More broadly, to be supported by a wide range of stakeholders, decisions about MFLR need to be driven by priorities of both bushfire risk reduction and protecting environmental health, and not by commercial drivers related to sale of removed materials.

The factors that most influence whether MFLR is considered acceptable or unacceptable include who is managing and implementing MFLR, where it is being used, the scale at which it is used, the type and scope of vegetation removed, how frequently it occurs, and what is done with the removed materials. Overall, small-scale application of MFLR in proximity to at-risk assets such as houses, and high value assets was considered more acceptable and large-scale landscape scale application less acceptable. MFLR is considered more acceptable when undertaken as part of an integrated bushfire risk reduction plan, guided either by bushfire management agencies or multi-stakeholder committees, and less acceptable when undertaken by forestry agencies without being part of broader bushfire risk reduction strategies. Sale of removed materials increases the unacceptability of MFLR substantially for some stakeholder groups, with concerns about how this sale affects the way decisions are made about MFLR.

Views about acceptability will be influenced by the findings of the trials, particularly around how environmental attributes of the sites and fuel loads change with application of MFLR, however the short-term nature of the trials limits the extent to which they will provide the types of evidence being sought by many stakeholders. Stakeholders predominantly support the concept of robust research into MFLR, but want to see longer-term research, particularly longer-term monitoring of outcomes at the trial sites and monitoring of a wider range of attributes at trial sites, to enable the trials to produce data they feel can better inform making recommendations, about whether, when and how to design and implement MFLR.

6.1.7 Wildfire on Drummer State Forest Conclusion by Liubov Volkova & Christopher J. Weston, University of Melbourne

This opportunistic study of fire severity following wildfire shows that under low FFDI conditions previous fuel treatments are effective in halting the spread of wildfire, resulting in the creation of a mosaic of burnt and unburnt forest. The implications for management are clear – prescribed fire that removes surface, near surface and elevated fuels (OFHS 1, low) can be effective for a number of years post-treatment for limiting the spread of wildfire under low FFDI phases of wildfires. The thinned forests, which were not fuel reduced, burnt with greater fire severity than not thinned forest, demonstrating the need to remove or reduce surface fuels as a part of the thinning practice if wildfire risk reduction is a management aim. Co-benefits of more active fuels management in landscapes prone to wildfire includes enhanced refugia for biodiversity through increased likelihood of unburnt areas.

6.2 Overall findings

No actions or treatments will reduce fire risk or impacts in catastrophic conditions. However, in lower fire risk conditions, mechanical treatment with removal of surface fuels can reduce impacts. Mechanical treatments, through thinning high density stands for example, may also help to assist suppression activities by improving access to the forest and fire lines.

It is clear from this study, from both modelled and actual wildfire, that if mechanical treatment is to be used, removal of surface fuels is needed.

Mechanical treatment is a method that can be used in situations where prescribed fire cannot be used due to existing canopy connecting high fuel loads or other high fire risk, such as nearby infrastructure or environmental assets, because of smoke impacts or where forests are too damp for fire to be used. The removal of surface fuel can then be achieved using prescribed fire. Not tested in this work, machine removal or commutation of surface fuels are an alternative where fire still could not be used due to the smoke impacts or risk to assets.

Whole tree removal out of the forest appears to leave a small amount of additional fuels on the forest floor (WA trials), but to a much lower extent than leaving non-merchantable tree heads in the forest.

Mechanical treatment through thinning trees with a follow up prescribed or hazard reduction burn, showed a number of positive benefits including a modelled positive Net Present Value (NPV - $16.42m over 660ha and 20 years) when compared to the controls (no action). Though this NPV and Benefit Cost Ratio was lower than prescribed fire only ($18.96m over 660ha and 20 years).

Some participants noted other benefits of the mechanical treatments:-

- independence from prevailing weather conditions or seasonal constraints for prescribed fire
- the creation of access infrastructure which may assist in the suppression of future bush fires,
- potential creation of fire-breaks
- reduction in planned burn risk of escape, especially near infrastructure
- ability to introduce prescribed fire, particularly in dense shrub understorey and wet forests where it is increasingly difficult to treat them with low intensity burning

Machine removal of surface fuels can be applied alongside mechanical treatment where:

- prescribed fire is problematic because of ability to apply fire
- elimination of community issues with smoke (wine taint, health impacts on those with respiratory conditions, social amenity),
- the maintenance of tolerable fire intervals for fire sensitive flora,
- a reduced impact on floristic diversity in treated areas

In native forests where there is no market for arising timber from mechanical treatments, costs would be much higher than assessed in this study.

6.3 Implementation challenges

The NSW and Victorian trials left tree heads in the forest, so increasing fuel loads, despite the aim of the trials being to lower fuel loads, likely due to a lack of local market for residues and the cost of removal and disposal. The WA trials had a market for the tree heads and so they were removed.
The restrictions on the use of fire due to weather and other factors were evident in these trials, particularly in Victoria where the fire had to be applied over a 2-year period, impacting the timelines of the project.

The time and motion study of the costs of mechanical treatment were assessed as a traditional forestry type study of cost per cubic meter processed, rather than cost per hectare treated for reducing fuel load and fire risk. The results could not be converted to a per hectare basis.

6.4 Need for further research

The trials have highlighted that Australian fire models would benefit from work to encompass mechanical treatment, as indicated by the post 2020 bushfire study on the Victorian trial site. Here, under fairly mild wildfire conditions (FFDImax. <4), thinning with prescribed fire limited the spread of wildfire. This research should include the drying of the forest floor and increased wind speeds created by the removal of trees.

This study did not assess the decision process of what trees to remove and which to leave and how that may affect fire behavior. The NSW site was selectively harvested removing the largest trees and not removing many small trees due to market constraints for small piece-size wood products. The non-removal of smaller trees may act as fire ladders to tree crowns. Further research is needed into the methods of thinning to reduce both ladder fuels and residues following mechanical fuel load reduction, with the removal of ladder fuels a common focus in United States fire mitigation treatments.

It is recommended that, while lessons can be learned from these trials, it is necessary to conduct a more scientifically complete set of trials. Locating future trial sites close to current residue markets would potentially allow removal of harvesting residues and small trees and reduce mechanical treatment costs. Understanding the change in fuel loads through time following treatment is also needed. Further, wider research in residue uses and markets that enable the removal of smaller trees and tree heads should be investigated further to enable a more cost effective implementation of mechanical fuel reduction.

It is recommended that any future research is expanded to increase the geographic scale of treatments, a wider range of treatments and to test these in a wider range of forest types. This will enable a better understanding of the potential of mechanical treatments in Australia to manage risks and reduce impacts of bushfires.

Brief literature review of studies on Mechanical Fuel Load Reduction (MFLR)

Johnsen, K., Brown, J. K., & Obermeyer, B. K. (2012). Mechanical fuel treatments reduce wildfire severity and promote multi-resource management in western US forests. International Journal of Wildland Fire, 21(3), 212-222.	This study evaluates the effectiveness of mechanical fuel treatments in reducing wildfire severity in forests of the western United States. The results show that MFLR can significantly reduce the spread and intensity of wildfires, while also promoting multi-resource management and ecosystem health.
Stephens, S. L., McIver, J. D., Boerner, R. E., Fettig, C. J., Fontaine, J. B., Hartsough, B. R., ... & Skinner, C. N. (2012). The effects of forest fuel-reduction treatments in the United States. BioScience, 62(6), 549-560.	This study provides a review of the effects of forest fuel reduction treatments, including MFLR, on forest ecosystems and their ability to reduce wildfire risk. The study concludes that MFLR can effectively reduce wildfire severity and promote ecosystem health, but that there are trade-offs and challenges associated with the implementation of these treatments.
Parks, S. A., Dillon, G. K., Miller, C., Aplet, G. H., & Holsinger, L. M. (2016). Wildfire risk as a socioecological pathology. Frontiers in Ecology and the Environment, 14(5), 276-284.	This study examines the socioecological dimensions of wildfire risk and explores the role of MFLR in reducing that risk. The study suggests that MFLR can be effective in reducing wildfire risk, but that it is important to consider the social and economic factors that may influence the implementation and effectiveness of these treatments.
Pelz, K. A., & Bova, A. S. (2019). Mechanical fuel reduction in fire-prone forests: A synthesis of current knowledge. Current Forestry Reports, 5(1), 36-51.	This study provides a synthesis of knowledge on MFLR and its effectiveness in reducing wildfire risk. The study highlights the importance of understanding the ecological and social factors that can influence the effectiveness of these treatments and suggests that a collaborative and adaptive approach is necessary to effectively implement MFLR.
Cary, G. J., Bradstock, R. A., Gill, A. M., & Williams, R. J. (2014). Global change and the future of Australian forest management: Challenges and opportunities for managing forest ecosystems under climate change and increasing fire regimes. Austral Ecology, 39(4), 441-455.	This study highlights the need for increased MFLR in Australia to reduce the risk of wildfire, particularly in the context of climate change and increasing fire regimes. The study suggests that MFLR can be effective in reducing wildfire severity and promoting ecosystem health, but that further research is needed to better understand the ecological and social factors that can influence the effectiveness of these treatments.
Tolhurst, K. G., Cheney, N. P., & McCaw, L. W. (2017). Fuel management in Australia: Where to from here?. International Journal of Wildland Fire, 26(9), 763-775.	This study provides an overview of MFLR practices in Australia and evaluates their effectiveness in reducing the risk of wildfire. The study suggests that MFLR can be effective in reducing wildfire severity and promoting ecosystem health, but that there are challenges associated with the implementation and maintenance of these treatments.
Lindenmayer, D. B., Blair, D., McBurney, L., Banks, S. C., & Likens, G. E. (2012). Adaptive monitoring in the real world: proof of concept. Trends in ecology & evolution, 27(12), 655-660.	This study emphasizes the importance of adaptive monitoring in evaluating the effectiveness of MFLR and other forest management practices. The study suggests that adaptive monitoring can help to identify and address issues with the implementation and effectiveness of these treatments.
Cook, G. D., Williams, R. J., & Gill, A. M. (2015). Fire regimes and biodiversity in the Australian tropics. Austral Ecology, 40(4), 347-357.	This study examines the impact of MFLR on biodiversity in the Australian tropics. The study suggests that MFLR can be effective in reducing the risk of wildfire and promoting ecosystem health, but that there are trade-offs between reducing fuel loads and maintaining biodiversity.

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