Fire Management

EFFECTIVENESS OF BROADSCALE FUEL REDUCTION BURNING IN ASSISTING WITH WILDFIRE CONTROL IN PARKS AND FORESTS IN VICTORIA

Research Report No. 51

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Forest Science Centre, Orbost & Creswick

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FOREWORD

In an average year over 600 unplanned bushfires start in Victoria's national parks and State forests. While around one quarter of these fires are started by lightning, the remainder are caused by human activity.

While every effort is made to prevent fires from starting, Victoria will always experience bushfires from either natural or human causes. These bushfires can threaten human life, property, assets and at times, the environment. Some of these fires are difficult to control, in spite of the use of the latest technology and highly trained firefighters.

One way of protecting settlements and also limiting the spread and severity of bushfires is by strategically reducing the 'fuel' in parts of our parks and forests. The reduction of fuels, such as leaves, twigs, grass, shrubs, bark or other vegetation, is referred to as 'Fuel Management'.

Fire behaviour is determined by weather, topography and fuel. However, fuel is the only factor that can be altered before an unplanned fire starts. Once a fire has started, fire intensity and the speed with which the fire spreads are affected by the fuel load.

Methods of reducing fuel hazard levels include mowing, raking, slashing or burning. Of these, only burning is feasible for larger areas.

By reducing fuel hazard levels in parts of our parks and forests, with fires lit during the cooler months of the year, a bushfire that either burns into a fuel reduced area or starts in one will have lower flame height, reduced intensity and will spread at a slower rate, making fire supression easier and more successful.

This report looks at the effectiveness of broadscale prescribed burning in assisting with wildfire suppression, in a number of the forest types that are found in Victoria's parks and forests. The study on which the report is based is retrospective in its approach. It also uses a limited data set. The nature of wildfire occurrence in Victoria, and the variable and complex nature of the factors which effect forest fire behaviour mean that a classical experimental approach to an evaluation is not possible at this stage.

Nonetheless I believe the study will make a valuable contribution to the understanding Victoria's park, forest and fire managers have of the role prescribed fires can play in helping protect human life and property. The study is also an important one in helping land managers strike the appropriate balance between life and property protection and the need to meet the fire related ecological requirements of many of our native ecosystems.

GARY MORGAN
CHIEF FIRE OFFICER

SUMMARY

This study investigated the general effectiveness, for subsequent wildfire control, of broadscale prescribed burning for fuel hazard reduction across Victoria. This form of prescribed burning is also commonly known as 'fuel reduction burning (FRB)'. It involves the deliberate lighting of fires to burn within a predetermined area, with a predetermined intensity and in a predetermined time of year (generally in autumn) to reduce forest fuels (surface litter, bark and understorey shrubs/grasses) which are available for burning in the event of wildfires.

This study was primarily done by sampling a relatively large number of fires (114) from a selection of fire districts, using the FIRES database of NRE. Sampling was aimed at identifying fires from the range of Fuel Management Zones and with a range of final fire sizes. (FMZs - all public land is divided into one of five FMZs for fire protection purposes. These are set out in the *Code of Practice for Fire Management on Public Land* (NRE 1995). Zones 1 to 3 have specific fuel management targets, and Zones 3, 4 and 5 have ecological targets - the zoning system is the basis for the production of Fire Protection Plans for fire districts and regions). Many wildfires known to be influenced by FRB were studied, and a selection of those fires where previous FRB did not assist in suppression were also investigated to determine what differences there were in fuel or other conditions which contributed to these outcomes. Wildfires sampled occurred between the 1990/91 and 1997/98 fire seasons inclusive.

The main aims of the study were to investigate how FRBs had moderated wildfire behaviour to an extent where it assisted in fire control, and to investigate whether there were significant differences between the strategic location of FMZs in terms of how likely a wildfire was to encounter a "helpful" FRB within each Zone.

The findings of this study are prefaced by the acknowledgment that the results have come from a deliberately biased data set. This, it is argued, was due to the nature of the data available at the time and was unavoidable. Further, a retrospective type study approach was taken in order to provide advanced insights into the effectiveness of broadscale FRB on public land in Victoria. A classical experimental approach to investigate this complex and highly variable issue would have been exceptionally difficult and expensive, with results not available for many years. The qualified results from the present study however can be immediately used to guide policy development and on-ground operational practice. It is likely that the qualified findings are generally correct from a Statewide perspective, but further analysis of an expanded data set is preferred.

A major finding of the study was that the maximum level of 'Overall Fuel Hazard' that would provide any assistance with suppression was that of ***High*** . This reinforces some earlier work on the subject (Wilson 1992, McCarthy *et al*. 1999).

Two predictive models were constructed from the data. The first predicts that, as fire danger increases, the benefits of previous FRB starts to reduce (particularly at FDIs 25-50, depending on the 'Overall Fuel Hazard' level). That is, at higher levels of fire danger, weather influences become more important than fuel conditions, in terms of successful suppression operations.

The second model predicts that, beyond about 10 years post-fire, the probability of an FRB still being 'helpful' for suppression operations decreases significantly. The highest probabilities of a previous FRB being helpful to subsequent suppression operations occur in the first four years

following the FRB, with decreasing probabilities up to about age 10 years. Assisting effects of a previous FRB that is between 4 and 10 years old are most likely to be in terms of reduced bark and elevated fuel hazards, as surface fuels appear to re-accumulate to pre-burn levels within the first 4 years.

This study has identified that FMZ 1 and FMZ 2 are the two Fuel Management Zones where a subsequent wildfire has the highest likelihood of running into a previous FRB which will both slow the headfire and assist with suppression. Depending on the fire district, between 1 in 5 and 1 in 2 wildfires will be likely to run into a 'helpful' FRB in FMZs 1 and 2. The frequency of burning in these zones is important, with the most effective areas in FMZ 1 being burnt every five years on average, and the most effective areas in FMZ 2 being burnt every seven years on average.

Only about 1 in 20, on average, of the fires sampled in conjunction with FMZ 3 ran into a 'helpful' FRB. This result suggests that in the current circumstances the impact of FMZ 3 treatment is close to that of random fuel management. Larger FMZ 3 areas, or more frequent treatment of these areas, however, would probably alter this outcome. At present, the lower likelihood of a wildfire being effectively reduced in intensity by FMZ 3s appears to be as a result of the lower frequency of burning within the current zone. An added factor here, given the often large size of FMZ 3, may be the possibility that the percentage area burnt within the total area in this Zone is less than in FMZ 1 and FMZ 2. Finally, the average burning frequency of 11 years appears to be sufficient to allow all fuel components (surface, bark and elevated) to increase to levels of more than ***High***. Once ***Very High*** and ***Extreme*** fuel hazard levels are reached, the effect of previous fuel reduction burning on wildfire behaviour is minimal.

The qualified results from this Statewide analysis of the effectiveness of broadscale FRB in assisting with subsequent wildfire control may be useful in terms of future policy development for fire management in Victoria. The results may also prompt consideration of current operational practice, particularly in relation to Zone 3. On-going research on this subject, however, is clearly warranted.

INTRODUCTION

Broadscale fuel reduction burning (FRB) has been practised in Victoria for nearly 30 years. FRB involves the deliberate use of fire, under prescribed (or pre-determined) weather and fuel moisture conditions (generally in the autumn), to reduce both the amount, and vertical extent, of forest fuels, including surface litter, bark and understorey shrubs. FRB is carried out to reduce these fuel hazards, and thereby assist with the control of wildfires in later years. On average approximately 100,000 hectares, out of a total of 7.8 million hectares (about 1.5%), of public land is burnt in the annual fuel reduction burning program. (Note: Some vegetation types in Victoria are not ecologically suited to prescribed burning and these are excluded from the FRB program.) The Department of Natural Resources and Environment (NRE) has most of the responsibility for fuel reduction burning on public land, due to its obligations for hazard reduction under the Forests Act 1958.

The majority of the area burnt is in areas identified in Fire Protection Plans as being of strategic importance. The *Code of Practice for Fire Management on Public Land* (NRE 1995) identifies five Fuel Management Zones (FMZs) that have a range of fuel management and ecological objectives. Zone 1 has as its aim the protection of human life, property and assets, and therefore the zone where fuel hazards are to be kept at their lowest possible levels commensurate with the local land management objectives. Zones 2, 3 and 4 are then seen as being of decreasing importance from a fuel management perspective. Zone 2 is intended to provide long strategic “corridors” of fuel reduced area which can act as a barrier to large, fast-moving wildfires. Zone 5 is intended not to be prescribed burnt during the period of the Fire Protection Plan.

Although a number of Victorian studies have investigated the effectiveness of fuel reduction burning in specific case studies (Billing 1981, Rawson *et al*. 1985, Grant and Wouters 1993) there had not been a Statewide evaluation of the effectiveness of the broadscale fuel reduction burning program.

The increase in the number of dwellings and other assets on private land in close proximity to forested public land means that it has become increasingly important to ensure that all fire protection works, involving both prevention and suppression strategies, are effective.

Whilst past research, combined with operational experience, strongly indicates that FRB is very effective in reducing fire hazard, it is equally important to acknowledge that FRB is associated with ecological impacts, and that factors such as human health (from smoke), and greenhouse issues should also be considered in any holistic evaluation of the practice. Neither does this study address the cost-benefits of FRB, nor the question of how much area should be burnt in the FRB program to achieve the desired level of fire protection. Such evaluations are well beyond the scope of this study, but these issues are the subject of complementary research and development by NRE and its collaborators.

Fuel reduction burning has a number of effects on forest fuels, and these effects diminish with time (Tolhurst *et al* 1992). Immediately following a fuel reduction burn (or a wildfire which may have similar effects on the fuel), litter and fine surface fuels are generally significantly reduced through burning. Depending on the site and the intensity of the burn, elevated shrub and bark fuels are often also significantly reduced.

Tolhurst *et al*. (1992) reported that, following fuel reduction burns in the Wombat Forest in Central Victoria, litter/surface fine fuels reaccumulated to pre-burn levels in 3 to 5 years (surface fine fuel being predominantly the dead leaf, bark and twig material on the ground and the fine grasses). Tolhurst *et al.* (1992) also reported that, where the burn consumed elevated shrub and tree bark fuels, the levels of these were significantly reduced for up to 25 years following the burn.

It therefore appears that, while fuel reduction burns may only reduce surface fuel levels for a relatively short time, there is a much longer effect on bark and elevated fuels.

McCarthy and Tolhurst (1998) reported that elevated and bark fuel hazard levels were significantly higher in the few cases where first attack failure occurred during wildfire suppression operations in Victoria for the period 1991/92 - 1994/95. They also reported the absence of any significant fuel reduction burning within the last 15 years for the sites where first attack operations failed.

Therefore, depending on the site and the vegetation, it is likely that fuel reduction burning would need to be less than 10 years old for it to have significant effects in assisting with wildfire suppression operations. This concurs with the findings of Grant and Wouters (1993) and Rawson *et al.* (1985) who found the best effect on wildfire incidence and containment occurred from burns which were less than 5 years old. Two burns older than this - 7 years old - were reported by Buckley (1990) and Grant and Wouters (1993) as still having a significant hazard-reducing effect, and in these cases the effect was attributed to a reduction in the bark and elevated fuel hazard levels.

The assessment of the various components of fuel hazard (viz. elevated fuel, bark on trees, and surface fine fuel) has been simplified in Victoria in recent years by the production of the Elevated Fuel Guide (Wilson 1993) and the Bark Hazard Guide (Wilson 1992a). These two guides follow a visual assessment procedure based on a series of reference photographs accompanied by verbal descriptions, and allow fire managers to assess the re-accumulation of bark and elevated fuel hazards and judge when levels have built up to the stage where fuel reduction burning is required. A visual and rapid measurement system for the assessment of litter/surface fine fuels and near-surface fuels was proposed by McCarthy (2000). Assessment of the three components of fuel hazard to give an Overall Fuel Hazard rating for a site can now be done operationally using the Overall Fuel Hazard Guide (McCarthy *et al*. 1999). This Guide represents a major advance in the assessment of fuel hazards in a rapid and cost effective manner.

The techniques outlined in the Overall Fuel Hazard Guide were used in this study to measure both the Overall Fuel Hazard levels for a site, as well as the hazard levels for the three individual components of surface fine fuel, bark and elevated fuels.

The aims of this study were to investigate:

1) What reduction in Overall Fuel Hazard was required to assist with the suppression of a subsequent wildfire on the same site.

2) How frequent fuel reduction burns need to be undertaken to maintain Overall Fuel Hazards at or below levels identified in 1) above.

3) How effective the strategic placement of Fuel Management Zones (1, 2 & 3) were and how well fuels in these Zones have been managed.

METHODS

The methods, results and analysis are presented in three parts. Part 1 deals with the primary sample of 114 fires Statewide, for which *detailed* data were collected on fuel hazard, weather, topography, resources and FRB effect. Part 2 uses two samples of fires (for which only distribution data and FRB effect were collected), the first of 152 fires - to investigate how *fires with an FRB effect were distributed across the FMZs* - and the second of 1501 fires, to investigate the *general occurrence of all fires by FMZ.* Part 3 deals with a sample of all fires (2425 fires) on public land over seven fire seasons from 1990/91 to 1996/97 (for which only FRB influence data were collected). It was done to investigate the *overall percentage of fires on public land which were influenced by previous FRB.*

Part 1. Wildfires for which detailed data were collected (114 fires, 1990/91 – 1997/98)

Selection of Fires

Wildfires to be analysed as part of this study were selected principally from the six fire seasons preceding and including 1997/98. There were two main reasons for this. Firstly, data collection relied principally on interviewing relevant fire control staff, and the most recent information was considered to be the freshest in people's memories and therefore of the best reliability. Secondly broad strategic FRB zones (Fuel Management Zone 2 - strategic corridors) have only been incorporated into Fire Protection Plans since the late 1980s, with limited opportunities for them all to be rotationally burnt between 1987/88 and 1993/94, due to a series of mild seasons.

One hundred and fourteen wildfires were selected from across Victoria to give Statewide applicability to the results. Approximately 25-30 wildfires in each of FMZs 1, 2 and 3 were selected to investigate possible differences in fuel hazard levels attained/maintained and hence their influence on fire suppression performance. While it was quite easy to find sufficient fires to collect data from in FMZ 3, there were relatively few fires in FMZ 1 and FMZ 2 for which useful data could be collected.

Fires were selected by sorting the FIRES database (Fire Information and Recording System, a database managed by NRE[1]). Sorting was carried out to select a range of sites and final fire sizes. Sorting was hampered by the fact that FMZ was not recorded on the Final Fire Report (the Final Fire Report is one of the primary information input forms into the FIRES database - it summarises wildfire information for each individual fire by site, times/dates, cause, weather, fire behaviour, FRB influence, NRE response, total suppression forces, costs and any investigation data). Fires for FMZs 1 & 2 were mostly identified by the fact that, on the Final Fire Report, they were noted as having some influence from a previous FRB . Hence the sample of fires obtained for these Zones was biased towards fires for which there was some influence of a previous FRB (as reported in the FIRES database).

[1] (The FIRES database is a computer-based data storage and analysis facility. It contains mainly records from Final Fire Reports, and has information back to 1972/73. It began in 1988, and was networked across the Department in 1988/89, which allowed remote viewing and data entry. It was designed specifically for reliability and integrity, using features such as finite selection lists, and data entry crosscheck rules, to reduce input error. Data were also checked centrally after fire district entry, and queried for obvious inconsistency. It has always had security via restricted and hierarchical access. It was superseded by the Fireweb/IFIS system in early 2001. Fireweb/IFIS now contains all the data from FIRES.)

For FMZ 3, the main aim was to sample a range of final fire sizes, which was relatively easy to achieve. Some of the fires in FMZ 3 were also deliberately selected from those which had influence of previous FRBs, in order to investigate the factors of previous fuel hazard reduction which may have influenced the suppression operation. This sampling was therefore not just a random selection from FMZ 3, as a random selection may not have sufficiently sampled either fire size variation, or influences due to previous fuel reduction.

The fire districts from which data were collected did not include any which had large amounts of urban interface. This was done deliberately, as it was found during data collection that the large number of small blocks of State forest scattered in and around larger regional centres, such as Ballarat and Bendigo, represented a set of circumstances which were quite complex. That is, the very large task of fuel management across these small blocks meant that it was very difficult to conduct fuel hazard reduction burning on a regular basis. The increased risk of deliberate ignitions further complicated the situation in these locations. Therefore, it was decided that they would be generally excluded from the current study, but may well warrant separate detailed investigation in the future.

The mallee vegetation in north-western Victoria was also not included in this study. The fire protection strategies used in that region differ from those used in forested areas and would have confounded the results. A separate study of the effectiveness of fuel management in this area is considered warranted, however.

Data collected for each fire

A range of fuel, weather, site, topography, fire behaviour and fuel reduction burn effect variables were collected for each fire as follows:

(i) Fuel

The three individual components of fuel hazard - surface fine fuel; bark; and elevated - were assessed for both the site at first attack, and also for the final control line. Fuel hazard, both component and Overall, was assessed using the Overall Fuel Hazard Guide (McCarthy *et al.* 1999). At the final control line, fuel hazard levels were recorded for both inside and outside the line, in order to evaluate situations where a wildfire was stopped by a recent FRB on the other side of a track or road. Thus fuel hazard was assessed at three locations altogether.

(ii) Weather

Air temperature, relative humidity, and wind direction and speed were collected for both the first attack period and also for the conditions at the final control line. Where local records were not available for this purpose, records from the nearest Bureau of Meteorology Automatic Weather Station (AWS) were used. Some interpolation of values was undertaken where the fire site differed substantially in altitude from the AWS site. These weather variables were then used to calculate the Forest Fire Danger Index (FDI) at both first attack and also the final control line.

(iii) Site and topography

The first attack and final control line sites were assessed for the site variables of slope and aspect. Occurrence on a ridge-top or side-slope was also noted.

(iv) Fire behaviour

Forward rate of spread (FROS), flame height and spotting distance were recorded as primary measures of fire behaviour at both first attack and also at the final control line. Initial fire size - that is the size of the fire at the time of first attack - and also final fire size were recorded. Figures were recorded for both perimeter and area. All fire behaviour information was the best estimate of the person on the fireline at the particular time. It was not measured precisely, except in the few instances where fire research or other fire situation staff were present.

(v) Fuel reduction burn effects

Where known, the age of the last wildfire or fuel reduction burn on the site was recorded. Where this was not known but appeared to be long unburnt, 15 years was used as a default figure. From the work of Tolhurst *et al.* (1992) it was inferred that all three components of fuel (surface fine, bark, and elevated) would be approaching pre-burn hazard levels at 15-20 years post-burn.

Various questions were asked of fire controllers to attempt to ascertain if any, and what level of, fuel reduction burning had influenced the behaviour of the subsequent wildfire on the site.

Questions asked were:

What percentage of the headfire burnt through or into an FRB?
Did the FRB slow the headfire?
Did the FRB assist suppression?
Did the FRB stop the headfire?
Did the headfire encounter an area of naturally low fuel hazard?
Was the headfire stopped on a fuelbreak such as a track or firebreak?

The data were analysed using non-linear regression techniques, as most of the information on the effects of FRB on subsequent wildfires was collected as categorical data.

Part 2. Sample of wildfires from nine fire districts (1653 fires, 1990/91 – 1996/97)

To investigate the relative proportions of how fires occurred by FMZ, as distinct from how wildfires encountered FRBs by FMZ, a sample of fires was taken from 9 of the 24 fire districts across Victoria. The first part of this sample entailed sending fire management officers (FMOs) a record of all the fires in their fire district which encountered an FRB in the period 1990/91 to 1996/97. The FMOs were then asked to classify these fires by FMZ.

The second part of the sample entailed overlaying the fire origins map on the FMZ map for each fire district, and counting overall numbers of fires by FMZ for the same period.

These two results were then graphed, and the relative occurrences were compared using a Chi-square test.

Part 3. Statewide sample of fires (2425 fires, 1990/91 – 1996/97)

A Statewide sample of wildfires was also taken (using the FIRES database) from the period 1990/91 to 1996/97. All fires which occurred on public land, and could therefore be expected to be subject to the influence of a previous wildfire or a FRB, were sorted from the total number of fires. Within this sample, the total number of fires having some influence from a previous FRB or wildfire was also sorted.

RESULTS

As highlighted in the Methods section of this report, data collection for the report could not be done on a completely random basis for a variety of technical or other reasons. As a consequence of this intentional (and unavoidable) bias in data collection, the results should not be regarded as definitive in a statistical sense, and any conclusions drawn from the findings must be appropriately qualified. Although it is likely that the general trends of the results are valid, further studies are necessary to confirm this. The future availability of digital Geographic Information System (GIS) data on fire occurrence, fire history and FMZ should make this possible.

Part 1. Fires for which detailed data was collected for this study

Selection of fires

Table 1 shows the range of fires sampled in terms of whether they encountered a previous FRB or not. For FMZs 1 and 2, it was quite difficult to identify the required number of 20-30 fires from the period sampled (8 fire seasons). There were very few fires in these Zones over the sampling period for which useful data could be collected.

Data in Table 1 indicates that there was a strong influence of previous FRBs within the wildfires which were sampled for each FMZ, but this is largely due to the manner in which the data was collected as will be seen later.

Table 1 Sample distribution of the 114 fires across the FMZs and by FRB influence

	Fuel Management Zone					
	FMZ 1	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**	***Totals***
Fires which encountered a previous FRB	23	31	10	4	1	*69*
Fires which did not encounter an FRB	2	7	21	11	4	*45*
Total fires for FMZ	*25*	*38*	*31*	*15*	*5*	***114***

(*Sampling Note*: Statewide data from Table 10 indicates that 11% of fires across all the FMZs were influenced by a previous FRB. The sample for FMZ 3 used here [31 fires and 10 with FRB influence shown in Table 1] contains a higher than average number of fires with FRB influence. That is, the expected outcome for FMZ 3 from a random sample would only be 3 or 4 fires in 31 influenced by a previous FRB – see Methods for an explanation.)

Table 2 shows the variation in Overall Fuel Hazard outside the final control line for all fires in the study by FMZ. It shows some distinct differences between FMZs 1 & 2 and FMZ 3. For FMZs 1 and 2, Overall Fuel Hazards are mostly grouped around the ***Moderate*** and ***High*** levels, whereas for FMZ 3, the grouping is much more toward the ***High*** to ***Very High*** levels. As fires for FMZ 3 were biased toward those which had influence from previous FRBs, they may be expected to have lower fuel hazard levels than if chosen at random.

Table 2. Sample of 114 fires by FMZ and Overall Fuel Hazard outside the final control line.

	Fuel Management Zone				
Overall Fuel Hazard (Figures in brackets are numerical hazard scores used for data analysis)	**FMZ 1**	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**
Low (1- 1.5)	0	0	0	0	0
Moderate (2 - 2.5)	11	14	2	5	0
High (3 - 3.5)	12	19	20	6	4
Very High (4 - 4.5)	2	5	7	4	1
Extreme (5)	0	0	2	0	0

Table 3 shows the ranges of all variables for the sample of 114 fires. The fires sampled ranged from small fires (<5 ha) with low rates of spread, up to large fires (largest 6500 ha) which moved quite rapidly.

Tables 4 and 5 show the mean values for all variables at both the time of first attack, and at the final control line respectively. The important variations in these data are for the FDI, fuel hazard and burning history variables.

Table 6 shows the mean values for important times and time intervals concerned with detecting the fire, commencement of the suppression action, and checking the forward progress of the fire.

Table 7 indicates mean values for FRB effect, on the subsequent wildfire, for the 114 fires in the study. The figures in bold indicate mean values which are substantially different for the five FMZs.

Table 3 All data variables collected and used in the analysis with their minimum and maximum values.

Variable (At first attack)	**Range**	**Variable (At the final control line)**	**Range**	**Variable (Times and FRB Effect)**	**Range**
Air Temperature (^{o}C)	13-36	Air Temperature (^{o}C)	2-35	Time of Detection (hrs)	0200-2315
Relative Humidity (%)	10-100	Relative Humidity (%)	10-99	Detection to First Suppn. Work (hrs)	0-20
Wind Speed (km/hr)	0-50	Wind Speed (km/hr)	0-50	First Suppn. Work to Checking (hrs)	0-72
Wind Direction (^{o})	0-360	Wind Direction (^{o})	0-360		
FDI[2]	0-90	FDI	0-90		
Surface Fine Fuel Hazard	2-5	Surface Fine Fuel Hazard (inside control line)	2-5	% of Headfire which encountered a FRB	0-100
Bark Hazard	2-5	Bark Hazard (inside control line)	2-4.5	Age of the FRB (yrs)	0-20
Elevated Fuel Hazard	2-5	Elevated Fuel Hazard (inside control line)	1-5	Did the FRB Slow the Headfire (%)	0/1
Overall Fuel Hazard	2-5	Overall Fuel Hazard (inside control line)	2-5	Did the FRB Assist Suppression (%)	0/1
Ridge	0/1	Surface Fine Fuel Hazard (outside control line)	2-5	Did the FRB Stop the Headfire (%)	0/1
Flat ground	0/1	Bark Hazard(outside control line)	1-5	Did the Headfire encounter an area of naturally low fuel hazard (%)	0/1
Mid-Slope	0/1	Elevated Fuel Hazard (outside control line)	1-5		
Slope (^{o})	-12/+25	Overall Fuel Hazard (outside control line)	2-5	Did the headfire encounter a fuel break such as a track or firebreak (%)	0/1
Aspect (^{o})	0-360	Ridge	0/1		
Crew NRE (no.)	0-59	Flat ground	0/1		
Crew Other (no.)	0-45	Mid-Slope	0/1		
D4 Dozer (no.)	0-2	Slope (^{o})	-12 /+25		
D6 Dozer (no.)	0-2	Aspect (^{o})	0-360		
Wheel Tractor (no.)	0-1	Crew NRE (no.)	0-97		
Fire Bomber (no.)	0-10	Crew Other (no.)	0-160		
Slip-on units (no.)	0-8	D4 Dozer (no.)	0-2		
Tanker NRE (no.)	0-4	D6 Dozer (no.)	0-4		
Tanker Other (no.)	0-10	Wheel Tractor (no.)	0-1		
Flame Ht (m)	0.2-7.5	Fire Bomber (no.)	0-4		
FROS (m/hr)	10-1500	Slip-on units (no.)	0-25		
Spotting Distance (m)	0-750	Tanker NRE (no.)	0-8		
First Size (ha)	0.01-250	Tanker Other (no.)	0-40		
Perimeter (m)	5-7000	Flame Ht (m)	0.2-7.5		
Fuel Mangt. Zone	1-5	FROS (m/hr)	5-1000		
Last Burnt (yrs)	0.5-20	Spotting Distance (m)	0-500		
		Final Size (ha)	0.01-6500		
		Perimeter (m)	5-120000		
		FMZ	1-5		
		Last Burnt (yrs)	0.2-20		

[2] FDI is the McArthur Forest Fire Danger Index.

Table 4 Mean values for weather, fuel hazard, slope, suppression effort, fire behaviour, fire size and fuel reduction history for all fires by Fuel Management Zone at the time of first attack.

Variable	Fuel Management Zone				
	FMZ 1	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**
Air Temperature (^oC)	22	26	23	26	18
Relative Humidity (%)	38	30.5	35	35	41
Wind Speed (km/hr)	12	14	10	12	8
Wind Direction (^{o})	200	223	199	204	302
FDI[3]	12	18	12	18	5
Surface Fine Fuel Hazard	2.7	2.4	3.3	2.5	2.7
Bark Hazard	2.6	3.1	3.1	2.8	2.6
Elevated Fuel Hazard	2.6	3.4	3.2	3.1	2.8
Overall Fuel Hazard	3.0	3.7	3.8	3.5	3.4
Ridge (0/1)	0.08	0.05	0.10	0.07	0
Flat ground (0/1)	0.33	0.58	0.30	0.63	0.60
Mid-Slope (0/1)	0.63	0.39	0.70	0.37	0.40
Slope (^{o})	6	5	8	4	5
Aspect (^{o})	127	79	152	88	76
Crew NRE (no.)	5	12.5	8	6	4
Crew Other (no.)	7	2	4	6	0
D4 Dozer (no.)	0.4	0.3	0.5	0.5	0.4
D6 Dozer (no.)	0.1	0.1	0	0.1	0
Wheel Tractor (no.)	0	0.1	0.03	0	0
Fire Bomber (no.)	0.2	0.2	0.03	0.8	0
Slip-on units (no.)	2	3	2	2	1.6
Tanker NRE (no.)	0.25	0.7	0.6	0.9	0
Tanker Other (no.)	2	0.5	1	1.5	
Flame Ht (m)	1.3	1.4	2.0	1.6	1.1
FROS (m/hr)	175	215	345	465	95
Spotting Distance (m)	17	37	66	33	14
First Size (ha)	2.5	15	9	15	5
Perimeter (m)	225	1300	660	1200	840
FMZ	1	2	3	4	5
Last Burnt (yrs)	5.8	11.5	8.4	14	12.4

[3] FDI is the McArthur Forest Fire Danger Index

Table 5 Mean values for weather, fuel hazard, slope, suppression effort, fire behaviour, fire size and fuel reduction history for all fires by FMZ the final control line.

	Fuel Management Zone				
Variable	**FMZ 1**	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**
Air Temperature (°C)	20	24	19	23	17
Relative Humidity (%)	45	32	40	42	51
Wind Speed (km/hr)	10	11.5	6.5	12	7
Wind Direction (°)	175	225	160	195	290
FDI	8	16	7	15	5
Surface Fine Fuel Hazard (inside control line)	2.6	2.1	3.2	2.6	2.9
Bark Hazard (inside control line)	2.7	3.0	3.0	2.7	2.4
Elevated Fuel Hazard (inside control line)	2.5	3.3	2.9	3.0	2.2
Overall Fuel Hazard (inside control line)	3.0	3.6	3.5	3.3	3.2
Surface Fine Fuel Hazard (outside control line)	2.5	2.2	3.2	2.6	2.9
Bark Hazard (outside control line)	2.6	2.4	3.0	2.5	2.4
Elevated Fuel Hazard (outside control line)	2.5	2.7	2.8	2.7	2.6
Overall Fuel Hazard (outside control line)	**2.9**	**3.0**	**3.6**	3.0	3.2
Ridge (0/1)	0.13	0.11	0.10	0.07	0
Flat ground (0/1)	0.38	0.55	0.30	0.50	0.60
Mid-Slope (0/1)	0.54	0.39	0.66	0.50	0.40
Slope (°)	5	5	8	6.5	5.5
Aspect (°)	110	7	135	120	75
Crew NRE (no.)	13	21	21	24	7
Crew Other (no.)	26	9	9	6	0
D4 Dozer (no.)	0.4	0.7	0.7	0.7	0.4
D6 Dozer (no.)	0.4	0.2	0.7	0.7	0
Wheel Tractor (no.)	0	0.2	0.05	0.1	0.2
Fire Bomber (no.)	0.4	0.2	0.3	0.2	0
Slip-on units (no.)	3	4.5	3.5	6	2
Tanker NRE (no.)	0.6	1	1.3	1.8	0.4
Tanker Other (no.)	7	1.7	2.5	2	0
Flame Ht (m)	0.8	1.2	1.3	0.7	0.8
FROS (m/hr)	95	170	160	180	85
Spotting Distance (m)	3	11	25	3	0
Final Size (ha)	17	200	340	395	12
Perimeter (m)	765	4260	8820	6675	1450
FMZ	1	2	3	4	5
Last Burnt (yrs)	**5.1**	**7.5**	**11.8**	13.1	13.4

Features to note from Table 5 are the mean values of Overall Fuel Hazard (outside final control line) and Last Burnt (yrs)which show substantial differences between FMZ. Both FMZ 1 and FMZ 2 appear to be substantially different from FMZ 3 for both of these variables.

Table 6 Mean values for time intervals for all fires by Fuel Management Zone at the final control line.

Time interval	Fuel Management Zone				
	FMZ 1	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**
Time of Detection (24 hr)	14:40	14:50	14:30	16:10	13:30
Detection to First Suppn. Work (hrs)	1.4	1.3	0.9	1.6	5
First Suppn. Work to Checking (hrs)	3.3	5.5	10.5	12	3

Table 7 Mean values for Fuel Reduction Effect for all fires by Fuel Management Zone at the final control line.

Fuel Reduction Effect	Fuel Management Zone				
	FMZ 1	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**
% of Headfire which encountered a FRB	**79**	**78**	30	27	16
Age of FRB (yrs)	**5.1**	**7.5**	11.6	13.0	13.4
Did FRB Slow the Headfire (%)	**79**	**68**	23	20	20
Did FRB Assist Suppression (%)	**80**	**78**	32	27	20
Did FRB Stop the Headfire (%)	7	26	3	13	0
Did the Headfire encounter an area of naturally low fuel hazard (%)	4	3	26	43	20
Did the headfire encounter a fuel break such as a track or firebreak (%)	29	42	19	40	30

Table 7 indicates that, FMZ 1 and FMZ 2 fires exhibited mean differences compared with the other FMZs in four areas of FRB effect, these being:

- a greater percentage of the headfire of a subsequent wildfire encountered a previous FRB in FMZ 1 and FMZ 2;
- the most recent FRB encountered by a subsequent wildfire in FMZ 1 and FMZ 2 was significantly more recent than in the other FMZs; and
- the FRB encountered by a subsequent wildfire in FMZ 1 and FMZ 2 was significantly better at both slowing the headfire and assisting with suppression.

A model was constructed using Overall Fuel Hazard at the final control line and Fire Danger Index (FDI) at the final control line, for predicting the probability of whether a previous FRB would slow the headfire of a subsequent wildfire. It was constructed using a logistic procedure as follows:

Probability of slowing headfire = $1 - (1/(1+(1/e^{b})$ (*Equation 1*)

Where: $b = (1.37*OVEROL) + (0.035*FDI) - 4.77$ (*Equation 2)*

OVEROL = Overall Fuel Hazard, outside final control line,
FDI = Forest Fire Danger Index

OVEROL Co-eff	FDI Co-eff	Const	p (model)	n (obs)
1.37^{**}(s.e. 0.35)	$0.035^{\#}$ (s.e. 0.021)	4.77	0.001	114

(** 99% signif., * 95% signif., # 91% signif.)

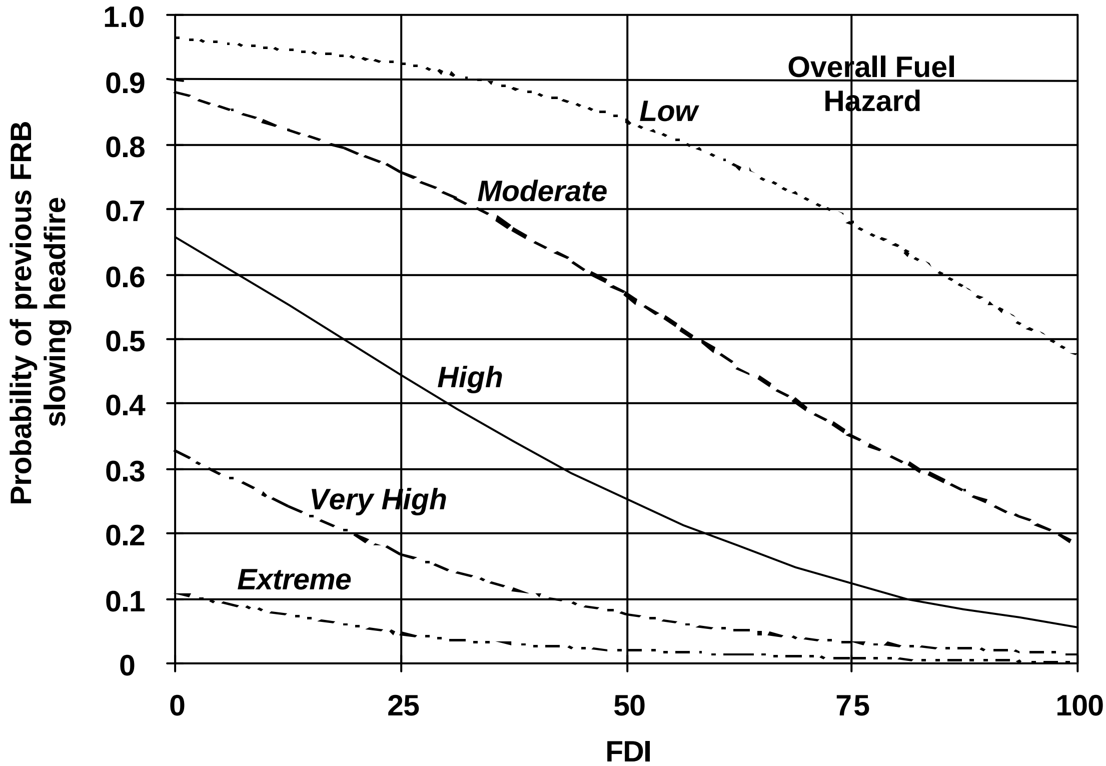

Figure 1 Probability of previous FRB slowing the headfire of a subsequent wildfire as a function of Overall Fuel Hazard and Fire Danger Index. (Probability of "1.0" means "certain", probability of "0" means "not possible".)

Figure 1 indicates that, as would be expected, there will be a significant decline in the probability of a previous FRB slowing the headfire of a subsequent wildfire as FDI increases. The effect is more pronounced for the lower fuel hazard levels (***High*** and ***Moderate*** in particular) which start out with relative high probabilities at lower FDIs and then decline dramatically, particularly between FDI 25 and FDI 50.

The most significant single factor model for explaining whether a previous FRB would assist with the suppression of a subsequent wildfire was one using the age of the previous FRB (or wildfire). It was constructed using a logistic procedure as follows:

Probability of assisting with suppression = $1 - (1/(1+(1/e^{b})$ (*Equation 3*)

Where: b = (0.68*LASTBURN) - 7.68 (*Equation 4*)

(LASTBURN = time since last burnt by FRB or wildfire)

LASTBURN Co-eff	Const	p (model)	n (obs)
0.68**(s.e. 0.35)	-7.68	<0.001	114

(** 99% signif.)

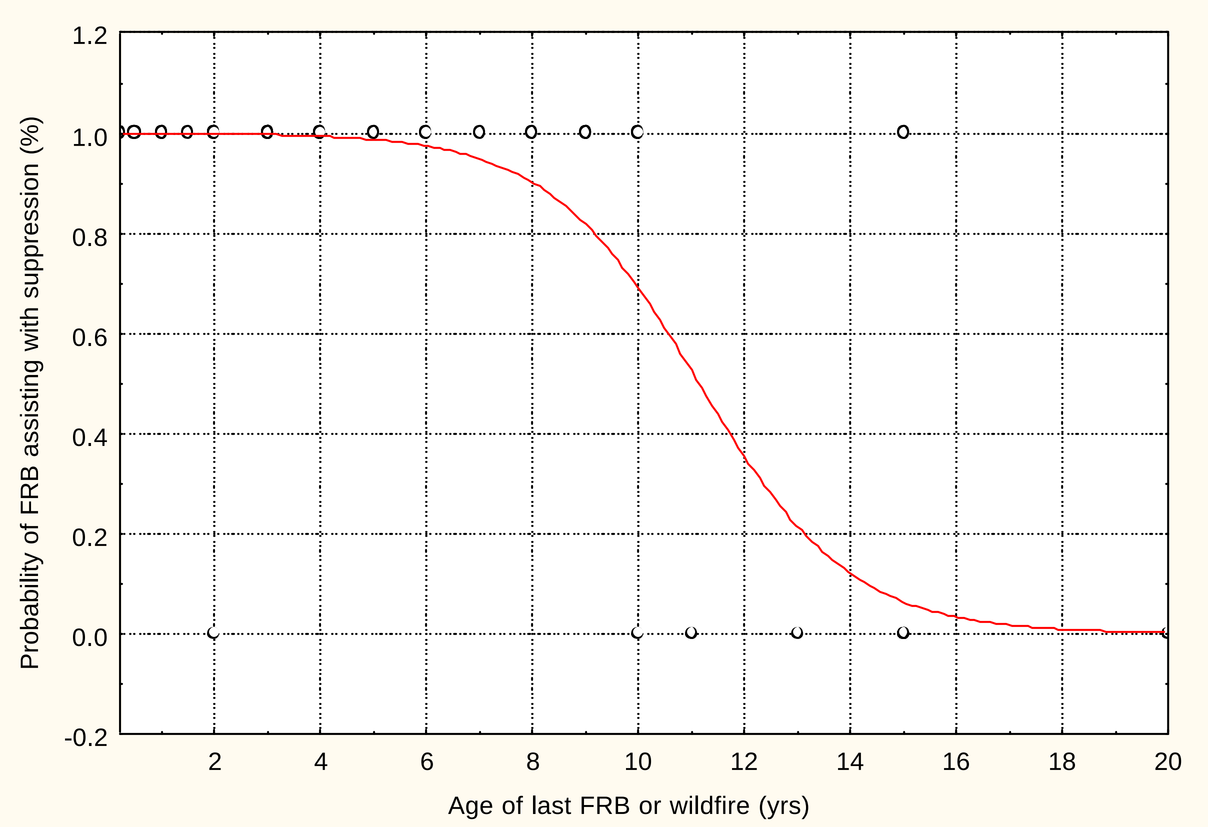

Figure 2 Probability of a previous FRB assisting with the suppression of a subsequent wildfire on the same site as a function of the time since the last FRB (or wildfire). Actual data values also shown as e.g. "o", to illustrate trends in raw data.

This model indicates the highest probability of there being an assisting effect between the ages of one and five years post-fire. This probability corresponds with the actual result that, of the 114 fires for which data were collected, there were only four fires where the previous FRB was actually reported to have stopped the headfire. All four of these fires had previous FRB ages of less than three years.

The model indicates that the probability of there being an assisting effect decreases rapidly after about age 7 or 8, and declined to quite low probabilities by 12 to 14 years post-fire.

Part 2. Sample of fires from nine fire districts

Table 8 categorises fires where an effect of a previous fuel hazard reduction burn was noted on the Final Fire Report for nine Fire Districts. It shows the distribution of fires with FRB effect across the Fuel Management Zones. These nine fire districts, from a total of 24 available, were chosen because they represent a large proportion of the forested public land, and because spatial data was more readily accessible for these areas on the hand-drawn maps then available (since put on to GIS managed by NRE).

It should be noted that the total number of fires with a FRB effect for these nine fire districts is 152, but, for various reasons, detailed data could only be collected from 114 fires for inclusion in the first part of this study.

Table 8 Fires with FRB effect by FMZ for selected fire districts for the period 1990/91 to 1996/97.

Fire District	Total fires with FRB effect 1990/91 - 1996/97	Fuel Management Zone				
		FMZ 1	FMZ 2	FMZ 3	FMZ 4	FMZ 5
Upper Murray	9	2	0	6	0	1
Heyfield (incl. Maffra)	9	0	0	4	5	0
Horsham	28	0	20	2	6	0
West Port Phillip	29	7	12	4	4	2
Nowa Nowa	22	4	5	7	4	2
Orbost	14	6	3	4		1
Bairnsdale	24	12	1	10	0	1
Cann River	17	3	0	10	1	3
Total	*152*	*34* (22%)	*41* (27%)	*47* (31%)	*20* (13%)	*10* (7%)

Table 9 shows, for a sample of nine Fire Districts, the distribution by Fuel Management Zone of the total numbers of fires for the eight seasons from 1990/91 to 1996/97. It indicates that fires in FMZ 3 are by far the most common, followed by FMZ 2 and FMZ 4. FMZs 1 and 5 show roughly equal likelihood of occurrence (ignoring the relative area of each FMZ).

Table 9 Fire numbers by Fuel Management Zone for selected Fire Districts (1990/91 to 1996/97)

Fire District	**Fuel Management Zone**					***Total***
	FMZ 1	**FMZ 2**	**FMZ 3**	**FMZ 4**	**FMZ 5**	
Heyfield	4	9	33	23	8	*77*
Maffra	15	17	40	27	12	*111*
Bairnsdale	34	65	149	45	32	*325*
Cann River	22	24	106	21	25	*198*
Orbost	24	36	190	19	45	*314*
West Port Phillip	28	39	53	0	4	*124*
Upper Murray	5	14	65	11	17	*112*
Nowa Nowa	8	15	33	4	10	*70*
Horsham	3	18	22	95	32	*170*
Total	*143* (10%)	*237* (16%)	*691* (47%)	*245* (16%)	*185* (12%)	*1501*

Comparison of FMZ data

Comparing the general fire frequencies by FMZ as shown in Table 9, with the occurrence of fires assisted by a previous FRB by FMZ as shown in Table 8, a Chi-square test indicates a significant difference in outcome. That is, it indicates that the frequency with which fires are assisted by a previous FRB within the FMZs, is significantly different from the frequency of fires generally within the FMZs. The data indicate that there is a higher probability of a wildfire encountering a previous FRB in FMZs 1 and 2, and a lower probability of a wildfire encountering a FRB (or at least one which is likely to provide some assistance with suppression) in FMZ 3 than would be expected just by chance.

Although these two datasets are derived from a slightly different set of Fire Districts, the fire occurrence and fire management practices are broadly similar across all of these districts. The data are summarised in Figure 3.

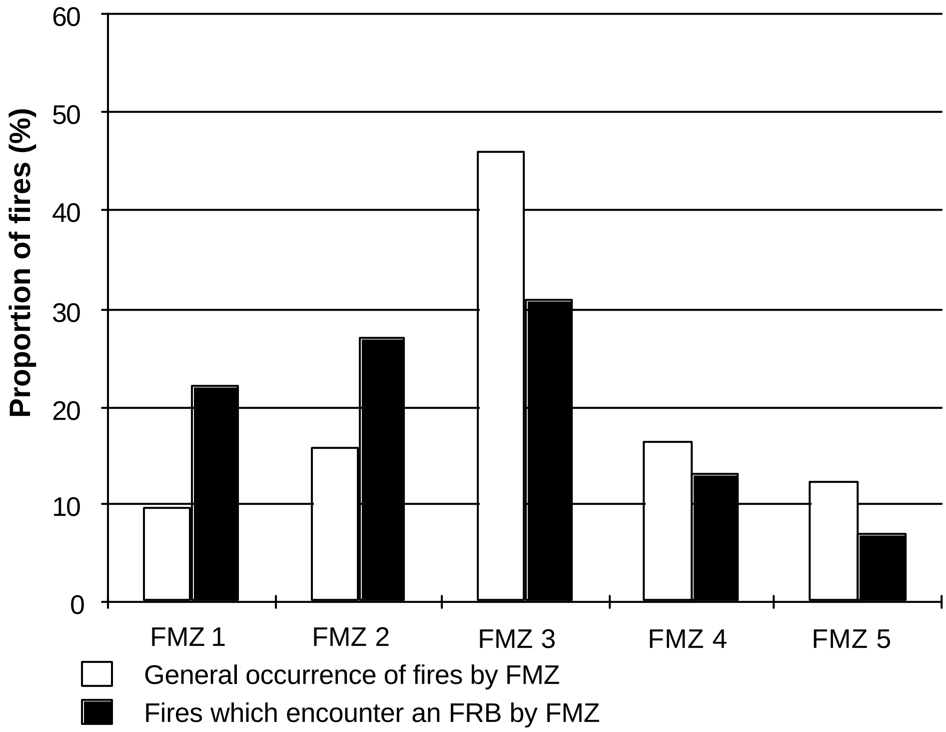

Figure 3 Comparison of the general occurrence of fires by FMZ and of fires which encounter a FRB by FMZ, as percentages.

Figure 4 shows the areas of each FMZ as a percentage of the total public land area for the ten fire districts in Gippsland (NRE 1999). Although it is based on Gippsland-only data, it gives a useful comparison for the percentages shown in Figure 3 for occurrence of fires by FMZ for nine more widely dispersed fire districts. This relative distribution of FMZs would not be representative of the Mallee region in NW Victoria, where there is no FMZ 1, and very little FMZ 2. For this reason, the NW region was not included in this study.

This comparison indicates that, although FMZ 1 only accounts for approximately 3.5% of the total area of public land, it appears to account for about 10% of the total fires. For FMZ 2, which comprises approximately 16% of the total area of public land, the general fire occurrence is approximately 16% (Table 9).

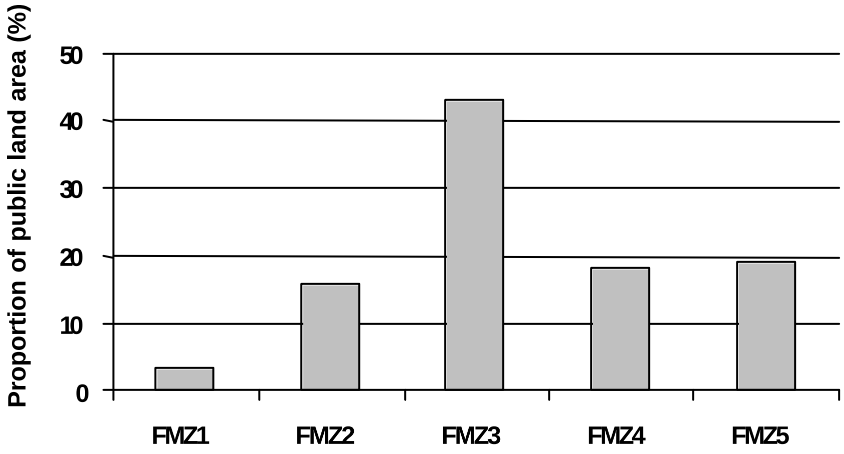

Figure 4 FMZ area by percentage of total area of public land for the ten fire districts in Gippsland.

Part 3. Statewide sample of fires

Overall FRB effect on public land

The following summary data (Table 10) were collected from the FIRES database. They indicate the total number of fires occurring on public land for each fire season since 1990/91, and also the number of fires for which an effect of a previous FRB assisting with suppression was noted on the Final Fire Report. Table 10 indicates that fires with FRB effect noted averaged 11% for this sample of seven consecutive fire seasons.

Table 10 Total fires on public land for seven consecutive fire seasons (1990/91 to 1996/97), and fires where suppression was assisted by a previous FRB effect (as noted on the Final Fire Report.

Fire Season	Total fires on public land	Fires with FRB effect recorded (% of total)
1990/91	558	61 (11%)
1991/92	412	42 (10%)
1992/93	160	20 (12%)
1993/94	258	22 (9%)
1994/95	471	57 (12%)
1995/96	266	27 (10%)
1996/97	300	38 (12%)
Total	***2425***	***267 (11%)***

The results given in Tables 8, 9 and 10 can be extrapolated across the State for an average fire season to see the effectiveness of each FMZ. If the total number of fires on public land for the seven fire seasons from 1990/91 to 1996/97 was 2425 as indicated by the FIRES database, then the annual average number of fires is 346. The FIRES database has also shown that around 11% of all fires encounter an area previously burnt by a FRB which assists in fire suppression (Table 10). If it is assumed that the distribution of fires across the State is similar to that in nine representative Fire Districts shown in Table 9, then around 10% of the 346 wildfires (35) will occur in FMZ 1, 16% of the 346 wildfires (55) will occur in FMZ 2 and 47% of the wildfires (163) will occur in FMZ 3 on average each year. Given that about 11% of all wildfires are likely to encounter a "helpful" FRB, then around 38 of the 346 wildfires should be easier to suppress because of a FRB. Again, assuming that the effectiveness of the FMZs is similar across the State to that of the nine representative Fire Districts shown in Table 8, then 22% of the 38 "helpful" FRBs should occur in FMZ 1, which represents eight of the 35 fires or 23% of wildfires in FMZ 1. Similarly, 18% of the wildfires in FMZ 2 and only 7% of the wildfires in FMZ 3 will encounter a FRB which will assist in fire suppression operations.

DISCUSSION

There are two aspects of this study which need to be considered. The first is the effectiveness of an individual FRB in assisting with suppression once a subsequent wildfire runs into it. The second is whether or not the current Fuel Management Zones are located in the right places to intercept potentially destructive wildfires.

Effectiveness of an FRB once encountered by a subsequent wildfire

That Overall Fuel Hazard level on the sites where a previous FRB assisted with suppression was never more than ***High*** appears to confirm the findings of previous work on Overall Fuel Hazard and first attack effectiveness (McCarthy *et al.* 1999, McCarthy and Tolhurst 1998). The evidence of all these studies strongly suggests, that sites which accumulate Overall Fuel Hazards of anything more than ***High*** offer little prospect of any assistance to suppression of a subsequently occurring wildfire.

The average age of the previous FRB in FMZ 1 areas was around five years (Table 7). This is somewhat less than the 10 year period suggested by Tolhurst *et al.* (1992) over which a previous FRB may provide useful reductions in bark and elevated fuel hazards. Tolhurst *et al.* (1992) also inferred that by five years post-fire, surface fine fuel hazards/loads would have easily re-accumulated to pre-burn levels. This suggests that the principal effect of a previous FRBs in assisting with suppression of subsequent wildfires in FMZ 1 is mostly in terms of reduced elevated and bark fuel hazards. This is almost certainly the case for FMZ 2 also where the average age of the previous FRB was around seven years.

The mean figures for Overall Fuel Hazard outside the final control line indicate that the type of fuel hazard reduction operations carried out in FMZ 1 and 2 areas have been more effective at maintaining levels of Overall Fuel Hazard of ***High*** or less. That is, these types of operations may have been, due to both higher fire intensities and higher fire frequencies, significantly more effective at reducing bark and elevated fuel hazards to the stage where Overall Fuel Hazard levels were likely to assist with subsequent suppression operations. The mean component fuel hazard level numerical scores of approximately 2.6 (***Moderate*** to ***High***) for Bark hazard, and 2.5 (***Moderate*** to ***High***) for Elevated fuel hazard for FMZs 1 and 2 support this (Table 5).

The single factor predictive model using the time since the last FRB or wildfire serves to enhance some trends which have been suggested by earlier work. In particular, the model indicates that the frequency of burning is very important to the usefulness of fuel reduction burning, and that the most obvious effects on subsequent wildfires are produced by FRBs which are no more than two to four years-old.

In the very few instances where a previous FRB actually stopped the headfire of a subsequent wildfire (only 4 fires out of 114), the age of the previous FRB was always less than 3 years. This is quite expected given the findings of Tolhurst *et al.* (1992), Chatto (1996) and McCarthy (2000) that surface fine fuel hazards re-accumulate to pre-burn levels within the first 2 to 4 years after burning for forests with extensive litter beds. It is likely that only a previous FRB of 3 years or less in age will have discontinuous surface fuels, and importantly, to the extent that they will not support a continuous surface fire.

The other important trend from this model is that FRBs any older than 10 years will have a very low probability of assisting with suppression. This concurs well with the findings of Tolhurst *et al.* (1992) in regard to reduced levels of bark and elevated fuels in Central Victoria. It seems likely that these results will apply more generally across the State, and particularly where substantial bark and elevated fuels are present.

The predictive model, using FDI and Overall Fuel Hazard to predict the probability of a previous FRB slowing the headfire of a subsequent wildfire, shows trends in relation to what is likely to occur as fire danger increases. It indicates that even for sites of ***High*** Overall Fuel Hazard or less, the probability of a previous FRB slowing the headfire of a subsequent wildfire, to a point which assists suppression, declines quite rapidly as FDI increases. There is a higher probability of a previous FRB slowing the headfire of a subsequent wildfire when FDIs are lower, while higher FDIs are more likely to give rise to uncontrollable fire behaviour even when fuel hazard levels are lower. More severe weather conditions and lower fuel moisture contents, which are able to negate the benefits of reduced fuel hazards, may explain this.

Another contributing factor may be that, at higher fire intensities due to higher FDIs, longer flame lengths are able to bridge the gap between surface fuels and unburnt bark fuels, particularly on sites where the bark has only been charred to 2 m or less (bark hazard ***High*** to ***Very High***). Future prescribed burning for hazard reduction may be more effective if more bark fuels further up the bole are burnt (thus reducing the bark hazard to ***Moderate*** to ***High***).

Effectiveness of the location of the FMZs.

The main implications of the results reported here are that, while there appears to have been a significant effect of previous Fuel Reduction Burns (FRBs) assisting with the suppression of wildfires in Fuel Management Zones (FMZs) 1 and 2, the results for FMZ 3 are inconclusive. That is, there was no clear strategic benefit from FMZ 3 - the likelihood of there being an assisting effect in FMZ 3 was no better than if burning had been located randomly across the forest. This probably relates to the frequency of burning which has been achieved in FMZ 3, which averaged just over 11 years for the fires analysed in this study (remembering also that this represents an "artificially" low mean figure for FMZ 3, because the sample for FMZ 3 deliberately included more than the expected number of fires which had some influence from a previous FRB).

It is possible that elevated and bark fuel hazards in many FMZ 3 areas, with inter-fire periods of 11 years or more, are re-accumulating to levels where they are unlikely to produce assistance with the suppression of subsequent wildfires. The mean numerical hazard score value obtained of 3.6 for Overall Fuel Hazard outside the final control line supports this, as this indicates an Overall Fuel Hazard rating of ***High*** to ***Very High***. Overall Fuel Hazards of this level are unlikely to be of any benefit to firefighters, and in fact substantially reduce the probability of first attack efforts succeeding (McCarthy and Tolhurst 1998).

The higher probabilities of assistance in FMZs 1 and 2 may also be related to both closer proximity of these zones generally to suppression force centres, as well as to the better access provided within them by the relative absence of elevated fuels.

The average of only 11% of fires on public land over the last decade having any influence from a previous FRB (as noted on the Final Fire Report) is a general concern. Given the emphasis which

NRE has placed on the implementation of Fire Protection Plans, and the consequent level of broadscale fuel hazard reduction burning undertaken, this level of 11% raises questions of just what constitutes an effective and lasting fuel hazard reduction prescribed burn. However the finding that fires in FMZs 1 and 2 have a relatively high probability of encountering a previous FRB indicates that they are well located, and effective if rotational burning is maintained.

Anecdotal information collected during this study indicated that some FMZ 1 and FMZ 2 areas may not have been rotationally burnt since the Fuel Management Zoning system came into place. That is, a combination of finite resources and relatively short prescribed burning seasons during the 1990s, may have led to planned FRB targets for FMZ 1 and FMZ 2 areas not being met.

This anecdotal information from Fire Management Officers also suggested that the level of fuel hazard reduction burning in FMZ 3 had never reached the original target levels set at the beginning of the Fire Protection Planning process in the late 1980s. This information further suggests that consistent under-achievement in FMZ 3 was a fact of operational life. Priority is given to burning in FMZ 1 and FMZ 2 where possible for obvious strategic reasons. In the light of this anecdotal information, it may be appropriate to review the way in which targets are set for prescribed burning for fuel management within the various FMZs, and particularly FMZ 3.

CONCLUSIONS

The following conclusions are prefaced by the acknowledgement that the results have been derived from a biased data set. Also, a retrospective type study approach was taken in order to provide advanced insights into the effectiveness of broadscale FRB on public land in Victoria. A classical experimental approach to investigate this complex and highly variable issue would have been exceptionally difficult and expensive, with results not available for many years, whereas qualified results from the present study can be immediately used to guide policy development and on-ground operational practice. It is likely that the qualified conclusions below are generally correct from a Statewide perspective, but further analysis of an expanded data set would be wise to confirm them.

Maintaining Overall Fuel Hazard levels at ***High*** or less by fuel hazard reduction, is significant in providing a situation where there will be assistance to the suppression of a subsequent wildfire. Levels of ***Moderate*** to ***High*** or less, as found in most FMZ 1 and 2 areas, give higher probabilities of there being an assisting effect. Models have been produced to illustrate this effect.

Increasing 'Fire Danger Indices' tend to reduce the probability of there being an effect of slowing rates of spread from previous fuel hazard reduction burning on most sites, even where Overall Fuel Hazards have been kept at ***Moderate*** or less. The predictive model constructed indicates that, on ***High*** Overall Fuel Hazard sites, the probability of a previous FRB slowing rates of spread drops to less than 50% at FDIs over 25.

The maximum period of usefulness of an FRB appears to be about 10 years, after which bark and elevated fuels add to surface fuels to produce fire behaviour which is not readily controllable. Effective fuel reduction in the future should be aimed at reducing particularly bark and elevated fuel hazards to produce the most lasting fuel reduction effects.

Prescribed burning for fuel hazard reduction has had a significant effect in assisting with the suppression of subsequent wildfires in Fuel Management Zones 1 and 2, with often between 20% and 50% of wildfires (depending on the fire district) in these zones encountering a previous fuel hazard reduction burn which can slow the headfire and assist with suppression.

In Fuel Management Zone 3, the general effect across this zone is such that only around 7% of wildfires in this zone encounter a previous fuel hazard reduction burn which is useful in assisting with suppression. Lack of effectiveness of previous FRBs in FMZ 3 appears to be mainly related to frequency of burning. This in turn could be related to either available resources to conduct FRB or limited opportunities for FRB due to unfavourable weather conditions during the prescribed burning seasons.

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REFERENCES

Billing, P. (1981) The effectiveness of fuel reduction burning. Five case histories. Fire Research Branch Report No. 10. Forests Commission Victoria. Nov 1981. 13pp.

Buckley, A. (1990) Fire behaviour and fuel reduction burning – Bemm River wildfire, October 1988. Fire Research Report No. 28, Dept. Conservation & Environment, Victoria. 25pp.

Chatto, K. (1996) Fuel hazard levels in relation to site characteristics and fire history - Chiltern Regional Park case study. Fire Research Report No. 43 Dept. Natural Resources and Environment, Victoria. 34pp.

Grant, S. and Wouters, M. (1993) The effect of fuel reduction burning on the suppression of four wildfires in western Victoria. Dept. Conservation and Natural Resources, Victoria, Fire Research Report No. 41, Dec 1993. 38pp.

McCarthy, G. J., Tolhurst, K.G., and Chatto, K. (1999) Overall Fuel Hazard Guide. Research Report 47. Fire Management. Dept. Natural Resources and Environment Victoria. 28pp.

McCarthy, G.J. (2000) Fuel hazard rating for forest fuels - surface fine fuel hazard. Research Report No. 44. Fire Management Branch, Dept. Natural Resources and Environment, Victoria. 30pp.

McCarthy, G.J. and Tolhurst, K.G. (1998) Effectiveness of fire-fighting first attack operations, NRE Victoria 1991/92-1994/95. Research Report No. 45. Fire Management Branch. Dept. Natural Resources and Environment, Victoria. 46pp.

NRE (1995) *Code of Practice for Fire Management on Public Land*. Dept. Natural Resources and Environment, Victoria. 38pp.

NRE (1999) Gippsland Fire Protection Plan. Prepared by McDonald, J. McI., Fire Management, Dept. Natural Resources and Environment, Victoria. 64pp.

Rawson, R., Billing, P., and Rees, B. (1985) Effectiveness of fuel reduction burning. Fire Research Report No. 25. Dept. Conservation, Forests & Lands, Victoria. 49pp.

Tolhurst, K.G., Kellas, J.D. and Wilson, A.A.G. (1992) Low intensity fire behaviour and fuel dynamics in dry sclerophyll forest, Wombat State Forest. **In:** Tolhurst, K.G. and Flinn, D.W. (1992) *Ecological Impacts of Fuel Reduction Burning in Dry Sclerophyll Forest*. Research Report No. 349. Forest Research, Dept. Conservation and Natural Resources, Victoria. 40pp.

Wilson, A.A.G. (1992) Eucalypt Bark Hazard Guide. Research Report No. 32, Fire Management Branch, Dept. Conservation and Environment, Victoria. 16pp.

Wilson, A.A.G. (1993) Elevated Fuel Guide. Research Report No. 35. Fire Management Branch, Dept. Conservation and Natural Resources, Victoria. 27pp.