Softwood Plantation Fire Synopsis

Compiled by:
Forest Fire Management Group (FFMG)

Endorsed by:
Australasian Fire Authorities Council Ltd (AFAC)

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Compiled by Forest Fire Management Group (FFMG) is a sub-Committee of the Forestry and Forest Products Committee which reports to the Primary Industry Ministerial Council

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On behalf of FFMG, I would like to thank the Forestry and Forest Products Committee (FFPC) of the Primary Industries Ministerial Council for its financial support for the project.

I am confident that this Softwood Plantation Fire Synopsis will be a valuable reference document for fire and land managers, land-use planners, plantation owners and companies, and fire researchers and students with interest in the fire protection and management of softwood plantations in the Australian and New Zealand landscapes.

Rick Sneeuwjagt

Chair, Forest Fire Management Group
November 2007

FOREST FIRE MANAGEMENT GROUP

(Sub Committee of Forestry and Forest Products Committee
of Primary Industries Ministerial Council)

Executive Summary

Softwood plantations play an important role in the economies of both Australia and New Zealand. As the pine species used in these plantations are relatively sensitive to fire, effective fire protection is an essential part of plantation management. This report summarises knowledge of how wildfires behave in softwood plantations, and of the actions that can be taken to protect both the forests and their adjoining communities.

Fire behaviour in softwood plantations varies with the age of the stand and the manner in which its silvicultural history has impacted on fuel loads. Generally speaking, the potential for medium and long distance spotting in softwood plantation fires is markedly reduced in comparison with eucalypt fires.

Rates of forward spread of wildfire in pine forests are similar to those encountered in eucalypt forest. In extreme conditions the rate of fire spread in forests is 30-40% less than wildfires burning in grassland or scrub. The biggest danger in softwood plantation fires is the formation of crown fire, which can cause a rapid increase in the rate of forward spread and the intensity of the burn. This sudden change in fire behaviour has serious implications for fire suppression and firefighter safety.

Planning for the protection of softwood plantations from wildfire should commence prior to establishment. Silvicultural treatments throughout the rotation should be linked with fire protection requirements where possible. Fuel reduction burning, pruning, thinning and crushing of slash can significantly reduce the level of hazard in plantations.

Public perceptions add another level of complexity to fire risk management, since pine plantations are seen by some people as adding to the overall level of wildfire threat in rural and regional communities. This review concluded that well managed softwood plantations pose no greater threat to communities than other forest or fuel types. As part of the risk management strategy, firebreaks should be at a width which, in addition to satisfy firefighter safety requirements and wildfire suppression objectives, reflects the likelihood and economic consequences of being breech by wildfires. This report stresses that the communities must recognise the need for effective fire protection actions in their own environment, to complement the fire suppression resources provided by forest protection agencies. Effective partnerships are required to ensure effective fire protection for both parties.

The rapid increase in Australia’s plantation area expected over the next two decades will see many softwood stands planted on cleared agricultural land that has previously carried predominately grassy fuels. This dramatic change in vegetation cover is creating new fire management issues related to fire behaviour, fire suppression and firefighter safety. For this reason, there needs to be a continuing strong focus on strategic planning of softwood plantations that recognises the risk of wildfire to the plantation as well as its neighbours.

1. Introduction

Softwood plantations form an important component of the economic bases of both New Zealand and Australia. However, wildfire can be a significant factor affecting the financial returns from the plantation estates in each country and, particularly in Australia, softwood plantations are seen by some people as adding to the overall level of threat from wildfire in rural and regional communities.

It is also true that, just as some people enjoy the amenity that comes with living close to a native forest or other natural areas, many people enjoy the amenity that comes with having ready access to softwood plantations, particularly when they are near maturity. This appreciation of the forested environment may impose considerable constraints on the forest manager in terms of harvesting activities for reasons of their visual impact, but it may also increase pressure on the forest manager with respect to fire protection. Community expectations can vary from *"I like it as it is so despite the hazard, I do not want anything done because it would impact on my use of the forest"*, to *"This forest is an unacceptable hazard next to my property so I want more fire protection work done."* These sort of competing demands on forest managers whose estate is adjacent to communities are very common, the community sometimes ignores the fact that often the forest was established prior to the community establishment. In such circumstances, resolving the competing demands is not easy, but resolution does not come from placing the entire onus on the forest manager. Just as a wildfire from softwood plantation may burn an adjoining estates, so a wildfire arising from within from the adjoining estates may burn the plantation. Protecting both the community and the forest, be it softwood plantation or otherwise, requires cooperation between, and contributions from, all affected parties.

During January 2003, large areas of native forest, grassland and softwood plantation were burnt in the Australian Capital Territory (ACT) but, much more significantly, four people died and approximately 460 houses (Ellis and Sullivan 2003) were destroyed or damaged. The perception of some people is that the fire in the softwood plantations was more severe than in previous occasions, and that it contributed in a more significant way to the losses in the broader community. Views concerning contribution of softwood plantations to the losses incurred include the following:

- *If the plantation hadn't been there, the losses would not have been as substantial.*
  or
- *If the plantations had been managed differently, or been at greater distances from urban communities, the losses would not have been as high.*
  or
- *The plantations made no significant contribution to the losses because during days of Extreme Fire Danger urban losses are independent of adjoining fuel types.*

The purpose of this paper is to examine the validity of such proposition by reviewing fire protection relating to softwood plantations in the rural landscapes of both New Zealand and Australia.

1.1. Background

As early as the 1960's, DR Douglas from South Australia and AG McArthur from the ACT were examining fire behaviour in softwood plantations, and the practices that might increase there level of protection from wildfire. This document is based upon an extensive examination of the relevant New Zealand and Australian literature. It has also had a peer review by knowledgeable wildfire scientists in Australasia, as well as representatives of some of the major softwood plantation managers in both countries.

The nature of softwood plantation estate, particularly in Australia, is still changing. In both Australia and New Zealand, ownership of particular softwood plantations has often transferred from the public to the private sector over the last 10-20 years, and that transfer is likely to continue. With a change in ownership will often come a change in the legislative responsibility for fire protection. In Australia, more plantations are now being established on already cleared farmland rather than on areas converted from native forest. Rural communities have expressed concerns that these changes are increasing the level of threat from wildfire for a number of reasons, including:

- The perception of increased fire hazard associated with the presence of softwood plantations compared with grassland.
- The possibility of reduced workforce availability because a long-rotation crop replaces short rotation crops or grazing.
- The possibility that the skills available to manage wildfires in softwood plantations are dissipated as the workforce changes.

The possible impact of the changes outlined above within Australia has been recognised by Gould *et al.* (2001) as follows:

> *"Effective fire protection is an essential part of plantation management in fire prone regions of Australia. The 2020 vision for plantations in Australia envisages a trebling of the national plantation estate during the next two decades, and in many regions plantations are being established on cleared agricultural land. Establishing plantations on agricultural land that has carried predominately grassy fuels for many decades is creating new fire management issues related to fire behaviour, fire suppression and firefighter safety."*

1.2. Report Context

Before presenting a summary of the available evidence, and indicating what that evidence might mean for the protection of both softwood plantations and their adjoining communities from wildfire, there are four important contextual issues that need to be considered:

- *Although the benefits and costs of investing in various fire prevention and fire suppression strategies are important considerations for plantation managers, and the communities within which they operate more generally, discussion of this issue falls outside the scope of this document*

- *The size of a plantation unit, and the size and scale of the plantations owned by an individual, company or government agency, will have a significant influence on the capacity of the owner to undertake or participate in fire prevention and fire suppression programs in, or adjoining, the plantation.*

- *The fire climates in which softwood plantations are established in New Zealand and Australia vary enormously, and the risk to a softwood plantation from wildfire may vary significantly from region to region. The actions required to protect a particular plantation will vary with the risk that is considered to be present in the region concerned.*

- *Although the fire climates in which softwood plantations are established vary considerably, and the risk of wildfire to a particular plantation may vary accordingly, what role should the fire climate play in determining the level of protection provided to adjoining communities? This is a key question that needs to be answered. We will see later that at least some of the planning tools that are used to determine the separation of a plantation from a community, or vice versa, provide for variable levels of fire protection based upon judgements of the 'local fire climate.'*

Note that references throughout the paper to levels of Fire Danger or the Fire Danger Index (FDI), refer to those described by the McArthur Mark 5 Forest Fire Meter (See Section 8.1) unless otherwise indicated.

1.3. The Objective

This document has been prepared to provide a summary of the knowledge of the way in which wildfires behave in softwood plantations, and of the actions that can be taken to protect softwood plantations and their adjoining communities from wildfire. In particular it is designed to:

- Provide an understanding of the level of involvement of softwood plantations in wildfires in Australia and New Zealand.
- Provide an overview of how wildfires behave in softwood plantations, and how that behaviour compares with wildfire behaviour in other significant forest and fuel types.
- Describe and compare various management practices that may improve the protection of softwood plantations from wildfire.
- Discuss issues associated with wildfire suppression in softwood plantations.
- Discuss issues related to softwood plantations and fire protection of the urban/rural interface.

2. The Softwood Plantation Industry in Australia

Although areas of softwood plantation already existed in Australia, significant new softwood plantation establishment occurred with the assistance of Commonwealth loan funds during the 1960's and 1970's, and State Government-owned plantations increased significantly in extent around the country. Most of these new areas came from the conversion of areas of native forest and, in at least some areas, the conversion practices left large volumes of heavy eucalypt fuels in place, creating subsequent access problems for both timber harvesting and wildfire suppression.

The National Forest Policy Statement (NFPS) (Commonwealth of Australia, 1995) was formulated in the early 1990's, and all governments had signed the policy by 1995. Although it has a major focus on the management of Australia's native forests, the NFPS also provided a new focus for plantation management and development. For example:

> *"One goal* (of the Governments) *is to expand Australia's commercial plantations of softwoods and hardwoods so as to provide an additional, economically viable, reliable and high-quality wood resource for industry."*

> *"The Governments recognise that, to ensure a reliable supply of wood from plantations as feedstock for world-competitive processing plants, large areas of plantation, such as those normally planted by private industrial and investment companies or public forestry agencies, are necessary. Accordingly, State and local governments will provide a planning framework that facilitates the development of large-scale industrial plantations."*

> *"All States share the policy, consistent with ecologically sustainable management, of not clearing public land for plantation establishment where this would compromise regional conservation and catchment management objectives."*

Plantations for Australia: the 2020 Vision (Commonwealth of Australia, 2002) arose as a consequence of the policy framework established by the NFPS. In essence the Vision set out to:

> *"...enhance regional wealth creation and international competitiveness through a sustainable increase in Australia's plantation resources, based on a notional target of trebling the area of commercial tree crops by 2020."*

Although first launched in 1997 the Review, published in 2002, indicates that:

> *"More than half a million hectares of new plantations have been established since 1997 - an average planting rate of around 85,000 hectares per annum. The majority of these plantings are hardwood (eucalypt) plantations .... In the softwood (pine) sector, most planting has been in second rotation forests to replace trees already harvested, with around 11,000 hectares per annum of new pine forests established since 1997."*

Other information from the 2002 document indicates that:

> *"The existing plantation forest estate has underpinned the attraction of substantial investment in the forest-based processing industries, in turn bringing employment growth to rural and regional Australia. The Department of Agriculture, Fisheries and Forestry estimates total employment in the forestry sector to be approximately 78,400 jobs; .... and ....the sector comprises a significant proportion of employment in the regionally-based forest industries."*
>
> *"Plantations supply over 70% of sawn timber produced in Australia, yet they comprise less than 1% of land area. In 2000-01, the value of products manufactured from timber grown in plantations was estimated at* (Aus)*$6.3 billion, including* (Aus)*$2.2 billion in paper and paperboard products."*
>
> *"Since 1997, around* (Aus)*$1.5 billion has been invested in plantation establishment, and* (Aus)*$1.01 billion in plantation-related processing infrastructure in the sawmilling, paper manufacturing and wood-based panel industries."*

The National Plantation Inventory (Parsons *et al.* 2004) shows that, as at December 2003, the total area of softwood plantations in Australia was approximately 988,000 ha of which approximately 55% was in full public ownership, compared with a total area of 676,000 ha of hardwood plantation of which only approximately 11% was in full public ownership. It also says:

> *"Although the total plantation estate continues to expand steadily, the area of new plantations being established has been less each year since the exceptionally large area established in 2000. The five-year average also declined – from 87,000 ha/year in the five years to 2002, to 82,000 ha/year in the five years to 2003."*

Tables illustrating the ownership of the trees, the ownership of the land on which the plantations are located, and the distribution of plantations by State and Territory are shown in the Inventory.

A breakdown of the plantation area by species is available as at September 2000 (Wood *et al.* 2001) and the major species and species groups, sourced from that reference, are shown in Table 1.

Table 1. Australian Softwood Plantation Areas, September 2000

Species	*Pinus radiata*	*Pinus elliottii*	*Pinus caribaea*	*Araucaria spp*	*Pinus pinaster*	Other species	**Total**
Area (ha)	716,543	78,758	57,847	46,588	39,614	32,815	**972,165**
Percent	73.7	8.1	6.0	4.8	4.1	3.3	**100**

Source: Plantations of Australia – A Report from the National Plantation Inventory and the National Farm Forest Inventory.

At the end of 2003, Australia had a total area of approximately 676,000 ha of hardwood plantation, with 37% of the area in Western Australia and 22% in each of Tasmania and Victoria. Hardwoods now constitute about 41% of the total plantation area in Australia, compared with 39% in 2002 and 15% in 1994. (Parsons *et al*. 2004).

3. The Softwood Plantation Industry in New Zealand

As at April 2002, New Zealand had a total softwood plantation area of approximately 1.81 million ha, nearly 90% of which was *P radiata*. (New Zealand Forest Industry, 2004) The areas of softwood plantation, and the contribution of species and/or species groups to the total area, are shown in Table 2. Only about 8% of the plantation area is managed by government or government-related bodies.

Table 2. New Zealand Plantation Areas, April 2002

Species	*Pinus radiata*	Douglas Fir	Other exotic softwoods	All exotic hardwoods	Totals
Area (ha)	1,622,000	104,000	34,000	54,000	1,814,000
Area (%)	89.4	5.7	1.9	3.0	100

Source: Derived from New Zealand Forest Industry – Facts and Figures 2003/2004

The industry based on this extensive plantation estate exported forest products with a value of about NZ$3.7 billion in the year ending March 2003, with the forestry sector contributing approximately 4.0% to GDP each year.

Plantations occupy approximately 7% of the total land area of New Zealand. Over 90% of the plantation area is privately owned, and the forest industry sector directly employs in excess of 25,000 people.

4. Fire Sensitivity of Softwoods

Softwood species used in plantations in Australia and New Zealand are relatively sensitive to fire, although the impact of fire on an individual tree will vary with the species concerned and the characteristics of the fire itself.

> *"The sensitivity of trees to fire depends not only on the protective mechanisms of the tree, but also on the characteristics of the fuel bed typically accumulated within the stand and the type of fire it supports under any given set of conditions."* **(**Cheney and Richmond 1980)

The impact on the tree may be such that the tree dies, that a significant loss in growth rate occurs and also that the quality of the wood produced from the tree is adversely affected. While it is usual to think in terms of fire intensity to characterise the type of fire that has occurred, fire intensity alone does not adequately describe the potential impact of a fire on a plantation or individual trees within a plantation.

> *"Recent work has shown that whilst fire intensity is useful to characterize some forms of damage it does not necessarily relate to stem damage. The heat pulse affecting the base of a tree and likely to cause fire scarring at the trunk is primarily a function of total heat output of the fuel and not the rate of heat output and is therefore related to the total fuel consumed near the tree........ Scorch and damage to the upper stem is related to the rate of heat output and is therefore closely correlated with flame height. Fire intensity as expressed in terms of the rate of energy released per unit length of fire front (kW/m) does not adequately describe the distribution of heat released behind the leading edge of the fire....... Thus a light fuel bed with a high combustion rate, such as grass, will produce a fire which has high spread rates, high flame heights and a low flame depth but can have a comparable intensity to a fire in a compact heavy fuel bed with a low combustion rate. The latter will produce a fire with low spread rates, low flame heights and either a large flame depth or a large zone of smouldering combustion behind the flame front. Although the same heat is released the structure of the combustion zones is quite dissimilar and the effects on the vegetation will be quite different."* (Cheney and Richmond 1980)

Woodman and Rawson (1982) mention work described by Billing (1980a) that supports the view that fire intensity alone is an unsuitable descriptor of the likely extent of damage to a softwood plantation.

> *"The importance of factors other than bark thickness and the intensity of the flame front in minimising damage is shown by the results of clear felling during 1980 of a section of the Mt Franklin plantation. The stand* (of <u>P radiata</u>) *was 18 years old when burnt by low intensity wildfire, with flame heights generally less than one metre, in January 1969. During felling extensive damage became apparent, including fire scars to heights of 5-7m and extending on average, depending on tree size, around 22% to 46% of the circumference at stump height. It is probable that increased fire residence time, caused by dry heavy fuels, and the lower moisture content of the inner bark likely during summer were contributing factors."*

4.1. Fire sensitivity of radiata pine

> "P radiata *is a fire sensitive species. It dies if the whole crown is scorched and in most stands this occurs when the fire intensity is less than 2500kW/m."* (Cheney 1985)

Nicholls and Cheney (1974) examined the effects of fires with a considerable range of intensity on both *P radiat*a and *P pinaster*, with at least some fires being of an intensity greater than those considered acceptable for prescribed burning. The stand ages studied in *P radiata* were approximately 28 years and 44 years old. The study results included:

> *"Although 11 percent of the total number of boards exhibited fire damage, the reduction in sawn volume as a result of this agent* (fire*) was only 0.4% of the total possible sawn volume."*
>
> And:
>
> *"A fire which removes the fine fuels up to 6 mm in diameter, and only a small proportion of the larger fuels, would suitably reduce litter accumulation for protection purposes and could have a maximum intensity of less than 200 kW/m. From the results reported herein such a fire would be unlikely to cause significant damage to a stand of this age."*

Peet and McCormick (1971) reported that low intensity prescribed burning under pole-sized *P radiata* in Western Australia had no effect on girth increment in the two years following burning. However, fires that resulted in crown scorch to within 0.5 m of the apical growing tip produced marked reductions in girth increment. Partial scorch did not cause significant growth loss provided that trees retained at least three metres of green tip. These experiments were conducted during winter and the high scorch was achieved because the elevated fuels were dry. Scorch to this extent in summer or autumn would normally result in considerable tree mortality as a result of damage to the cambium near ground level.

Woodman and Rawson (1982) summarise work done in Victoria from the mid-1970's to early 1980's concerning the impact of fuel reduction burning in *P radiata*. The following extract indicates that, at fuel reduction burning intensities, the impacts on stands just before or at the age of first thinning are insignificant.

> *"In a trial established in the 11 and 16 year old stands used by Thomson (1978), Woodman (1981) found that 4 years after* (fuel reduction) *burning there were no significant differences .... between diameter increment and stem mortality on burnt and unburnt plots, even though most of the plots had by then been burnt twice and in some instances three times. Similarly, Billing (1980b) found no significant difference ..... two years after burning between the mean diameter increment of trees on areas where first thinning slash was burnt and trees on adjacent unburnt areas. Even trees visually classified as severely burnt showed no loss of increment."*

"Billing (1980) described a fuel reduction burning operation in first thinning slash in which some areas of crown scorch occurred. Approximately one year after burning, both dominant and co-dominant trees which had more than 50% of their green crown depth scorched had a mean diameter increment significantly less .... than trees which were not scorched. The mean diameter increments were 59% and 38% of the increments of unscorched dominants and co-dominants respectively. There was no difference between trees with less than 50% scorch and those without scorch (Billing, 1981)."

This later work supports the earlier views of Nicholls and Cheney (1974) that:

"Prescribed burning may therefore be used for these two important species (P. radiata *and* P. pinaster) *without prejudice to growth rate or density characteristics."*

The importance of moisture levels in the duff layer on determining fire intensity, and therefore the potential for significant damage to the plantation is also emphasised by Woodman and Rawson (1982).

"The BKDI is related to the moisture content of these fuels (heavy fuels and the duff layer) *and the importance of this relationship to the quantity of available fuel, and hence fire intensity, is shown in* (Table 3, derived from McArthur and Cheney, 1966 and McArthur 1966). *The results were obtained from a series of experimental fires in a 23 year old radiata pine stand. At indices greater than 100 substantial quantities of heavy fuels were burnt and fire intensities increased dramatically."*

Table 3. The Byram-Keetch Drought Index (BKDI)* and Fire Intensity

BKDI	Fire Intensity (kW/m)	Fuel Consumed** (t/ha)
48	231	7.0
54	290	6.5
120	1868	23.6
268	3875	34.7

Source: Woodman and Rawson (1982) after McArthur and Cheney (1966) and McArthur (1966)
* The BKDI as measured in 'points' of rain.
** The total amount of fuel consumed.

4.2. Fire sensitivity of maritime pine

In the period from 1967 to 1972, McCormick (1976), examined the effect of crown scorch from prescribed burning on growth in 17 and 38 year old *P pinaster* stands in Western Australia, and he found *"a marked deterioration in growth rate which persisted for several years was related to the severity of crown damage."* It was three to four years before growth rates of the scorched trees returned to normal.

His conclusion from the study was, effectively, that properly conducted prescribed burning, which results in either no scorch or very limited crown scorch, would not have a negative impact on growth.

> *"Green-crown height reduction by burning in maritime pine is followed by several years reduction in girth increment, but where branch-kill is limited to the lower crown, the detrimental effect appears to be negligible. It is doubtful, therefore, whether light crown scorch in which no branches are killed can result in loss of tree growth."*

This finding was consistent with the earlier studies of *P pinaster* conducted by Peet and McCormick (1971).

After a large wildfire in the Gnangara plantation in Western Australia on 30 December 1994, Burrows *et al.* (2000) found that *"All* P. pinaster *trees that were defoliated or fully scorched by the fire died, but trees with more than 2m of green crown tip survived. In stands that carried heavy needle bed fuel loads, low intensity backfires killed large mature trees* (the stands burnt were aged from 30-43 years old) *by girdling the stems near ground level."*

Nicholls and Cheney (1974), in the study mentioned earlier, found that in relation to *P pinaster* there was *"no overall observable influence of burning treatment on average* (wood) *density."*

4.3. Fire Sensitivity of slash pine

The Department of Forestry, Queensland (1976) comments on the work done in relation to the effects of fuel reduction burning on *P elliottii* as follows:

> *"All experiments have been consistent in the finding that there is no increment disadvantage caused by* (prescribed) *burning except where crown scorch occurs. Growth loss due to scorching is directly related to the proportion of the crown which is defoliated by scorching. Properly supervised and conducted, prescribed burning can be done with a minimum of scorch, and whereas scorch may be undesirable and it must remain the objective to keep it to a minimum, its only significant effect is a short-term reduction in growth."*

Hunt and Simpson (1985) compared the effects on growth and nutrition of prescribed burning every three years in *P elliottii*, over a ten year period, in south east Queensland and, compared with areas that had not been burnt, they found *"no overall differences in diameter or height growth ..... .between treatments."* The prescribed fires had maximum intensities of 203, 138 and 106 kW/m in each of the years when burns were conducted.

4.4. Summary comments

- Softwood plantations are fire sensitive. Of the major New Zealand and Australian species, *P radiata* is the most sensitive to fire while *P pinaster*, *P elliottii* and *P caribaea* are more fire resistant. There is nothing published that compares the relative sensitivity of each species, but Cheney[1] (*pers comm.*) considers that the order of decreasing sensitivity is *P radiata* followed by *P elliottii*, and then *P pinaster* and *P caribaea* grouped as being similar in their resistance to fire.
- Fire intensity alone does not determine the damage to a stand or an individual tree. Increased residence time as a fire burns in relatively dry heavy fuels or duff layers will increase the likelihood of significant stem damage.
- At fire intensities typically used for fuel reduction burning in softwood plantations (200-300 kW/m) there should be no significant impacts on growth or stem damage (and subsequent sawn timber quality), provided also that the heavy fuels and duff layer do not ignite.
- Crown scorch will typically reduce stand growth in all species, with the extent of crown scorch determining the magnitude of the impact.

[1] P Cheney CSIRO Honorary Research Fellow, Canberra, ACT.

5. Plantation Fire Statistics

"The plantation forestry sector does require accurate statistics on areas and values lost to fire because:

- *That detailed information is a fundamental part of normal forest asset management.*
- *They will provide an accurate basis for future evidence-based forest fire insurance premiums.*
- *They will contribute to the long-run justification for fire protection expenditure.*
- *They will contribute to the on-going analysis of total wildfire threat.*
- *Forest valuations and annual harvest programmes are based on accurate area data.*

Also, fire managers should be able to analyse this statistical information, along with data on the cause and source of fires, to improve their overall rural fire management processes." (Cameron 2001).

Despite the need for good information on the incidence and extent of fires associated with softwood plantations, it is very difficult to understand the relationship between fires in the rural landscape and softwood plantations. There is often debate about whether or not softwood plantations have altered the fire load in a particular locality, but the reality is that there are no data that allow any reasonable consideration of this issue. The data required are those for wildfire numbers and extent before and after the plantation was established, and these data simply do not exist.

From the records that are available, (See Appendix 2, Table 1) lists the major plantation fires that have occurred in New Zealand and Australia, and the available records have also been used to provide some information for each jurisdiction. Summary of the data in Table 1, Appendix 2 indicates that the losses of softwood plantation due to wildfire are as low as 0.07% of the total estate per annum, in New Zealand, to as high as 0.4% of the total estate per annum, in Western Australia and Queensland.

5.1. Australian Capital Territory

"The January 2003 fires in the ACT destroyed 10,500ha of pine plantations, with a standing timber value of (Aus*) $56.142 million, making it the second largest softwood plantation loss* (in Australia) *on record. It is important however to keep the 2003 loss in perspective, both in terms of Australian plantation losses and the pre-2003 experience in the ACT. Before 2003, about 2500 hectares of plantation* (in the ACT) *has been destroyed over an 80 year period, which is an average loss of about 30 hectares a year."* (Bartlett 2004)

5.2. New South Wales

Data collected by State Forests NSW shows that for the seven-year period 1996/97 to 2002/03, State Forests responded to 1379 fires of which 1136 (82.4%) originated in native forest and 243 (17.6%) within softwood plantations. The total area burnt in all land categories by all fires was at least 576,000 ha because significant areas of the Kosciusko National Park that were burnt in early 2003 are not included in the available figures. During the period concerned, approximately 2,000 ha of softwood plantation (both publicly and privately owned) were burnt.

Although the losses of softwood plantation are comparatively small, the data do not allow an analysis of the relative contribution to total area burnt by fires originating in softwood plantation compared with fires that originated in native forest. However, Forests NSW (2003) provides further information as the following extract shows:

> *"In terms of historical losses in plantation areas as compared with non-plantation areas….. there is no evidence that house/agricultural infrastructure losses are greater in plantation areas than in non-plantation areas….. Large plantation fires, which emerge from plantations into agricultural areas are very rare."* (See Appendix 2 for further comments on specific plantation areas within NSW.)

5.3. Queensland

The Department of Forestry, Queensland has attended an average of 96 fires each year over the past 23 years, with 68 on average burning native forest and other areas, while 28 burnt softwood plantation as well as other areas. Those fires that affected softwood plantations burnt an average area of 635 ha/yr of softwood plantation although not all of the plantation areas burnt would have been totally lost. Although accurate figures on total losses are not available, the loss due to wildfire is estimated to be less than 0.5% per annum.

5.4. South Australia

The Forest Owners Conference (FOC) involves nine major plantation growers in the Green Triangle on the border of South Australia and Victoria. In 2002 this area comprised some 300,000 ha of land managed primarily for the production of hardwood and softwood products. The FOC (2003) has produced guidelines to assist in protecting these plantations from fire and in her Foreword, the Chairperson, Ruth Ryan, says, *"These guidelines have stood the test of time. Since their adoption by FOC members in 1986, these guidelines, along with other fire prevention measures have contributed to the reduction of plantation area lost in fires to less than 0.1% per annum."*

Statistics available from Forestry South Australia from 1974/75 to 2003/04 indicate that the average area of softwood plantation burnt was 97.6 ha/yr or approximately 0.1% of the total plantation area each year.

5.5. Tasmania

Statistics for the ten year period from 1994/95 to 2003/04 show that the average area of softwood plantations burnt was 68 ha/yr which is 0.1% per annum of the total estate.

5.6. Victoria

Data collected over the 31 years from 1973 to 2003 indicates that the Department of Sustainability and Environment (DSE), and its equivalent agencies in earlier years, attended an average of 516 fires each year on land it manages, with each fire burning an average area of 203 ha. Of the 516 fires each year, on average 12 commenced in State-owned softwood plantation, or plantation that was originally owned by the State. The fires that did not originate in softwood plantation burnt an average area of 207 ha, while the fires that did originate in plantation burnt an average area of 51 ha.

For the 27 year period from 1973 to 1999, Tolhurst (2001) indicates the loss of State-owned softwood plantation averaged 0.15% pa of the total softwood plantation area.

5.7. Western Australia

Over the 18 year period from 1984/85 to 2002/03 the average annual area burnt in softwood plantations managed by the Department of Conservation and Land Management (CALM)(or its successors) was approximately 250 ha, or an average of 0.4% per annum of the total plantation estate. Many of the fires were caused by arson in the Gnangara plantation, with Burrows *et al.* (2000) indicating that *"Over the last 5 years, CALM has attended 222 wildfires in the* (Gnangara) *plantation of which 156 were suspected arson."*

5.8. New Zealand

Information provided by the National Rural Fire Authority of New Zealand for the period 1998/99 to 2003/04 shows that the average annual area of forest burnt over the period was approximately 248 ha. The average annual total area burnt within the rural landscape was 7879 ha from an average of 3689 fires. Although the area of plantation forest is not separately identified, *"the vast majority of the area of forest burnt would have been softwood plantation."*

For 2000/01, Cameron (2001) provides an estimate of 516 ha of forest burnt across the whole of New Zealand in one of the drier seasons on record. Even though the loss of area was obviously small in relation to the total extent (approx. 1.81 million ha) of softwood plantation in New Zealand, Cameron estimates the financial loss to be as high as NZ$3.2million.

Pearce[2] (*pers comm.)* has provided information that shows that from 1936 to 2003 approximately 40,000 ha of 'exotic forest' were burnt in New Zealand, which is an annual loss of approximately 600 ha or 0.13% of the planted area. Over the last decade the annual loss has reduced to approximately 470 ha, or 0.07% of the planted area. A major forest fire has occurred nationally about once in each decade.

Cameron (2001) noted that *"the plantation forestry sector in New Zealand has a small and declining loss from wildfire, but the statistics mask the potential for extreme fire weather conditions to contribute to or escalate a major plantation fire incident.*

[2] G Pearce Fire Scientists Ensis-SCION, Christchurch, New Zealand

The sector also needs to maintain or improve its current levels of skill and interest in rural fire training and rural fire management for such a state to continue."

5.9. Summary comments

- Consistent and comprehensive data are not available to describe the occurrence, cause, origin and extent of areas burnt in softwood plantations by wildfire.
- No data exist to allow ‘before and after’ comparisons of occurrence in areas where softwood plantations have been established.
- From the data that are available, losses of softwood plantation due to wildfire in the jurisdictions concerned vary from 0.07% to about 0.4% - 0.5% of the softwood plantation estate per annum.
- Victorian data from the last 31 years indicate that fires that have originated in softwood plantations have burnt less total area, on average, than fires that burnt softwood plantation where the origin was outside the plantation boundary. Good access to softwood plantations and effective first attack arrangements are probably the reasons for this result.
- New Zealand has a very low and declining incidence and extent of softwood plantation fires.

6. Softwood Plantation Fuel Characteristics

Fires in softwood plantations will be affected by the factors of fuel, weather and topography that influence the behaviour of all fires, be they prescribed fires or wildfires. In relation to plantations, Gould *et al.* (2001) describe the influence of plantation fuels as follows:

> *"One of the important factors determining the fire hazard and behaviour of fires is the amount of fuel that is available to burn under the prevailing fire weather conditions. This depends on both fuel moisture and fuel characteristics (ie. structure, composition, continuity and load) that have developed since the establishment of the plantation. The rate of fuel accumulation is important in:*
> - *Determining the fuel loading, and thus the potential rate of spread and intensity of bushfires at any time during the plantation rotation*
> - *Determining the changes in the fuel quantity and structure over the rotation of the plantation and following thinning and harvesting operations*
> - *Difficulty of suppression at different stages of fuel development in the plantation, and*
> - *Determining the changes in bushfire threat or hazards of forest plantations in the region."*

Softwood plantations will generally have rotations of from 30-40 years. During the rotation, the fuel loads and fuel arrangements will change as various silvicultural treatments, including pruning and thinning, are applied before final harvesting. Tolhurst (2001) provides a simple but useful description of the changes that occur in the fuels through time as follows:

The predominant fuels in each time period are:

0-4 years;	*Slash, grass and shrubs*
4-8 years.	*Grasses, shrubs and the developing pine canopy*
8-15 years.	*Needle bed, suspended needles in the lower crown and the pine canopy*
15-40 years.	*Needle bed and canopy*

The Country Fire Authority, Victoria (CFA 1999) provides more detailed descriptions of the changes in fuel structure occurring through a rotation, and the links between the fuel load, fuel arrangement and wildfire behaviour.

Fuel development is influenced substantially by the site conditions at the time of establishment. Plantations established in Australia on cleared native forest sites often retain a substantial component of understorey shrubs that have re-established from the soil seed store or persistent rootstocks. Native shrubs may form a dense layer of elevated fuel in the early years leading up to canopy closure. Where plantations have been established on sites converted from pasture or cropping, the predominant fuel is annual grass and there is little development of an elevated fuel layer. At a localised scale, fuel development in young plantations is also affected by establishment techniques such as mounding and ripping. Needle fall accumulates along the gutters on either side of the mounds, while the tops of mounds may remain bare for up to five years after planting.

In young second rotation plantations, harvesting slash is commonly mulched or treated with a chopper-roller. This results in a compacted layer of fine and coarse fuels, often quite fragmented as a result of treatment. In the Blackwood Valley plantations of Western Australia, Ward and Walsh (1988) found that burning the slash created by final felling of first rotation stands led to the regeneration of a dense understorey of native shrubs, creating a substantial fire hazard during the early years of the second rotation.

Table 4, in Section 7.1.4, provides some insight into how changes in plantation age and structure may influence wildfire behaviour under Very High to Extreme Fire Danger, and observations from other wildfires have provided further evidence. For example, in his analysis of the Millbrook Fire of 8 March 1990, Pratt (1990) noted that, under conditions of Very High to Extreme Fire Danger:

> *"1984 and 1985 plantations, although grazed, carried sufficient continuous fuel to burn readily. However, well grazed 1987 plantation, did not carry fire. A few spot fires were observed in the 1987's* (sic) *but neither spot fires nor elevated fuels provided the continuity to allow these spots to develop."*

In the extensive fires of Ash Wednesday (16 February 1983) in South Australia, Keeves and Douglas (1983) noted:

> *"Fuel quantities in the pine plantation areas varied markedly from plantation to plantation. The areas where the fires were most intense had been either recently thinned or were awaiting first thinning. Fuel quantities were very high and, in some cases, well distributed vertically."*

> *"In old multi-thinned stands in both the South-eastern and Central Regions, crown fire formation was only intermittent. This usually occurred where patches of seedling advanced growth provided a 'ladder' into the crowns of the quite widely spaced older trees."*

6.1. Fuel characteristics in radiata pine

Williams (1976), working in unthinned 12 year old *P. radiata* in north-eastern Victoria, found approximately 22.7 t/ha of fuel on the plantation floor comprising 7.3 t/ha of coarse fuel, 5.6 t/ha of fine fuel (4.9 t/ha of needle litter) and 9.8 t/ha of duff fuel. He found that the mean annual growth of needles was approximately 2.6 t/ha. He also estimated the weights of various components of the tree crowns finding that, of a total weight of 115.5 t/ha, 56% was merchantable stem and the remaining approximately 51 t/ha comprised coarse fuels (34 t/ha) and fine fuels (17 t/ha), a significant proportion of which would remain on site after first thinning.

Woodman (1982a) measured needle and duff fuel quantities at ground level in *P radiata* plantations in north-eastern Victoria in stands aged from 10 to 34 years. Mean litter weights in each five year age class varied from 2.4 to 4.4 t/ha, and duff fuel weights from 7.3 to 9.6 t/ha. In north-eastern Victoria, the total ground fuel load (fine fuels and duff) was shown not to increase after 15 years. Forrest and Ovington (1969) showed this equilibrium in fuel load to occur at 12 years in stands near Tumut, NSW.

Litter fuel loads of 37 t/ha were measured in a compartment of 35 year-old *P radiata* growing on infertile coastal sands at Myalup in Western Australia. (Smith 1992) The average depth of needle bed in this compartment was almost 10 cm. These fuel loads appear high compared with loads measured elsewhere in Australia and New Zealand, and the reason may be associated with the infertile nature of the soils on which the plantations have been established and the correspondingly lower rates of decomposition of the fuel bed. McCaw[3] (*pers comm.*) identifies this as one factor contributing to higher fuel loads in *P. pinaster* plantations, and it is probably a contributing factor here as well (see Section 6.2).

Fine fuel loads both in the crown and on the ground appear to stabilise after crown closure.

> *"Forrest and Ovington (1969) found the build up in radiata pine foliage to be slow until age 5 years after which a rapid increase occurred until an equilibrium value of 10 t/ha was reached between the ages of 7 and 10 years. Similarly, Williams (1977) estimated a foliage weight of 10 t/ha in a 12 year old stand at Myrtleford, Stewart and Flinn (1981) 10.9 t/ha in a 15 year old stand in South Gippsland and Will (1964, 1966) 9.0 t/ha and 10.6 t/ha for 12 and 18 year old stands respectively in New Zealand. From fire behaviour viewpoint the most significant feature is the relatively constant weight of foliage in the crowns following canopy closure."* (Woodman and Rawson 1982)

Woodman and Rawson (1982) also collate research work that shows average rates of litter fall are between 3 and 4 t/ha/yr, with Woodman (1980) finding 3.3 t/ha in north-eastern Victoria, Forrest and Ovington (1969) 3 t/ha/yr for Tumut, Will (1959) 4 t/ha/yr in New Zealand, and 3.4 t/ha and 3.3-4.2 t/ha by Pausey (1959) and Florence and Lamb (1973) respectively for South Australia.

Thinning will obviously add to the fine fuel load on the floor of the plantation, and leave a considerable load of elevated fuel that will ignite and burn at higher moisture contents than more compact fine fuels. Williams (1978) found 19.1 t/ha (7.2 t/ha of fine fuel and 11.9 t/ha of heavy fuel) added after third row outrow first thinning in a 12 year old stand, and 26.0 t/ha (7.7 t/ha of fine fuel and 18.3 t/ha of heavy fuel) after a sixth row outrow first thinning. Woodman (1980a) found that the hazard created by elevated fine fuel from thinning was significantly reduced after three years by which time 80% of it was gone.

Burrows (1980), working in five and 11 year old *P. radiata* in Western Australia, developed a method of assessing the likely contribution of various thinning regimes to slash fuel accumulation.

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[3] L McCaw Research Scientist, Department of Environment and Conservation, Manjimup, WA

6.2. Fuel characteristics in maritime pine

Burrows *et al.* (2000) record needle bed fuel loads in the Gnangara Plantation in Western Australia as high as 37.4 t/ha in a 43 year old stand and 40 t/ha in a 41 year old stand. These are high in comparison with the loads (needle plus duff) described for *P. radiata* in Section 6.1.

> *"With regard to fuels in maritime pine plantations, they accumulate to a much greater extent than is generally the case for radiata pine,, probably because of the coarse nature of the needles and the fact that they are generally planted on infertile sandy soils that have low organic matter and don't tend to develop a microclimate favourable for decomposition. Litter fuel loadings of 30 to 40 t/ha are quite commonplace in the absence of regular prescribed burning. The relationship between litter depth and fuel loading diverges for maritime pine and radiate pine once the litter is more than 25 mm deep with maritime pine having a heavier load for the same depth (suggesting it's more compact - it may also be that the needles are more resistant to decay and don't break down as readily as radiate pine which tends to form a mulch in fuel beds that haven't been burnt for some years)."* (L McCaw *pers comm.*)

6.3. Fuel characteristics in slash pine

In Queensland, five fuel types for *P. elliottii*, based on degree of litter suspension and species composition of the understorey vegetation, have been identified: (Department of Forestry, Queensland 1976). Abbreviated descriptions of each type are given below.

Fuel Type 1 - Fuel suspension on less than 50% of the area

Understorey species cover less than 50 percent of the area. Fuel consists of a moderately compacted litter layer forming a continuous fuel layer which produces very uniform fire behaviour. Fuel quantity may exceed 18 t/ha. Surface needles dry out fairly quickly after rain but the lower profile of the fuel bed is much slower drying because of the compressed litter.

Fuel Type 2 - Fuel suspension on 50 to 80% of the area

*Understorey species cover 50 to 80 percent of the area, creating a suspension of litter to a depth ranging from 15 cm to 45 cm. Fuel quantity may vary from 10 t/ha in areas where kangaroo grass (*Themeda spp*.) predominates to 17 t/ha in areas where grass tree (*Xanthorrhoea spp.*) predominates.*

Fuel Type 3 - Fuel suspension on greater than 80% of the area

Heavy understorey of grass tree or sedges occurs on 80% or more of the area and fuel quantity normally exceeds 16 t/ha. Litter is suspended for an average depth of 45 cm, but may exceed 100 cm in very heavy fuels.

Fuel Type 4 - Dense blady grass

Understorey of blady grass and/or bracken fern over 80 percent or more of the area. This type normally occurs on plantation edges where light conditions favour the blady grass, but may be more extensive in areas of low crown density (low site index or poor stocking).

Fuel Type 5 - Intermediate understorey (ladder fuels) present

This fuel type is virtually a type 3 fuel with the addition of an intermediate understorey in the 1 to 5 m stratum, usually tea-tree (Leptospermum, Baeckea etc.) and cutty grass, Casuarina, Lantana or blueberry ash.

Byrne (1980) indicates that total annual litter fall in *P elliottii* plantations older than 10-13 years is from 4 to 5.5 t/ha and that, *"above about 13 years the quantity of needle litter remaining on the forest floor not decomposed remains relatively constant in the range 10 to 20 t/ha."*

6.4. Summary comments

- The fine fuels that may be available to a wildfire on the surface and in the crowns of trees within a softwood plantation tend to stabilise from the time of canopy closure.
- After crown closure the rates of litter fall are between 3 and 5 t/ha/yr.
- Thinning obviously increases fine fuel loads at ground level (perhaps as much as 7 t/ha) and it creates a fuel bed that has a large elevated, and therefore more flammable, component.
- Pruning will similarly increase fine fuel loads at ground level.
- Evidence from past wildfires indicates that the space between the surface fuels and the base of the crown will have a large influence on the likelihood of crown fire formation, as will the space between tree crowns.

7. Fire Behaviour in Softwood Plantations

"The drivers of fire are well understood. They are the moisture content of the fuel, the amount and structure of fuel and the wind speed. The speed and distances that fire can travel under extreme conditions of very dry and abundant fuels and high wind speeds are difficult for many people to appreciate but this basic characteristic must be understood if people are to manage fire and to live with fire. Rates of spread of single fires in forests (both, conifer and eucalypt) of 10 km/h have been documented under extreme conditions and rates of spread of grass fires in abundant fuels have exceeded 20 km/h. This means that under extreme conditions a single fire can burn out between 60,000 and 100,000 hectares in eight hours. Multiple fires burning in close proximity may induce even higher rates of spread." (Cheney 2004)

There is obviously a considerable body of literature on the factors that influence wildfire development and behaviour, and this paper assumes that the reader has a reasonable understanding of those factors. However, Tolhurst and Cheney (1999) provide an excellent summary of the factors that influence forest fire behaviour and, although their paper is focussed upon fire behaviour in eucalypt forests, it also provides a sound basis on which to begin understanding fire behaviour in softwood plantations and the rural landscape more generally. Cheney and Sullivan (1997) also present a considerable body of work concerning fire behaviour in grasslands.

Within Australia, while most of the research that has been undertaken in relationship to forest fire has, understandably, concentrated on fire protection in eucalypt forests, a significant body of work applicable to softwood plantations does exist. Not as much fire research has been undertaken within New Zealand, but the substantial body of work in Canadian softwood forests has been used to help inform fire authorities in that country of how plantation fires may behave. Indeed, as we shall see shortly, New Zealand has adapted its Forest Fire Danger Rating System from the Canadian model (See Appendix 1). In more recent years New Zealand has also produced some very well documented studies of particular wildfire events. Fogarty *et al.* (1996) produced a very comprehensive report on fire behaviour and reported rates of forward spread up to 2.8 km/h, and the applicability of existing systems to the prediction of fire behaviour, and suppression response to a wildfire in the Berwick Forest.

Considerable work has been done within Australia on the conditions under which fuel reduction burning in softwood plantations comprising *P radiata, P pinaster, P elliottii and P caribaea* can be applied, and that work is discussed in Section 9.3 (Fuel Reduction Burning in Softwood Plantations).

7.1. Characteristics of wildfires in softwood plantations

In both Australia and New Zealand, analyses of a number of significant wildfires that have impacted on softwood plantations are available. Some of the key characteristics of those wildfires that have been studied, or for which information is available from other sources, is provided in Appendix 3. The data that are available do not allow for any quantitative analysis of fire spread and spotting characteristics under different levels of Fire Danger, but they do indicate the rates of forward spread and spotting distances that have occurred.

The exceptional weather conditions experienced on Ash Wednesday in south-eastern Australia produced rates of forward spread in softwood plantations that have not been matched before or since, although spread rates during the ACT fires of January 2003 in mature pine forest were estimated at 6.4 km/h. (Cheney, *pers comm.*) More detail on the ACT fires is provided in Section 7.2 Fire behaviour comparisons. At all other times, the maximum rates of forward spread experienced have been of the order of 3-4 km/h even under conditions of Extreme Fire Danger. The other notable feature from Appendix 4 is that the maximum spotting distance recorded at a wildfire in a softwood plantation is 2.6 km at Myalup in Western Australia on 21 April 1991.

7.1.1. Rates of forward spread

Very high rates of forward spread are possible in softwood plantations, as the Ash Wednesday fires (Keeves and Douglas 1983) indicate. *"The rates of fire spread in the Furner-Mount Burr area were of the order of 12-14 km/h over periods from one half to one hour. These are very high rates for forested lands by any standards."*

However, the maximum rates of forward spread that are possible in softwood plantations are considered to be no greater than those generally found in eucalypt forest, and they are certainly less than those that are possible in fuel types, such as scrub and grass, which allow higher wind speeds to penetrate to the flame zone. (See Section 7.2 Fire behaviour comparisons)

While very high rates of forward spread were experienced on Ash Wednesday, Appendix 3 shows that under conditions of Very High to Extreme Fire Danger, rates of forward spread are more commonly of the order of 3-4 km/h or less depending on the structure of the plantation. The rates of forward spread quoted are generally average rates calculated for periods of 30 minutes or more. However, rates of forward spread can vary dramatically over very short periods of time as wildfires are influenced by changes in fuel, topography and weather, and whether or not crown fire formation occurs. For example, very dramatic fluctuations in rates of forward spread were recorded by Burrows *et al.* (1988a) during some trial burning in 17 year old unpruned *P pinaster* stands in Western Australia.

> *"Observed rates of fire spread varied considerably during each burn. Fires pulsated from severe crown fires to slow burning backfires. Hence, within any one plot, spread rates varied from about 40 m/h to in excess of 1,000 m/h during short bursts of crown fire activity."*
>
> *The observed pulsating fire behaviour can best be explained by the continual interplay between the ambient wind field and the fire induced convection column. When a large area of dry and heavy fuels is burning (that is, the flames are deep) then the energy in the convection column is greater than that in the wind field, so the flames are erect. This causes torching and the development of crown fires. As*

the ground fuels in the deep flaming zone burn out, the convection column collapses and the flames lean over the unburnt fuels and spread as a ground fire.”

This interaction between convective activity and the wind field was a prominent feature of the Caroline Fire in South Australia on 2 February 1979 (Geddes and Pfeiffer 1981) and it is discussed in more detail in Section 7.1.7 (Some Characteristics of Extreme Wildfires in Softwood Plantations).

While average rates of spread are a useful indicator of wildfire behaviour, firefighters need to be aware that very dramatic and dangerous short term fluctuations can occur.

7.1.2. Spotting characteristics

For the purposes of this paper it is useful to categorise spotting distances in some way. The term ‘short distance spotting’, for example, is often used, but no agreed definition of the term appears to exist. In this paper, and admittedly somewhat arbitrarily, the descriptive terms of spotting distance are as shown below.

- Short distance - <1 km
- Medium distance - 1-6 km
- Long distance - >6 km

The maximum spotting distance recorded in Appendix 3 is 2.6 km from the Myalup Fire in Western Australia on 21 April 1991. There is little doubt that spotting distances from softwood plantations are considerably less than those that are possible from eucalypt forests under similar levels of Fire Danger. Mass short distance spotting also occurs in eucalypt forests and, even at relatively low levels of Fire Danger, short distance spotting in these fuel types can create problems during fire suppression operations as well as prescribed burning operations. *“Spotting over control lines is the most common cause of escape from prescribed burns in Victoria.”* (Tolhurst and Cheney 1999) Although the spotting potential in softwood plantations is generally lower than in eucalypt forests, significant short distance spotting can occur when the relative humidity is very low.

> *“Spotting potential* (in softwood plantations) *is lower than stringy-barked eucalypts, and pines do not produce large firebrands (like candle bark) and long distance spotting rarely occurs. However, under low humidities the bark is flammable and produces abundant firebrands in the form of bark plates. This feature can carry fire into the crown fuels and produce heavy short distance spotting even when surface fuels are low.”* (Cheney, *pers comm.*)

The presence of patches of remnant native forest within a plantation may add considerably to the spotting potential of a fire, particularly if the remnant vegetation contains rough-barked trees that have not been burnt for several decades.

Do short and medium distance spot fires increase that rate of forward spread or do they simply make suppression action more difficult? It has long been assumed that spot fires increase the rate of forward spread of all wildfires, and certainly this was the view of McArthur during his early work leading to the development of the McArthur

Fire Danger Meter. The situation as it is now understood is more complicated. If the wind direction is relatively constant, then spot fires are thought to contribute little to increasing the rate of forward spread because they tend to be sheltered by the convection column before being overrun by the head fire. If, however, the wind direction is highly variable, they may significantly increase the width of the head fire and, in that way, contribute to increasing the rate of forward spread. Some more comments on this issue occur in Section 8.4 (Project Vesta).

7.1.3. The impact of crown fire development

While crown fires in eucalypt forests, and many other fuel types, occur as part of a continual and steady increase in fire intensity, wildfires in softwood plantations, when the plantations have a significant gap between the surface fuels and the crown fuels, can move very quickly from surface fire to crown fire conditions. This rapid transition can create not only a dramatic and sudden increase in fire spread, but it can also threaten the safety of firefighters if it was neither predicted nor taken into account in developing the fire suppression plan.

Van Wagner (1977, 1993) discusses some theories and observations of crown fire formation in conifer forests. In his 1977 paper he indicates that it is possible to *"imagine three different classes of crown fire behaviour, the stage reached on any given day depending on the properties of the crown layer."* His theory depends on *"three simple crown properties: height above ground, foliar bulk density and foliar moisture content."* In essence, is the gap between the surface and crown fuels such that the crown will burn at the existing foliar moisture content, and is there enough fuel within the crown layer to maintain combustion in a lateral direction?

His three possible classes of crown fire are *passive crown fire, active crown fire* and *independent crown fire* and he describes them in his 1993 paper as follows:

- *"In a **passive crown fire**, the crowns may burn sporadically and partially or be too sparse to permit continuous flame in the crown space. The burning crowns may reinforce forward heat transfer, but the main control resides in the surface phase. The crown phase may appear to lag somewhat behind the surface phase but remains connected with it."*

- *"In an **active crown fire**, the crowns burn more or less completely with continuous deep flame. Although the crown flame is steady and continuous, the crown phase still depends on the surface phase for part of the crown layer's requirements for ignition energy. The crown phase assumes the main control, leaning ahead of the surface fire but remaining linked with it."*

- *"The concept of **independent crown fire** remains dubious. Both Van Wagner (1977), by a simple analysis, and Albini and Stocks (1986), by a more sophisticated process, determined that true independent crown fire spread ahead of the surface phase could only proceed if the flame front from crown base to flame tip were tilted well forward, perhaps so much as to approach the horizontal. In other words, the spread of crown fire independent of any surface fire is essentially ruled out as a stable phenomenon on level terrain.*

The concept may still have value in rough or steep terrain and as a short-term fluctuation under the most extreme conditions, but is not pursued further here."

While Van Wagner is doubtful about the validity of the concept of independent crown fire formation, (Cheney, *pers comm.*) does not believe the concept is valid under any circumstances. It is therefore, more useful to think of crown fires as either passive or active as described above. When an active crown fire is formed, think of it as being when all the fuel layers are fully involved in the fire.

However it is described, the impact of crown fire formation can be dramatic. In a report prepared for the Queensland Forest Service on the Toolara Fire of 22 September 1991, Alexander (1998) says:

> *"Generally one can expect a fire to at least double or triple its forward spread rate after crowning with a corresponding increase in area burned to the power of two. Had the plantation stands not been managed to the extent they were (ie. by pruning, thinning and prescribed burning), the area burned over could have easily been at least four to six times larger."*

In the trial burning conducted in *P pinaster* referred to earlier, Burrows *et al.* (1988b) say:

> *"It seemed that fuel, weather and stand conditions during this exercise were just below the threshold for sustaining crown fires. Perhaps crown fires would have been sustained if wind speeds were slightly higher. However, when crowning did occur, then fire spread rates were 2-5 times that of surface fires."*

Recent experimental burning by Fernandes *et al.* (2004) in a 28-year old *P pinaster* plantation in north-eastern Portugal has also demonstrated the significant impact small changes in wind speed may have on the possibility of crown fire formation. *"Minor wind speed increases were critical to the transition of a surface fire to a crown fire or greatly enhanced the propagation and intensity of the crown fire phase."*

7.1.4. Fire behaviour related to stand characteristics

After examining the extensive fires in South Australia on Ash Wednesday, which burnt a total plantation area of approximately 21,000 ha, Keeves & Douglas (1983) describe the impacts on wildfire behaviour of different plantation stand characteristics in the following terms, as we have already seen:

> *"Fuel quantities in the pine plantation areas varied markedly from plantation to plantation. The areas where the fires were most intense had been either recently thinned or were awaiting first thinning. Fuel quantities were very high and, in some cases, well distributed vertically."*

> *"In old multi-thinned stands in both the South-eastern and Central Regions, crown fire formation was only intermittent. This usually occurred where patches*

of seedling advanced growth provided a 'ladder' into the crowns of the quite widely spaced older trees."

Smith (1992) suggested that past pruning operations and fuel reduction burning limited the extent of crown fire development during the Myalup Fire in south-west Western Australia, which burnt under conditions of Very High Fire Danger.

Douglas (1964), based upon experience with fires in mainly *P radiata* plantations in South Australia in the previous decade or so, summarised how the age of the plantation and the silvicultural treatment that it had received may influence wildfire behaviour. That summary, converted to metric measurements, is shown below in Table 4. The table assumes *"average bad conditions"* and that the *"FFDI = 50"* ie. A Fire Danger Index of 50, based on the McArthur Forest Fire Danger Meter. Douglas uses the term 'ground fire', which is synonymous with the preferred term of 'surface fire'. However, although the table still presents a valuable insight into the way in which changes in stand age and treatment may affect fire behaviour, more recent experience indicates that it should now be read with caution with respect to the comments on likely rates of forward spread. His indicated rates are likely to be quite conservative. For example, if we look at the rates of forward spread recorded at the Caroline Fire of 2 February 1979, we see that under a FDI of 66, the maximum rate of forward spread was about 4 km/h, much of which occurred in what Douglas would have classified as 'middle-aged' stands. In the ACT fires of January 2003, Cheney (*pers comm.*) estimated rates of forward spread of 6.4 km/h in mature pine forest (See Table 7), which would be equivalent to 'Old well thinned stands at or near final crop stage' as described by Douglas below.

Table 4. Fire behaviour in very high and extreme conditions.

Plantation Stage	Flame Height	Spotting Potential	Rate of Forward Spread
Juvenile Plantations	Almost always tree height and often greater.	Low in very young plantings unless slash from previous crop is present; at or near canopy formation much higher.	Depends on fuel quantity; in very young plantations, with little or no auxiliary vegetation, low; following second spring, usually much auxiliary vegetation, and ROS high, probably 4-10 km/h.
From canopy formation to age of first thinning.	Usually tree height or greater. When pruned, the slash usually has not compacted enough to create a large enough air barrier between ground and crown. Fire runs up unpruned stems because of needles caught in "elbow" between branch and trunk.	Moderately high	Dense fuel type with little chance for wind entry at ground level; of order of 0.4-1.6 km/h with higher values where crown fires are throwing spots well ahead.
Middle aged stands.	Ground fires with flames 3-6 m only are possible in pruned stands where slash is not heavy and is well compacted. Crown fires occur frequently in unpruned stands and where thinning slash is high and widespread.	Low High	0.4-0.8 km/h. 1.2-1.6 km/h.
Old well thinned stands at or near final crop stage.	Ground fires are usually maintained with flame heights 3-6m. However, patchy crown fire development occurs where heavy ground fuels or patches of regrowth are able to lift the flame height close enough to the green level	Moderate, reduced by the filtering effect of the crowns.	Varies quite widely, say 0.6-1.4 km/h, with higher rates where intermittent crowning occurs, or where stockings are low enough to allow greater ingress of wind.
Slash after clearfelling.	Fire intensity and flame height vary with quantity and condition of slash. Old slash with needles fallen from limbs burns less fiercely.	Very high with marked tendency for whirlwind development	High, may exceed 1.6-2.4 km/h.

Source: Douglas DR (1964)

Alexander (1998) provides a *"semi-theoretical comparison of fire behaviour"* in pruned and unpruned stands of pine plantations that also illustrates how variation in the vertical fuel structure within a plantation may influence fire behaviour. The table prepared by Alexander is reproduced as Table 5.

Table 5. Semi-theoretical comparison of fire behaviour in pruned vs unpruned exotic pine plantation under high fire danger conditions.

Fire Description and Characteristics	**Stand A - Pruned to 5m**	**Stand B – Unpruned**
Type of fire	***Surface***	***Crown***
Forward spread (m/h)	300	600
Fuel consumed (t/ha)	18	28
Head fire intensity (kW/m)	2700	8400
Flame height (m)	2	12
Fire area at 1 hr (ha)	4.86	19.44
Fire perimeter at 1 hr (km)	0.83	1.65
Percent perimeter contained	91	55
Spotting distance (m)	<200	Up to 2000

Source: Alexander (1998)

7.1.5. The influence of plantation species on fire behaviour

To understand the interaction between a particular softwood plantation species and fire behaviour requires thinking about how different fuel characteristics are affected by the species concerned. Although fuel characteristics have already been discussed in Section 6, there has been no real attempt so far in this paper to compare the influences of a species itself on fire behaviour. The factors that may give rise to different fire behaviour between species include characteristics such as needle length and thickness, branching and the depth of the green crown. In addition, the fuel complex associated with a particular species, as we have already seen in Section 6, will also be affected by the site conditions that suit the species concerned and the silvicultural regimes that suit stand growth and the development of desirable wood qualities.

The dominant plantation species in New Zealand and Australia more generally is *P radiata*. *P pinaster* in Western Australia and *P elliottii* in south-eastern Queensland and northern NSW are other significant species, in terms of areas planted, which have also been studied with respect to fire behaviour.

Woods and Forests South Australia (1990) commented on the different flammability of different species:

> *"Most plantation fires experienced in South Australia have been in* P radiata. *The only other species which have been burnt in any significant area are* P pinaster, P muricata *and some* P canariensis.
>
> *As far as fire behaviour is concerned,* P pinaster *and* P muricata *provide more problems than the others.*

> *The very deep coarse needle litter of* <u>P pinaster</u> *burns very fiercely and the heavy clusters of needles caught in the 'elbows' of unpruned lower branches provide a very significant aerial fuel"*

In their extensive analysis of the Wandilo Fire of 5 April 1958 in South Australia, McArthur *et al.* (1966) also compare the different contributions of *P pinaster* and *P radiata* fuels to overall wildfire behaviour:

> *"Because of specific differences in fuel characteristics, various pine species affect fire behaviour in different ways. In this fire, the rapid combustion of the* <u>Pinus pinaster</u> *was an important factor in spreading the fire in the early stages.*
>
> <u>Pinus pinaster</u> *stands almost invariably accumulate a much greater quantity of loosely compacted needle at ground level than do stands of* <u>Pinus radiata</u>. *Fuel quantities in excess of 20 tons per acre* (50 t/ha) *have been measured in 30 year old stands on the coastal plain of Western Australia. It would appear also that the decomposition rate of the coarser* <u>Pinus pinaster</u> *needles is much slower than the finer* <u>Pinus radiata</u> *needles. Having plantations of this species in vulnerable locations, such as adjacent to external boundaries, is a risk which at least must be recognized if not avoided."*

The Forest Fire Behaviour Tables for Western Australia (Sneeuwjagt and Peet 1985) reflect the earlier observations about *P pinaster* by predicting that fires burning under the same conditions of wind, fuel moisture content, and fuel loading will spread up to 15% faster in *P pinaster* than in *P radiata*, although the tables predict that this difference becomes negligible when fine fuel moisture contents are less than 7%.

Based on observation (Cheney, *pers comm.*) believes that, all other factors being equal, *P radiata* stands are less hazardous than *P elliottii* stands which, in turn, are less hazardous than stands of both of *P pinaster* and *P caribaea*.

7.1.6. The influence of fuel moisture on fire behaviour

Fuel moisture content has a major influence on fire behaviour, and fires in pine fuels will ignite and be sustained at considerably higher moisture contents than in eucalypt fuels.

> *"Because of the resin in dead pine needles they can be burnt at higher moisture contents (about 30%) than eucalypt litter (18-20%). This means that light surface fires to remove needles can be carried out under very mild conditions. Also suspended needles can be burnt when surface fuels cannot. In Victoria, needles are burned from standing trees in unpruned plantations. Piles of thinning slash can be partially burned if the operation is carried out when only the suspended needles are dry enough to burn."* (Cheney 1985)

Woodman and Rawson (1982) include work by Williams (1977) in *P radiata* stands in north-eastern Victoria to indicate the impact of various fuel moisture contents on potential fire behaviour in *P radiata* plantations.

Table 6. Fuel moisture content and fire behaviour in radiata pine plantations

Moisture Content (%ODW)	Fire Behaviour
25-30	* Elevated dead needles will just ignite and will carry fire only with assistance of wind. ** Surface needles will not ignite.
20-25	Elevated dead needles will ignite and just carry a fire (e.g. ROS <0.2 m/min. Surface needles will just ignite and only carry fire with the assistance of wind.
15-20	Elevated dead needles easily ignited and carry fire of low intensity (eg. ROS up to l m/min). Surface needles ignite and carry slow moving fire (eg. ROS <0.5 m/min).
10-15	Elevated dead needles carry fire of moderate intensity (eg. ROS >l m/min). Surface needles easily ignited and carry fire of moderate intensity.
7-10	Elevated dead needles carry fire of high intensity which is difficult to control. Surface needles carry fire of moderate to high intensity.
<7	Very intense wildfire possible.

Source: Woodman and Rawson (1982) after Williams (1977)

* Elevated dead needles refer to dead pine needles lodged on branches, vegetation or debris on the forest floor so that they are well aerated and above the ground.

** Surface needles refer to the top layer of dead pine needles on the plantation floor. They are more compacted than elevated dead needles but better aerated than the duff layer.

ROS = Rate of spread

The probability of spotting occurring is also directly related to the moisture content of the fine fuels. *"When the surface fuel moisture content is above 7%, then McArthur says that 'only very large flaming brands will be effective in starting new fires' and that when fuel moisture contents are 4% or less, then even the smallest firebrand will start spot fires."* (Tolhurst and Cheney 1999)

Woodman (1982) studied fuel moisture changes in *P radiata* in an unthinned 17 year old stand, as well as a 28 year old stand thinned to 204 stems/ha, throughout one 24 hour sampling period to show that:

- *"Variations in moisture content are likely to be more pronounced in thinned stands, i.e. those exposed to greater fluctuations in temperature, relative humidity and air movement.*
- *The fuel moisture differential which commonly exists between elevated fuels and litter fuels.*
- *Significant moisture loss from the duff layer can occur in a few hours if the initial moisture content is high.*
- *The moisture content of the needle fuels can change rapidly from levels where burning is difficult to sustain to levels where moderate to severe fire intensities can occur."*

Forests NSW (2003) comments on how the moisture contents of fuels in plantations and native forests might respond to rising relative humidity, compared with the moisture contents of grass fuels outside forest areas.

> *"Both pine litter and eucalypt litter respond slower to changes in atmospheric moisture than grass fuel and fires in both forests will burn for longer during the evening when the humidity rises than fires in grasslands. In South Australia in 1983, fires in the pine plantations persisted overnight and continued burning for several days when the fire perimeter in the surrounding grasslands largely went out during the first night. This is typical of fires burning in landscapes with a mix of grasslands and forests."*

It is important, however, to recognise also that as relative humidity falls cured grass fuels will dry out more rapidly than coarser eucalypt and pine fuels, and therefore become available for burning earlier in the day than forest fuels.

7.1.7. Some characteristics of extreme wildfires in softwood plantations

The Ash Wednesday fires in South Australian plantations exhibited rates of forward spread of up to 12-14 km/h. (Section 7.1.1). Other extreme wildfire behaviour described by Keeves & Douglas (1983) includes:

> *"At Furner, some extraordinary flame heights have been recorded by M Sutton who photographed the fire from a light aircraft 5 km distant at a height of 375 m. Flame heights of 200-300m are indicated by the photographs."*

The Caroline Fire of 2 February 1979 (Geddes and Pfeiffer 1981) *"burnt almost continuously as a crown fire on a narrow front, at a fairly constant forward rate of spread, and more or less in a straight line."* The highest periodic rate of spread recorded was 4 km/h and *"multiple short distance spotting was prevalent"*. Aerial observations soon after the fire show spread patterns created by periods when the prevailing winds had dominance over convective activity as described earlier by Burrows *et al.* (1988a) and repeated below.

> *"The observed pulsating fire behaviour can best be explained by the continual interplay between the ambient wind field and the fire induced convection column. When a large area of dry and heavy fuels is burning (that is, the flames are deep) then the energy in the convection column is greater than that in the wind field, so the flames are erect. This causes torching and the development of crown fires. As the ground fuels in the deep flaming zone burn out, the convection column collapses and the flames lean over the unburnt fuels and spread as a ground fire."*

This phenomenon also received comment by Billing (1980c) in relation to the Caroline Fire of 2 February 1979.

> *"Throughout most of its spread within the plantation area, the behaviour of the fire was characterised by periodic changes in the level of fire intensity. These changes showed up as wide bands burnt by very intense crown fire, with all*

foliage being removed, and much narrower bands where the foliage was only scorched.

Such behaviour appears to be particularly noticeable in very high intensity fires occurring in relatively uniform fuel distributions, and where topography does not have a great influence on fire spread.

Cheney (pers comm.) considers that this behaviour is probably associated with changes in the strength of convective activity over the fire and that the following sequence of events may be responsible for the observed behaviour.

- *Convective activity increases as the fire spreads more rapidly*

- *The convection column eventually dominates the wind field near the fire and air movement becomes inwards to the base of the column from all directions.*

- *Without any strong directional wind influence the fire becomes relatively slow spreading, although a very rapid and intense burn out of fuels continues over most of the fire area.*

- *After burn out the convective activity lessens and the external wind field again exerts an influence on fire spread.*

In the Caroline fire this complete cycle must have been occurring over fairly short intervals. For example, in some areas the lengths of the intensively burnt sections were up to 400 metres. At a spread rate of 5 km per hour the cycle would therefore be occurring, on average, at approximately 5 minute intervals."

The wildfire at Ross's Sharefarm in Western Australia on 4 January 2003 (Appendix 2) also exhibited this type of behaviour.

In analysing the Millbrook Fire in South Australia of 8 March 1990, Pratt (1990) also makes some observations about this feature of intense wildfire behaviour that becomes very apparent after the fire has burnt in relatively uniform plantation fuels.

"It is postulated that the presence of vortices in convection columns over forest fires in Australia is more common than previously thought, and may account for some observed unusual fire behaviour. Some crown "streets" in otherwise crowned-out areas are probably due to "horizontal roll vortices" where flank vortices are forced over parallel to the ground surface due to ambient winds having dominance over convective forces."

Is the concept of 'horizontal roll vortices' valid? Cheney (*pers comm.*) thinks not. He believes that the earlier comments about the Caroline Fire, concerning the relative dominance of the convection column and the prevailing wind field, is what explains the presence of at least most of the 'crown streets' referred to by Pratt. Cheney also cautions that similar patterns can be created by changes in wind direction and the resulting changes in intensity of the front and flanks of the fire. In this case, the crown streets do not form ellipses, as they do when the convection column gains and then loses dominance over the wind field for a period, but rather bands of scorched crown that do not connect to form an ellipse.

7.2. Fire behaviour comparisons

We have already examined how a range of factors may influence the behaviour of fires in softwood plantations. However, because one of the objectives of the paper is to ***"Provide an overview of how wildfires behave in softwood plantations, and how that behaviour compares with wildfire characteristics in other significant forest and fuel types"***, we need also to look at some of the comparisons that are available.

Before looking at examples of wildfire behaviour in different forest and fuel types, it is useful to consider not only the maximum possible rates of forward spread, but also how quickly a wildfire might reach that rate of spread. Both factors have a significant influence on the difficulty of fire suppression. Under Extreme Fire Danger conditions, wildfires in any fuel type can be extremely destructive and intense. However, there can be some significant differences in the early development of fires in different fuel types which may affect the probability of successfully controlling a fire while it is still small. Under Very High to Extreme Fire Danger, a fire in grassland will quickly spread, driven by the wind. Under similar weather conditions, fire in a eucalypt forest will be slower to develop because of the reduced wind under the tree canopy, but once established, control will be made difficult by spot fires starting ahead of the main fire front. In a mature pine plantation with little understorey, a fire will be slower to develop and will have minimal amounts of spotting. In young pine stands and plantations where there is a significant grass or shrub understorey or where tree crowns are close to the ground a fire will crown early and therefore exposed to the full force of wind and likely to reach equilibrium earlier than a fire in dry eucalypt and mature managed pine stands. The combination of good access and slower initial fire development means that many pine plantation fires are kept small.

We can expect that, under the same weather and topographical conditions, the maximum rate of forward spread in grassland will be greater than in forested areas, and that we can also expect the maximum to be reached more quickly than in forested areas. While the maximum rates of forward spread in a softwood plantation and a eucalypt forest may be similar, the reduced wind speed within a softwood plantation compared with a more open eucalypt forests can mean that it takes longer to reach the maximum rate of spread within the softwood plantation.

What is the magnitude of the difference in spread rates? *"At the top end of Extreme Fire Danger, wildfires in softwood plantations will generally have rates of forward spread that are some 30%-40% less, under the same weather and topographical conditions, than wildfires burning in grassland, or other fuel types where the prevailing wind can impact directly on the flame zone. This differential will increase at lower levels of Fire Danger."* (Cheney *pers comm.*)

There are examples we can draw upon to compare the behaviour of wildfires in eucalypt forest, grassland and softwood plantation fuels. Before doing so it is useful to summarise at least some of those factors that will cause a wildfire in a softwood plantation to behave differently from a wildfire in other fuel types. Cheney (*pers comm.*) has listed factors that he considers can both moderate and exacerbate wildfire behaviour in softwood plantations when compared with wildfire behaviour in eucalypt forests.

"Moderating Factors:

- *Plantations form a denser canopy that largely suppresses native understorey plants, and generally reduces wind speeds within the plantation.*
- *Fine needles compact more easily producing a relatively uniform fuel bed that produces surface fires with lower flame heights.*
- *Spotting potential is lower than stringy-barked eucalypts, and pines do not produce large firebrands (like candle bark) and long distance spotting rarely occurs.*
- *Plantations can be treated silviculturally to change the fuel structure and improve access (although this is becoming less common and this complicates the comparison of present day wildfire behaviour with historical wildfire behaviour)*

Exacerbating Factors:

- *Pines are not self pruning, which reduces visibility and access, and provides ladder fuels which promote the development of crown fires.*
- *The crowns of pines are generally deeper than eucalypts and support more dead material in the crowns and lower branches.*
- *Because of the above two factors, fires in pine plantations change from a surface fire to a crown fire in a stepwise fashion, often very rapidly and with little warning. Fires in eucalypts progressively increase flame heights as fire intensity increases until the crowns become involved. This is a critical difference in fire behaviour which makes direct firefighting more hazardous for the unwary and has lead to entrapment of experienced firefighters (e.g. the Wandilo fire of 5 April 1958).*
- *Under low humidities the bark is flammable and produces abundant firebrands (bark plates). This feature can carry fire into the crown fuels and produce heavy short distance spotting even when surface fuels are low."*

Some reasonably direct comparisons of wildfire behaviour are available from evidence collected from wildfires in both South Australia and Victoria on Ash Wednesday. The wildfires in each State burnt, under very similar conditions of Fire Danger, through grassland, softwood plantations and eucalypt forests.

In South Australia, Keeves and Douglas (1983) found that:

- Fires burnt under conditions where the McArthur FDI was greater than 100 at Mount Gambier for approximately 6 hours during the day.

- Maximum rates of forward spread in softwood plantation of the order of 12-14 km/h occurred over sustained periods.
- At the Narraweena fire, which started at 1210 hrs, the *"average speed was 17 km/h"* in grassland, *"in spite of the fire passing between and over quite large patches of irrigated pastures, green crops of potatoes and other non-flammable areas."*

In Victoria, on the same day, Rawson *et al.* (1983) found that the Deans Marsh/Lorne Fire, that started at 1448 hrs when the McArthur FFDI was *"about 100"*, had:

- An average rate of forward spread of 22 km/h in grassland before the fire entered native forest.
- An average rate of forward spread in eucalypt forest of about 10 km/h with spotting distances of 8-10 km.

At the East Trentham/Macedon fire, on the same day, Rawson *et al.* (1983) recorded spotting distances of up to 25 km from the fire when it was in eucalypt forest.

In New Zealand, Rasmussen and Fogarty (1997) recorded average rates of forward spread of approximately 14 km/h in close to fully-cured grasslands near Tikokino, under relatively mild conditions (25^{o}C and 31% RH) except for wind speeds up to 56 km/h.

Cheney (*pers comm.*) indicates rates of forward spread calculated for the McIntyre Fire (Table 7) on 18 January 2003 (at FFDI's of about 100), the day the fire impacted on the urban communities of the ACT. The mix of fuel types makes direct comparisons difficult, but it is clear that the rates of forward spread in the grasslands were greater than in the softwood plantation, despite the very low fuel quantities in the grassland areas.

Table 7. Rates of forward spread, McIntyres Fire, 18 January 2003

Time (Hours)	ROS (km/h)	Fuel Type
1300-1400	3.8	Eaten-out grassland
	3.3	Eaten-out grassland
1340-1400	3	Pine forest (developing spotfire)
1400-1430	11	Ungrazed and eaten-out grasslands
	7.6	Pine forest and grassland
	4.8	Pine forest and grassland (Mt McDonald spotfire)
1430-1500	6.4	Mature pine forest
1500-1508	10*	Pine regeneration of various ages and grass

Source: Cheney (pers comm.)
* The short observation period means that this rate may well be an overestimate.

Gould *et al*. (2001) discuss aspects of fire protection in hardwood plantations and, despite the extensive areas that have now been planted, indicate that little is known about wildfire behaviour in hardwood plantations, and that any meaningful comparison with fire behaviour in softwood plantations is not possible at this stage of our knowledge.

> *"There is some practical evidence that fire behaviour within eucalypt plantations at certain stages of development may be less severe than in grass or native forest. A number of case studies have shown that, even under quite severe fire weather conditions, wildfires encountering blue gum plantations aged between about two and six years are unlikely to spread far into plantations, or be difficult to suppress with ground crews and tankers. Perhaps the best examples of this are provided by the fires which occurred in the Albany and Mt Barker area of south-western Australia on 28 December 2000. Four separate fires burning under conditions of Extreme fire danger impacted on a number of properties partially or wholly planted with bluegums, but the area of plantation burnt was only about 60 ha. In several instances, low fuels in bluegum plantations assisted fire-fighters in containing fires. Some patches of remnant vegetation within plantations burnt at high intensity, but fires did not spread extensively into adjacent plantation.*
>
> *In contrast to these observations, there have been several examples where fires in bluegum plantations older than about 8 years have burnt at moderate to high intensity and have been difficult to suppress, even though fire danger conditions have only been High. These fires have resulted in complete crown scorch of trees 20-30 m tall, and in some instances torching of individual trees or crowning of patches up to 1 ha in area.*
>
> *Clearly, there is a need to better understand the relationship between fuel dynamics in plantations and potential fire behaviour. Extending rotations beyond 10 years on a broad scale could result in escalating fire hazard across the landscape. Silvicultural treatments to reduce the hazard level in older plantations need to be examined."*

7.3. Summary comments

- Maximum rates of forward spread in softwood plantations of the order of 12-14 km/h are possible under conditions of Extreme Fire Danger, as shown in South Australia on Ash Wednesday. These rates were very similar to those in wildfires burning in eucalypt forest under similar Fire Danger Indices, but less than those burning in grasslands.
- Rates of forward spread can change very quickly if a fire changes from a surface fire to a crown fire.
- Rates of forward spread of a crown fire can be two to three times faster than a surface fire burning under equivalent weather and topographical conditions, and the change to crown fire formation can be so rapid as to pose significant issues for firefighter safety and wildfire control.

- Stand age and treatment can have a dramatic influence on whether or not crown fire formation occurs. Older stands, and stands where specific treatments have increased the space between surface fuels and crown fuels, are much less likely to provide the conditions necessary for crown fire formation.
- Under conditions of Extreme Fire Danger, wildfires in softwood plantations may move to and from crown fire conditions as the balance between the fire's convective activity and the wind field changes as fuels are consumed in a given location.
- Significant spotting activity can occur but, compared with wildfires in eucalypt forest, the distance of spotting is markedly reduced. Maximum spotting distances of the order of 2-3 km have been recorded under conditions of Extreme Fire Danger. Under similar conditions a fire in a eucalypt forest may spot over distances of more than 10 km.
- Under Extreme Fire Danger conditions, when relative humidities are very low, mass short distance spotting (at distances up to at least 200 metres) is a prominent feature of wildfires in softwood plantations.
- Fires in softwood plantations will ignite and remain alight at higher fine fuel moisture contents (about 30%) than fires in eucalypt forest (18-20%).
- The moisture content of needle fuels can change rapidly from levels where burning is difficult to sustain, to levels where moderate to severe fire intensities can occur.
- *P pinaster and P caribaea* fuels are more hazardous than *P elliotti* fuels that, in turn, are more hazardous than *P radiata* fuels.
- Not enough is known about fire behaviour in hardwood plantations in Australia to allow quantitative comparison with fire behaviour in softwood plantations or, indeed, other forest and fuel types.

8. Fire Danger Rating Systems and Predicting Fire Behaviour

This section examines Fire Danger Rating Systems and how they relate to softwood plantations. It also discusses recent and ongoing research that has begun to change some long held views about wildfire behaviour in eucalypt forests, and the implications of that work for our understanding of wildfire behaviour more generally.

Pearce (2004), in describing the relevance of Fire Danger Rating Systems to fire managers mentions the following key points:

> *"Fire danger rating systems produce one or more qualitative and/or numerical indexes of ignition potential and probable fire behaviour which are used as guides in a wide variety of fire management activities such as........:*
>
> - *Prevention planning. (e.g. informing the public of pending fire danger, regulating access and risk associated with public and industrial use of forest and rural areas)*
> - *Preparedness planning. (e.g. level of readiness and pre-positioning of suppression resources)*
> - *Detection planning (e.g. lookout manning and aerial patrol routing)*
> - *Initial attack dispatching.*
> - *Suppression tactics and strategies on active wildfires; and*
> - *Prescribed fire planning and execution."*

Similarly, Burrows and Sneeuwjagt (1991) list *"... three main applications for which fire behaviour models have been developed.*

- *Firstly, to provide a measure of seasonal and daily fire danger.*
- *Secondly, to predict rates of wildfire spread.*
- *Thirdly, for assisting in the conduct of prescribed burning operations."*

To understand wildfire management in softwood plantations, and how that management may compare with wildfire management in other forest types and grassland, a broad understanding of the current fire danger rating systems and fire behaviour models available in both New Zealand and Australia is required. Three such models are described briefly below. There has been concern for some time that the forest fire models available within Australia underestimate fire behaviour characteristics at the higher levels of Fire Danger. Project Vesta, described below, was designed to help address this concern. However, while the tools to predict fire behaviour are under review, the general systems used to describe regional levels of Fire Danger are considered to remain valid and useful. Project Vesta will make changes to the predictions of fire behaviour, but will not be changing the methods to forecast the levels of Fire Danger.

8.1. The McArthur Mark 5 Forest Fire Meter

McArthur (1967) conducted some of the earliest work in Australia designed to assist managers with an understanding of fire behaviour in eucalypt forests. This work has resulted into the McArthur Mark 5 Forest Fire Meter. The Meter can be used to calculate the Forest Fire Danger Index, but it also can be used to predict the behaviour (including estimated rates of forward spread and spotting distances) of individual fires under various fuel, weather and topographical conditions. The Meter is commonly used throughout the south-eastern States of Australia by organisations with fire management responsibilities in native forests.

Alexander (1990) comments on the relationship between fire behaviour in eucalypt forests and softwood plantations, quoting the work of others as follows:

> *"Cheney (1970) has indicated that 'Experiments in Australia have shown that there is little difference between the behaviour of eucalypt and pine fires except in the very high to extreme category when spotting becomes an important factor in the spread of eucalypt fires.' There is collaborative evidence for this statement ...."*

Alexander goes on to indicate that the McArthur Meter has often been used to predict fire behaviour in softwood plantations and that *"This fire behaviour guideline is deemed to be most relevant to intermediate to middle-aged plantations which have been pruned and thinned and carry ground and surface fuel loads of 10 to 15 t/ha."*

Despite these comments, Project Vesta is indicating that in its present form the Meter under-predicts fire behaviour at the higher levels of Fire Danger, and its application in predicting fire behaviour is therefore under review. It is also likely that, instead of using one Meter to forecast Fire Danger and predict fire behaviour, individual Meters will be prepared specifically for each purpose. This has already occurred in relation to grassland fires. (See Section 8.6)

8.2. Forest Fire Behaviour Tables for Western Australia – the "Red Book"

Sneeuwjagt and Peet (1985) have produced the 3rd edition of Forest Fire Behaviour Tables for Western Australia (the "Red Book"), and it is used to help predict fire behaviour in six standard eucalypt fuel types. It has also been adapted to predict rates of forward spread in *P radiata* and *P pinaster* plantations, and to assist with the planning and implementation of fuel reduction burning operations in softwood plantations.

> *"The Forest Fire Behaviour Tables* (FFBT) *… use the same underlying procedure to calculate the moisture content of the surface litter for both eucalypt forest and pines. The tables also use the same primary rate of spread relationship between wind and fuel moisture content for eucalypts and pines, but then makes a distinction between* P radiata, P pinaster *and eucalypts to adjust the rate of spread according to the quantity of litter fuel available. The effect of this fuel quantity adjustment is to make* P pinaster *fuel more flammable (i.e. Higher rate of spread) at a given moisture content than* P radiata *which is in turn slightly more flammable than jarrah."* (McCaw *pers comm.*)

McCaw also says that the "Red Book" may well suffer from the same issues as the McArthur Meter in terms of under-predicting fire behaviour at high levels of fire danger, and that this issue is relevant to both eucalypt forests and softwood plantations.

> *"I suspect that because it relies on the same basic relationship between wind, moisture content and rate of spread that jarrah does in the FFBT, then the pine tables might also tend to under-predict."*

Burrows *et al.* (2000) studying the Gnangara Fire of 30 December 1994 found that *"Burning under hot, dry weather conditions ….. the wildfire spread 2-3 times faster than predicted. Over-prediction of fuel moisture content and under-prediction of wind speeds in the plantation contributed to the under-prediction of headfire rates of spread, which exceeded 2000 m/hr."*

8.3. The New Zealand Fire Danger Rating System (NZFDRS)

> *"The New Zealand Fire Danger Rating System is based on the Canadian Fire Danger Rating System. The Canadian Forest Fire Behaviour Prediction (FBP) System is used by New Zealand for two major fuels - grasslands and* Pinus radiata *plantations with very good correlation between observed and predicted fire behaviour at low to moderate wind speeds."* (P Baker[4] *pers comm.*)

The NZFDRS is depicted diagrammatically in Appendix 1. It is derived from the Canadian Forest Fire Danger Rating System, and includes:

- A Fire Weather Index (FWI) module that produces a set of codes and indices based on the current and preceding weather conditions, which estimate the relative flammability and availability of fuels and their effect on potential rate of spread and intensity.
- A Fire Behaviour Prediction system, which combines the FWI spread indicators with data on fuel type and topography to make quantitative predictions of fire behaviour. It has been adopted in part in New Zealand, with several of the Canadian fuel models being used for fire danger rating and fire behaviour prediction for two major fuel types as mentioned above by Baker.
- An Accessory Fuel Moisture System. This is an incomplete system being developed to allow the estimation of fuel moisture content for a range of components (e.g. elevated scrub, twigs, grass, forest litter) and larger woody material.
- A Fire Occurrence Prediction System. This has not yet been developed fully in Canada, but it aims to combine causes of ignition and their location as a means of predicting the probability of ignition from both natural (ie. lightning) and human causes.

The NZFDRS (Alexander 1994) that is relevant to forested areas is based upon five classes of fire danger as shown in Appendix 1.

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[4] P Baker, National Rural Fire Authority, New Zealand

Pearce *et al.* (2004) compared fire behaviour in softwood plantation compared with the behaviour predicted by the NZFDRS and found, *"the predictions made using the forest models compare relatively well with fire behaviour observations made soon after the fire's ignition."*

Fogarty *et al*. (1996) similarly compared fire behaviour and predictions and they commented that *"... the....coniferous plantation models* (in the NZFDRS*) provide reasonable estimates of fire spread rates, particularly in severe weather conditions."* They indicated a cautious approach is still required in the use of the system for prediction of fire spread rates by stating, *"However, the Fire Behaviour Prediction System component of the New Zealand Fire Danger Rating System has not yet been adequately validated and interpreted for New Zealand conditions."*

8.4. Project Vesta

Project Vesta is being undertaken by CSIRO in collaboration with Department of Conservation and Land Management, Western Australian land management agencies and fire authorities in other States.

It is designed to*:*

- *"Quantify the changes in the behaviour of fires with the characteristics of high-intensity wildfires in dry eucalypt forests as fuels develop with age. (i.e. time since last fuel reduction burn)*
- *Develop new algorithms describing the relationship between fire spread and wind speed, and fire spread and fuel characteristics. (eg. fuel load, fuel structure, etc.)*
- *Develop a National Fire Behaviour Prediction System for dry eucalypt forests.***"**

Although Project Vesta is still underway preliminary results indicate that:

- ***"The McArthur forest fire spread table under-predicts***

  The fire spread table on the back of the McArthur Mk 5 Forest Fire Danger Meter under-predicts the potential rate of spread (ROS) for most fire danger indices.

- ***Shrub fuel is important in fire spread***

  Forest fires in fuels with a developed shrub layer taller than 1 metre can spread up to 3 times faster than predicted by McArthur's forest fire spread table. Fires in litter fuels with a low shrub layer can spread 2 times faster.

- ***Watch out when the wind speed is 15 km/h***

  There appears to be a threshold wind speed around 12-15 km/h in the open that makes a huge difference in the behaviour of forest fires. Fires in heavy fuels may spread deceptively slowly, well below their potential ROS, when the wind speed is below the threshold. A slight increase in wind speed can result in a sudden jump in fire behaviour.

- ***Forest winds are spatially very variable***

  Fire behaviour observed at one location is not the same elsewhere in the forest. Detailed wind measurements showed that gusts under the canopy did not travel more than 40 m. Five-minute mean wind speeds at one location can be ± 20% of the measured value at another location. This can make a big difference in fire behaviour, particularly around the threshold wind speed.

- ***Line fires don't wait***

  A fire starting from a line greater than 100 m long will burn at its potential ROS immediately. It may take 2-4 minutes for the flames to develop their full dimensions but the fire is already travelling at full speed before this happens. Conversely, a fire lit from a point ignition and whose head fire remains narrow may spread all day and still not reach its potential ROS."

At least some of the implications for using the McArthur Mark 5 Forest Meter from the results so far available from Project Vesta are:

> *"The fire spread table in McArthur's Forest Fire Danger Meter was derived from relatively small fires of intensities generally less than 2000 kW/m, and observational reports of spread of wildfires. McArthur's table may still predict reasonably well during the first hour of development of a fire if the head fire remains narrow - but be aware that there could be a sudden jump in fire behaviour if the head fire becomes wider. Under prescribed burning conditions satisfactory results will be achieved using the accepted prescribed burning guide."*

In relation to Western Australian conditions and Project Vesta:

> *"We are proposing that the main reason for the under-prediction of the FFBT (the Red Book) and the McArthur Forest Meter relates to the size of the fires on which the original research was based and the fact that they had not achieved their full potential rate of spread at the time when they were measured. The extent of under-prediction for pine may be somewhat less than for jarrah because the fuel load multipliers for pine are quite large for heavy fuels and dry conditions."* (McCaw *pers comm.*)

Why include this work in a paper on fire in softwood plantations? Apart from the differences that are obvious between eucalypt forests and softwood plantations in terms of the potential for medium and long distance spotting, the rates of forward spread that are possible in both classes of forest are very similar. There is every reason to believe that the fundamental principles arising from this work will apply to softwood plantation fuel complexes as well. Certainly, at this stage of our knowledge, every firefighter should be aware that dramatic changes in fire behaviour within a softwood plantation might also occur as a result of factors similar to those outlined above as preliminary results from Project Vesta. For example, a small fire that has been spreading very slowly may suddenly spread very rapidly if even a small increase in wind speed occurs so as to reach the critical threshold referred to earlier.

8.5. Other related work

Fernandes *et al.* (2002) working in *P pinaster* in Portugal indicate that:

> *"Three potentially interesting alternatives to predict fire spread rate in maritime pine stands* (in Portugal) *were identified, respectively the Forest Fire Behaviour Tables for Western Australia (FFBT) (Sneeuwjagt & Peet 1985; Beck 1995), the Canadian Forest Fire Behaviour Prediction System (CFFBPS) (Forestry Canada Fire Danger Group 1992), and the model of Rothermel (1972)."*
>
> And
>
> *"Performance of the three systems is unsatisfactory. They all tend to underestimate fire spread rate and to produce biased estimates, and paired tests indicate significant differences between observations and predictions."*
>
> And
>
> *"None of the systems can be recommended for use in prescribed burning operations."*

However, in Section 9.3.2 it is noted that the FFBT for Western Australia are considered to be *"working fairly well"* as a guide to the conduct of fuel reduction burning operations in *P pinaster*. McCaw (*pers comm.*) believes that this matter is worthy of further investigation but also that *"the reasons for the tendency to under-prediction found by Fernandes et al.(2002) have not yet been clearly established. It may be due to subtle differences in the fuel bed between* P pinaster *stands in Australia and Portugal. It may also be related to differences in the ignition techniques used in the original Australian experiments and the subsequent validation by Fernandes et al. (2002)."*

8.6. The Grassland Fire Danger Meter and Fire Spread Meters

The Grassland Fire Danger Meter and Grassland Fire Spread Meter (Cheney and Sullivan 1997) are tools commonly used by rural fire agencies in Australia. The Fire Danger Meter *"employs only one fuel variable, degree of curing. Combined with temperature, relative humidity and wind speed, this gives an index of the degree of difficulty of suppressing fire in a standard, average pasture carrying 4 t/ha. The five fire danger rating classes – Low, Moderate, High, Very High and Extreme – represent the degree of suppression difficulty in such a pasture. These classes were defined by A.G. McArthur in 1966 and remain widely accepted."* The Fire Spread Meter *"predicts a fires potential rate of forward spread across continuous grassland in gently undulating terrain."*

8.7. Summary comments

- In New Zealand the evidence is that, based on some studies comparing actual with predicted fire behaviour, the NZFDRS provides a useful guide to likely fire behaviour in softwood plantations. However, there is also a note of caution that more information is required to be confident that the System will works across the range of conditions that can be encountered.
- In Australia, there is evidence that the McArthur Mark 5 Forest Fire Meter, and the Forest Fire Behaviour Tables used in Western Australia, underestimate fire behaviour in eucalypt forests at higher levels of Fire Danger. There is every reason to believe that the same concern exists in relation to the use of both systems for predicting fire behaviour in softwood plantations at high levels of Fire Danger.
- Project Vesta, when completed, should assist in resolving at least some of these concerns with respect to softwood plantations, even though it is being conducted in eucalypt forest fuel types.

9. Protecting Softwood Plantations from Wildfire

This Section focuses on actions that can be taken to protect plantations from wildfire. Later sections look more specifically at the interface between plantations and the protection of community assets, and specific aspects of wildfire suppression in softwood plantations.

9.1. Principles

The basis for protecting softwood plantations from wildfire should be established during planning for plantation establishment. This principle, together with others that should operate once the plantation is established, is identified in a number of publications.

The Fire and Emergency Services Authority of Western Australia, (FESA 2001) *"...promotes that potential fire protection should be recognised in the early stages of plantation development and that appropriate action is taken to reduce possible hazards. It is widely recognised that attention to fire protection early in the life of a plantation can dramatically reduce future risks and costly fire protection measures."*

Cheney & Richmond (1980) recognise that:

"Four principal aspects of plantation design affect fire protection. These are:

- *The shape and size of discrete planted units.*
- *The intensity and standard of access.*
- *The provision for firebreaks and/or fuel breaks.*
- *The distribution of age classes through the area.*

The Victorian Code of Practice for Fire Management on Public Land (Department of Sustainability and Environment-DSE 1996) also establishes a number of principles that should be considered when planning for, establishing and protecting plantations. The principles are:

- *"When planning and establishing plantations the need for a strategic network of perimeter and internal fuel breaks, according to the risk of wildfires entering or spreading from the plantation and the difficulty of suppressing fire within the plantation must be considered.*
- *Perimeter and internal fuel breaks in a plantation must be of a width which, in addition to satisfying wildfire suppression objectives and firefighter safety requirements, reflects the likelihood and economic consequences of being crossed by wildfire.*
- *Where a plantation adjoins native vegetation and wider boundary protection is necessary, additional fire protection measures in both the plantation and the adjoining vegetation must be considered.*
- *Where the plantation and native vegetation have separate managers, the plantation manager must seek the cooperation of the owner, occupier or manager of the adjoining land in implementing measures which reflect, as far*

as possible, the risk of fire spreading from one area to the other and the protection benefit of those measures to each respective land manager.

- *When establishing new plantation which abuts residential areas, consideration must be given to any perimeter setback guidelines contained in the local municipal planning scheme."*

9.2. Plantation design

9.2.1. Consolidation or dispersal?

In Australia the largest areas of plantation (ACT, Jan 2003 and South Australia, February 1983) have been burnt when fast moving wildfires have entered from outside the plantation. (Appendix 2) This history therefore raises the question of whether, all other considerations being equal, it is better to have a consolidated or a dispersed plantation estate.

Cheney (1988) expressed the following view on this issue:

> *"The Australian experience is that where protection is difficult, fire protection is most efficient in large concentrated plantation units even though the potential for loss from a single fire is high. Where the main fire threat comes from outside the plantation the external boundary should be as short as possible and located where access and fire suppression is easiest."*

Billing (1983) examined wildfire suppression operations related to the protection of four relatively small plantations in south-western Victoria during the late hours of Ash Wednesday. The plantations adjoined, or were surrounded by, native forest. Even under FFDI's between 5 and 7, two of these plantations could not be saved. The firebreaks were of poor standard and once the fires entered the relatively young plantations suppression was impossible. *"Young plantations are particularly vulnerable once fire enters a plantation because the restricted access and poor visibility make attack difficult, and the almost continuous arrangement of fuel promotes crown fire at quite low FFDI's. If a fire enters a young plantation on a wide front substantial losses are inevitable, even at relatively low FFDI's."*

One of the reasons for the poor condition of the firebreaks was that long lengths of firebreak were required to protect relatively small areas of plantation. The two smaller plantations, of 80 ha and 85 ha, required a kilometre of properly maintained firebreak for every 19 ha of plantation. Works to protect small plantations will cost more per hectare than works to protect large plantations, and the costs may well be prohibitive for small growers.

9.2.2. Firebreaks generally

External and internal firebreaks are common features of large plantations. They are not only designed to provide impediment to fire spread in the absence of fire suppression forces, but also to provide access and well established control lines from which back burning and other fire suppression operations can be conducted effectively. Their size and location will be determined by such factors as the risk of a fire entering the plantation from surrounding areas, the level and extent of fuel modification that can be undertaken in the plantation and surrounding areas, the expected requirement to move large machinery and other vehicles and plant into and through the plantation, and the need to provide safe access at all times for personnel involved in fighting a fire.

Some examples of these considerations in relation to “Boundary Firebreaks” are provided in a draft discussion paper prepared by State Forests of NSW (2004).

> *“**Primary Objective**: Boundary firebreaks provide access into the plantation and adjacent vegetation from the boundary for 4WD firefighting vehicles up to Category 1 fire tanker capacity (up to 4000 litre water capacity).*
>
> > *Notes: Apart from providing access into the plantation and adjacent vegetation, boundary breaks if maintained as mineral earth breaks (which is not always necessary or desirable) may also serve to prevent low intensity fires from entering the plantation.*
> >
> > *Like all fire breaks they may be useful for mounting direct and parallel attack on flank fires. They are not designed to provide a barrier to crown fire or fires beyond direct or parallel attack intensities, nor are they designed as places to conduct headfire attack on such fires.*
> >
> > *In strategic areas, boundary firebreak width may be increased with the duel objectives of increasing the likelihood that unattended low intensity fires do not enter the plantation, and to facilitate efficient back burning from the plantation boundary in the event that indirect firefighting methods are required to prevent uncontained fires entering the plantation.*
>
> And:
>
> *“Additional considerations for widening boundary breaks:*

- *Where fire prone forest or heath abuts the plantation boundary (particularly in the direction from which adverse fire weather comes) and there is limited opportunity (by way of natural or man-made features) in the landscape to contain forest fires before they reach the plantation, wider boundary breaks should be considered to facilitate more efficient indirect firefighting from the plantation boundary.*
- *Where areas of high fire ignition frequency are adjacent to the plantation, wider breaks should be considered to reduce the likelihood of ignitions entering the plantation.”*

McArthur *et al*. (1966) made a number of comments related to plantation design after their examination of the Wandilo Fire of 5 April 1958. Their view was that:

> *“Firebreaks of one chain* (20m) *width were generally sufficient to hold flank fires during the course of this fire. It is considered, however, that breaks of ½ chain* (10m) *width would also have served adequately ...”*

They also warned of the danger of breaks in the plantation canopy creating the possibility of dramatic increases in wildfire behaviour associated with the impact of those breaks on wind speed and direction.

Cheney (1988) makes extensive comment about the usefulness of firebreaks:

> *"Fire breaks are most effective against grass fires and their effectiveness reduces dramatically where wooded or forested areas are adjacent to the plantation estate (Wilson 1988). In these areas, firebreaks need to be combined with protective burning around the external boundary sufficient to prevent wildfires spotting into the plantation. Firebreaks are of little use unless they are associated with a trafficable road. The requirement for internal firebreaks is greatest when the plantations are young, the fuels are mostly grassy, and the forest has not developed a high spotting potential. Under these conditions wide internal firebreaks provide additional security for fire fighters when high flames can occur under moderate weather conditions and visibility within the plantation is low due to low green branches and dense fuels. As the plantation ages the requirement for wide firebreaks is reduced and internal roads designed for logging and fire access is sufficient to assist fire fighters to suppress surface fires."*

History says that major wildfires will not be stopped from entering plantation areas by even significant firebreaks. That does not mean they do not add to the overall level of protection given to a plantation area, but it does mean that care is required when their effectiveness in a major wildfire situation is being considered. Cheney (1970) also points to some of the possible disadvantages of firebreaks**.**

> *"While wide firebreaks give one a feeling of security, particularly when the forest is young, they have several severe disadvantages:*
>
> - *They are generally not wide enough to be effective against a high intensity fire which is throwing spotfires........*
> - *They channel the wind flow along the firebreak and cause severe turbulence on the edge of the plantation. This often results in a fire increasing in severity as it approaches the firebreak and increases the chance of spotfires being thrown across the firebreak*
> - *Wide firebreaks are expensive and costly to maintain........."*

Beer (1990) quotes work which supports the earlier comments of McArthur *et al.* (1966) in that it *"...implies that firebreaks whose width exceed the canopy height will experience increased wind speeds - and at two canopy heights the canopy wind will be transferred down to the firebreak."*

9.2.3. External firebreaks

Firebreaks on the external boundaries of a plantation will play a critical role in limiting the spread of wildfires burning under conditions of Low to Moderate Fire Danger into the body of the plantation, particularly if they are grass fires as Cheney noted earlier. However, what configuration constitutes an external firebreak of acceptable standard?

FESA (2001) in Western Australia recommends *"Firebreaks constructed 15 metres wide on the boundaries of plantations or on such alternative locations as may be agreed between the Local Government Authority and the plantation owner (Figure 1)."*

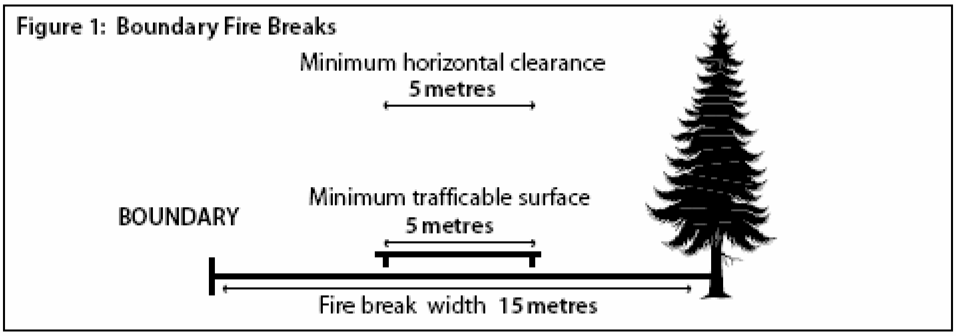

Figure 1. Boundary firebreak configuration recommended by FESA (Source: FESA, 2001).

The Forest Owners Conference (FOC) involves nine major plantation growers in the Green Triangle Region of south-eastern South Australia and western Victoria. The FOC (2003) publication indicates:

"All plantations need an external boundary firebreak. This shall consist of either:
- *A 20m wide break (external to the plantation) or*
- *A 10m wide break (external to the plantation) plus a 10m fuel modified zone (within the plantation).*

And:

"Fire breaks adjoining public roads must be constructed to a width of 15 metres."

Bartlett (2004) comments on ACT and NSW practice as follows:

"External firebreaks are generally recommended to be between 10-15 metres wide (in the ACT) *and maintained in a low fuel condition with no overhanging branches for a vertical height of 10 metres. In NSW, they range from 20-50 metres depending on slope and form part of the asset protection zones."*

While firebreaks of these dimensions may be considered adequate for the protection of plantations from fire, they will not be adequate by themselves to separate the plantation from adjoining residences or rural/urban communities. Comments on this issue are contained in Section 11 (Softwood Plantations and Protecting Communities from Wildfire).

9.2.4. Internal firebreaks and access

Internal firebreaks and access trails within plantations are provided to meet a range of objectives. Recognising this, there is no 'one-size-fits-all' prescription for internal breaks and trails. Firebreak dimensions and characteristics will be determined by their purpose. Some access trails need to provide access for larger vehicles such as fire tankers and prime mover/float combinations carrying large bulldozers. Other access trails may only need to provide access for small four wheel drive utility type initial attack vehicles. A number of systems are in use to classify or categorise fire trails. In a number of jurisdictions, fire trails are categorised into different standards according to the purpose of the trail. Below is description of a typical two-level fire trail classification system:

Primary fire access roads

Primary Objective: To provide suitably trafficable access into and out of plantation areas for firefighting resources including heavy vehicles/equipment – eg. Heavy fire tankers (up to 4000 litre water capacity) and large dozers (floated in) for plantations of a size that requires internal access in addition to access from the plantation boundary.

> *Note: These roads are not designed to provide a barrier to crown fire or fires beyond direct or parallel attack intensities, nor are they designed as places to conduct headfire attack on such fires. Primary access trails often provide suitable areas from which to conduct direct or parallel attack on small fires or flank fires to contain the spread and size of fires. These also usually provide the primary escape route from the plantation in the event of rapid fire escalation.*

Points of consideration:

- Need to be trafficable by trucks with float carrying large dozer.
- Need to serve network of secondary fire access trails/firebreaks.
- Need to consider a plantation size threshold for heavy machinery float access provision (e.g. 500ha).
- Planting setback from road should be such that edge-row branches of mature trees do not encroach on the road edge and maintain access to vehicles.
- Primary access provision for heavy plant in the plantation difficult to justify if local public road network does not provide for floated plant/heavy truck access.

Secondary fire access trails and internal breaks

Primary Objective: To provide access within the plantation for 4WD firefighting vehicles. On fire trails access for up to heavy fire tanker capacity (up to 4000 litre water capacity). On fire breaks access for light 4WD first attack units (<650 litre capacity).

> *Note: These firebreaks and trails provide for closer access to plantation compartments (beyond that provided by primary access roads), for initial attack and low intensity fire containment purposes. These can include paved and unpaved single lane roads (providing access to major sections of plantation), and unformed four wheel drive easements/tracks. In newly*

established plantations, a significant proportion will be unformed, with road formation works progressively undertaken as required for harvesting.

Points of consideration:

- Need to be trafficable by 4WD firefighting vehicles (single lane) up to Heavy Fire Tanker on trails, and by light 4WD vehicles on fire breaks.
- Dead ends to be avoided where practicable – where dead ends are unavoidable a turnaround area providing for three-point turn around by heavy tankers should be provided (12 metres).
- On single lane trails, provision for vehicles to pass should be provided at approximately 250 metre intervals or as topography allows.

Examples of standards in use include:

In the Green Triangle the FOC (2003) says:

"*Large plantations should generally be divided into units, not exceeding 400ha, by firebreaks ..."*

And:

- *"All access tracks shall, where possible be a minimum of 7m wide to allow for the simultaneous access of two fire trucks. Pruning may be required to achieve a minimum clearance for fire truck access to 7m in width and 4m in height.*
- *Vehicular access tracks shall where practicable, enclose individual plantation units of such dimensions that a hose lay can reach any point in the unit. Generally units will not exceed 40ha in size."*

In Western Australia, FESA (2001), the areas defined as compartments size may be described differently because:

"If potential losses are to be minimised, there must be an emphasis on safe internal access for firefighters. The recommended maximum compartment size for both pine and eucalyptus species plantations is 30 hectare compartments. Up to 100 hectares may be considered depending on prevailing conditions such as local climate, terrain, topography and proximity to local development."

"Internal firebreaks between compartments of up to 30 hectares must be a minimum of 6 metres wide and for compartments over 30 hectares, a minimum of 10 metres wide. In all cases a 5 metre running surface should be maintained to allow access by firefighting appliances. (See Figure 2)*"*

"Note: *For all fire breaks it may be necessary for trees on both sides of firebreaks to be progressively pruned to a minimum height of 4 metres to allow unrestricted access for maintenance and firefighting equipment and so as to maintain an effective width of fire break."*

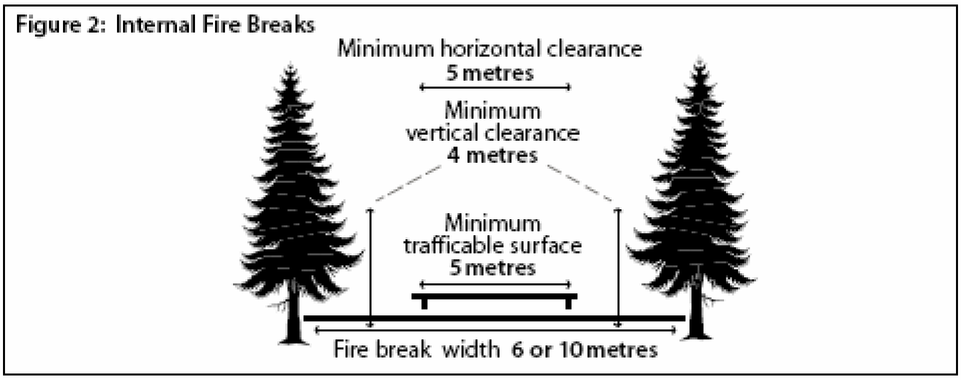

Figure 2. Internal firebreak configuration recommended by FESA). (Source: FESA, 2001)
Notes: For compartments up to 30 hectares internal fire break width should be 6 metres.
For compartments over 30 hectares internal fire break width should be 10 metres.

Bartlett (2004) says, "*Internal firebreaks are generally recommended to be between 8-10 metres wide and aligned on a grid pattern 600 to 800 metres apart. To enhance their effectiveness, some plantation managers conduct fuel modification (eg. high pruning and shrub removal) within adjacent stands up to 80 to 90 metres on the northern and western sides of the firebreak and 30 to 40 metres on the southern and eastern sides of the firebreak.*"

On the basis of the FESA and FOC documents, the area recommended for enclosure by suitable vehicular access is of the order of 30-40 ha, with trafficable surfaces varying from 5 to 7 metres in width. The areas mentioned by Bartlett are somewhat larger, varying from about 35 ha to 65 ha.

6.2.5. Managing plantation fuels

As early as site preparation, steps can be taken to minimise fire hazard. Activities to reduce the hazard can then occur at strategic locations through the rotation as deemed necessary.

> **"***Fire management of plantations is facilitated if fuel management is planned from the inception of the plantation program and silvicultural techniques are scheduled to avoid excessive fuel accumulations.*" (Cheney 1988)

Cheney (1988) considered the following practices important:

- Completely remove large debris from the converted forest or previous rotation so access is not impeded.
- Control grass and herbaceous weeds.
- Consider grazing as a fuel reduction option in the years before canopy closure.
- Use establishment practices that achieve rapid growth and early crown closure to suppress grasses and weeds.
- Retain a high stocking, by replanting if necessary, to avoid adverse wind patterns in a wildfire situation.
- Remove unwanted stems in the first 2 to 3 years after planting before they contribute substantial fuel loads.

- Form prune as early as possible to remove large 'wolf' branches.
- Conduct required pruning operations at short intervals to prevent excessive accumulations of pruning debris.
- Consider prescribed burning or mechanical treatment to reduce fuel hazards.

Table 4 and Table 5 have already indicated the potential benefit of pruning in mitigating wildfire behaviour. McArthur (1965) used data from studies of three wildfires to indicate the potential beneficial impacts on fire behaviour of pruning (Figure 3). *"All other factors being equal, a fire in an unpruned plantation will spread almost three times as fast as one in a pruned plantation."* However, McArthur also qualified the results shown in Figure 3 by indicating that *"Logic would suggest that beyond an index of 50 .... long-distance spotting would result in greatly increased rate of spread and the spread in pruned plantations may approach the unpruned rates of spread."* More recent work suggests that any difference between pruned and unpruned stands would diminish at higher FDI's although the explanation is more likely to be associated with factors other than '*long-distance spotting*'. Pruning will assist fire suppression operations, but it alone will not prevent crown fire formation and rapid fire spread under conditions of Very High to Extreme Fire Danger.

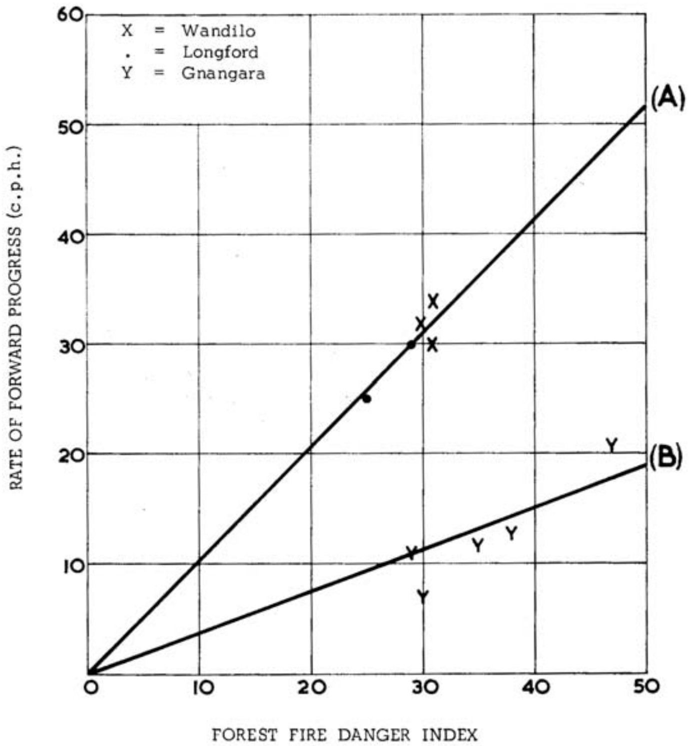

Figure 3. Rate of spread in exotic pine plantations vs. Forest Fire Danger Index
(A): In unpruned *P radiata* plantations at Longford *(Victoria)* and Wandilo, South Australia,
(B): In pruned *P pinaster* plantations at Gnangara, Western Australia (Source: McArthur 1965).

In the short term, the increased elevated fuel load created at ground level may offset the benefits of a pruning program. Burrows (1980a) working in *P radiata* after thinning found that a scrub roller could effectively reduce the fire hazard created by thinning slash. Best results were obtained when the slash was older than 20 months when, in subsequent test fires, *"flame heights and rates of spread were reduced by up to 65%"* under mild burning conditions. Mechanical treatment in strategic areas to reduce elevated fuel loads following pruning or thinning will help to reduce wildfire rates of spread.

Just as with fuel reduction burning, pruning modifies the fuel arrangement and makes it harder for crown fire formation to occur. It also expands the 'window of opportunity' for firefighters to achieve early control. (See Section 9.2.6)

9.2.6. Strategic fuel modification programs

"While they remain on the surface (i.e. do not climb into the crowns), forest (softwood plantation) *fires can be combated in most circumstances."* Forestry South Australia (1996) describes an approach for achieving fuel modification over large strategic areas, or Fuel Modified Protection Areas (FMPA), of plantation to:

- *"Protect assets within or near large plantation areas.*
- *Reduce intensity and rate of spread of fire, increasing the likelihood of suppressing fires in initial attack.*
- *Provide safer access routes in time of fire and safe areas from which fire suppression forces can operate.*
- *Reduce the overall size of fires in large plantation areas."*

Gill (2001) traces the history of the development of FMPA's in South Australia dating from experiences in the 1983 Ash Wednesday fires, and the original concept of creating Crown Fire Free Zones (CFZZ).

> *"The CCFZ concept has been traced back to South Australia where it is now called the fuel modified zone (FMZ) or Fuel Modified Protection Areas (FMPA) of pine plantations in the southeast portion of the State. Currently there are about 1000 ha of FMZ in SA. FMZ is preferred to CFFZ because the latter implies the absence of crown fires, an inadvertently misleading terminology because crown-fire free cannot be guaranteed."*

The characteristics of FMPA's (derived from Forestry South Australia 1996) are:

- Have a minimum width of 200 metres and enclose areas of up to approximately 3,000 ha.
- Fuel modification commences at a very early with low pruning at 5-6 years, high pruning at 7-8 years and non-commercial thinning of every 5th row for improved access and mechanical treatments to reduce fuel hazards.
- Older stands that are to be included in FMPA's may not be able to receive all these treatments in the first rotation, but fuel modification by pruning and mechanical treatment is used wherever possible.

The program commenced in 1987 and, by 2001 about 1000 ha of the total planned FMPA area of had been treated in this way. The area to be treated will vary as the age class of the plantation estate recovers to a more normal distribution following the 1983 fires.

Has this strategy of fuel modification worked in practice? The intermittent nature of severe wildfires impacting on softwood plantations means that the approach has not yet been tested under severe conditions. *"I have no examples to date as there has not been a fire that has tested this strip. I can say that there have been many examples of where a 20 metre pruning strip has slowed down a fire or started on the adjacent fire break and moved very slowly into the plantation giving ground crews an opportunity to suppress the fire before it moved into the plantation proper."* (Page[5] *pers comm.*)

9.2.7. Water supply for fire suppression

The following information has been taken directly from a draft Country Fire Authority, Victoria (CFA 2004), paper concerning fire protection of plantations. Although the document is still in draft form, and the specific requirements may vary from region to region across New Zealand and Australia, it does provide a focus on those issues that should be considered in establishing appropriate water supplies for plantation firefighting. The water supply infrastructure established for any particular plantation or group of plantations, will depend very much on the fire climate in the region concerned.

"Principle

Strategically locating an adequate water supply can minimise the turn around time of firefighting resources and thus the proportion of time they may be away from the fire edge. This can enable a restriction of fire spread, and minimise the area burnt.

Guidelines

- *For plantations less than 400 ha in area, a minimum 25,000 litres of water per 40 ha should be accessible to fire fighting vehicles. Each water point is to hold a minimum of 100,000 litres.*
- *For plantations greater than 400 ha in area, a minimum 100,000 litres per 400 ha should be supplied, and storage should be across more than one site.*
- *Water supplies should be located within 3 to 5 km (i.e. a 10 minute drive) of any point within a plantation estate.*
- *Water supplies should be located in an open and clear area (0.1-0.2 ha, flat clearing), such as at or near a plantation boundary.*
- *For plantations greater than 1000 ha, supply should be located on major internal roads or firebreaks.*
- *Immediate access should involve a loop system or adequate turning circle, and generally* (be) *supported by fuel reduction in the immediate area.*

[5] D Page Forestry SA, Mt Gambier South Australia

- *A hard standing area should be provided to allow a fire suppression pump to be within 4 m of the water.*
- *Allowances should be made for lower water levels during the summer months.*
- *Water points may not necessarily be on the property. There could be an appropriate water supply on a nearby property or standpipe which, upon formal agreement with that landholder, be incorporated into the Plantation Fire Protection Design.*
- *Water supplies should be clearly signposted and wherever possible be consistent with the local CFA standard.*
- *Water supply, its access, capacity and signage etc should be checked and maintained prior to each fire season.*
- *Consideration should be given to access to the water supply by helicopters.*
- *Water supply access should meet the design guidelines for internal access tracks, and the Code of Forest Practices for Timber Production (1996) with respect to road design, coupe design, etc.*
- *Supplementary or alternate water supplies to water points can include bores, tanks and the use of water tenders. If these are being used as an alternative to water points, availability, reliability and performance standards need to be documented and formalised."*

9.3. Fuel reduction burning in softwood plantations

"Hazard reduction burning reduces fire behaviour by:

- *Reducing the speed of growth of the fire from its ignition point;*
- *Reducing the height of flames and rate of spread;*
- *Reducing the spotting potential by reducing the number of firebrands and the distance they are carried downwind; and,*
- *Reducing the total heat output or intensity of the fire.*

Prescribed burning is not intended to stop forest fires, but it does reduce their intensity and this makes fire suppression safer and more efficient. Prescribed burning is not a panacea nor does it work in isolation. It must be used in conjunction with an efficient fire fighting force." (Cheney 2004)

Fuel reduction burning is practical, from the point of view of achieving low fire intensities that reduce fuel quantities but have limited or no impact on stand growth and wood quality, in four of the major softwood species planted in New Zealand and Australia. i.e. *P radiata*, *P pinaster* , *P elliottii* and *P caribaea*. (Section 4, Fire Sensitivity of Softwoods.) However, while very little, if any, low intensity prescribed burning is used in *P radiata* to manage fuel loads, active programs are in place for *P pinaster* in Western Australia, and *P elliottii* and *P caribaea* in Queensland.

Although fuel reduction burning in *P radiata* is possible, deMar[6] (*pers comm.*) indicates why, in NSW at least, it is not part of routine practice. *"One of the major reasons that prescribed burning trials under radiata pine in NSW didn't proceed to more routine practice, is that in many places where it was tried, there were significant*

[6] P deMar Forests New South Wales

issues around re-ignition. Due to fuel moisture variability within burning sites, particularly sites with variation in topography and aspect, prescribed burns did hold-over in the duff layer and old stumps etc in dryer areas, introducing significant ignition risk later in adverse weather and generating significant patrol costs. Accordingly, prescribed burning under radiata pine is somewhat of a resource intensive practice requiring frequent application for best results, and limited to relatively small and strategic areas such as in high community risk areas."

9.3.1. Fuel reduction burning in radiata pine plantations

Considerable research was done in Victoria in the mid 1970's to early 1980's to look at aspects of fuel characteristics and fire behaviour in *P radiata* plantations. Burrows *et al.* (1988a) also report on research conducted in Western Australia.

Woodman and Rawson (1982) summarise much of the Victorian work as follows:

> *"During spring, and under carefully prescribed conditions of fuel moisture and wind speed in particular, fuel reduction burning in both the needle litter layer and elevated fuel from thinning can be conducted with safety. Operations confined to stands aged 11 years or older should cause little or no stem damage and no reduction in stand growth.*
>
> *After first thinning operations fire can also be used, as an alternative to pruning, to remove much of the dead needle fuel from the lower crown."*

This work produced three very simple burning guides, all based on burning being conducted during winter or spring when moisture levels in the duff layer are high enough to prevent that layer being ignited. Those guides are provided in Appendix 4. The guides generally involve wind speeds, measured inside the plantation, of less than 5 km/h, surface fine fuel moisture contents of 12%-20% and elevated fine fuel (from pruning or thinning) moisture contents of 15%-22%. Burning of dead needles held in the lower branches of trees retained after first thinning generally requires fine fuel moisture contents of 25%-35% although, under some circumstances, *"because they are extremely well aerated the aerial fuels can sustain burning at moisture contents up to 45%."* Further evidence of the influence of fine fuel moisture contents on fire behaviour in *P radiata* is provided earlier in Table 6.

However, while under conventional thinning regimes these burning guides proved to be acceptable, Norman (1985) examine how the burning guide can be applied in stands that had been very heavily first thinned in north-eastern Victoria. He conducted experimental fires in stands where fuels (fine and heavy) after thinning totalled approximately 83 t/ha, or about twice the load found after thinning operations where earlier experimental burning was conducted. In addition the fuel was concentrated in just 30% of the stand area. Under these conditions, unacceptable levels of scorch and stem damage occurred using the burning prescriptions described earlier.

The importance of ensuring the duff layer is too moist to ignite and continue to burn is also emphasised by Woodman and Rawson (1982), and further information on this issue has already been presented in Table 3. The important influence lighting technique can have on fire intensity is also highlighted.

The reduction in fuel loads achieved appears to last for about 18 months to two years in young stands, while the fuel loads appear to remain lower for longer periods in older stands. There was also some evidence that successive burning resulted in reduced fuel loads for longer periods in young stands.

9.3.2. Fuel reduction burning in maritime pine plantations

The Western Australia "Red Book", described earlier, provides guidance for fuel reduction burning in both *P radiata* and *P pinaster* plantations. The general conditions considered suitable for both species are similar to those developed in Victoria and they are presented in Appendix 4.

Fuel reduction burning in *P pinaster* plantations has been undertaken for a number of years within plantations managed by CALM or its predecessors. McCaw (*pers comm.*) indicates that an average area of 5840 ha/yr of *P pinaster* plantation has been fuel reduced by low intensity prescribed fire over the 11 years from 1992/93 to 2002/03, equivalent to about 20% of the estate per annum. In addition *"the FFBT are used for prescribed burning, mostly in* P pinaster, *and are judged by most practitioners as working fairly well. Most of this burning is done in late autumn and winter making use of periods of fine stable weather with light winds. Aerial ignition from a helicopter is a routine operation in* P pinaster *plantations in WA."*

He also indicates that the fuel reduction burning program has *"made a fundamental contribution to the establishment and sustainability of Maritime Pine plantations on the Swan Coastal Plain in WA. The hot dry Mediterranean climate, and high level of ignition resulting from arson within the plantations adjoining the outer metropolitan area, provide ample scope for large scale fire losses every summer. Without an active program of fuel management, fire losses could escalate to a level that would threaten the sustainability of the plantation enterprise."*

Recent work by Fernandes *et al.* (2004) in a 28-year old *P pinaster* plantation in north-eastern Portugal has also demonstrated the beneficial effects of fuel reduction burning. In areas that had been fuel reduced two and three years prior to experimental burning under conditions where *"a high-intensity fire involving partially or totally the tree canopy and killing all trees was experienced in the ….. untreated part of the stand …. the benefits of fuel management were still detectable …. Surface fire intensity, crown fire potential and fire severity (including tree mortality) were drastically reduced where prescribed fire had been carried* (out) *recently.*"

9.3.3. Fuel reduction burning in slash pine plantations

Byrne (1980) describes a Prescribed Burning Guide for *P elliottii* plantations in Queensland based upon experimental fire data collected in Queensland and elsewhere.

The Guide is based upon:

- Recognition of five fuel types. (See Section 6.3)
- Recognition of acceptable maximum flame heights (and therefore scorch levels) for the stands concerned.
- Calculation of the amount of fuel available for burning based on to the number of days since at least 7 mm of rainfall.
- Prediction of rates of fire spread and flame heights based on wind speed and relative humidity.
- The implementation of an appropriate lighting pattern.
- Burning in the months of March to June when the BKDI is less than 200 points.

Initial trials began in 1967, and in 1974 the technique was first used on a large scale. *"Approximately 3,500ha of slash and caribaean pine were burnt at Tuan, Toolara, Beerburrum and Byfield during the winter of 1975"* (Department of Forestry, Queensland 1976). Byrne and Just (1982) also describes the first trials of aerial methods to conduct fuel reduction burning operations in Queensland plantations.

The importance of controlling the lighting pattern and the rate of lighting in such operations was highlighted during the 1975 operations mentioned above. Although the results obtained were considered to be generally excellent, "*In almost every instance where scorch occurred, inexperience on the part of the lighting crew was responsible rather than selection of inappropriate burning conditions by the officer supervising the operations.*" (Department of Forestry, Queensland 1976)

The impact on fuel levels of these operations is also described by Byrne (1980), as *"... for practical purposes, it can be assumed that fuel quantities over most plantation areas almost fully recover* (to) *pre-fire levels three years after a low intensity fire."*

The beneficial impact fuel reduction burning can have was illustrated on 14 August 2004 when, under conditions of Very High Fire Danger, a wildfire near Beerburrum was controlled quickly because of the rapid response by suppression forces and the presence of an area that had been fuel reduced in 2003. *"This fire had the potential to seriously affect several hundred hectares. The 2003 prescribed burn had slowed the initial rate of spread, allowing the first crews on the spot to quickly contain it."* (Stark[7] *pers comm.*) In addition, one of the Beerburrum fires that originated on 6 November 1994 (Appendix 3) burnt through about 900 hectares of pine plantation that had been fuel reduced in the previous winter. Although the conditions were too severe for the head fire to be contained, some 250 hectares of the total of 900 hectares burnt did not have to be salvaged because of the reduction in fire intensity that was achieved. (Stark *pers comm.*)

[7] B Stark Department of Forestry, Department of Primary Industries, Queensland

The average area of fuel reduction burning in exotic plantations in Queensland between 1981/82 and 1999/00 was 12,200 ha/yr and the target is now about 10,000 ha/yr of the 130,000 ha managed by the Department of Forestry, Queensland.

9.4. Summary comments

- Planning to protect a softwood plantation from wildfire should commence before planting occurs.
- External boundary firebreaks that are approximately 20 m wide and readily trafficable will provide good protection under Moderate Fire Danger Conditions from wildfires in grass fuels.
- Internal firebreaks that are approximately 10 m wide and readily trafficable will provide rapid and secure access for first attack under most circumstances.
- First attack will be expedited if the plantation areas enclosed by internal breaks as described above are limited to about 30-40 ha, although there may well be circumstances where it will be too costly to establish such small units.
- Firebreaks, and other gaps in the canopy, can create wind effects that may cause unexpectedly severe wildfire behaviour.
- Strategic fuel modification programs based on thinning, pruning and mechanical treatment or removal of fuels can be implemented to improve plantation protection.
- Mechanical methods can be used to reduce fuel loads and modify fuel arrangements to advantage, and fuel reduction burning can also be used in each of *P radiata*, *P pinaster*, *P elliottii* and *P caribaea*.

10. Fire Suppression in Softwood Plantations

"Plantation fire suppression is based on mounting successful initial attack. The resources required to achieve this objective include early detection, efficient despatching and rapid travel to the fire." (Cheney 1988)

There have been many changes in ownership of softwood plantations in both Australia and New Zealand in recent years, with ownership often having transferred from the government sector to the private sector. Even if ownership changes have brought about changes in the legislative responsibility for fire suppression in the plantations concerned, the fundamental approach to fire suppression should not be changed. Firefighting in softwood plantations, despite the difference in fuel properties from other forest and fuel types, must be based on the same fundamental principles. In simple terms, sufficient personnel need to be well trained, well equipped, well organised and well led. They also need to be well supported by effective planning and logistical arrangements, and capable of working effectively with other fire agencies within the fire control organisation established at the time. The good access that is available into well-managed softwood plantations means that 'wet firefighting' techniques are generally feasible, particularly during first attack. With this in mind, it is worth looking more closely at the principles that should form the basis for fire suppression operations in softwood plantations.

10.1. Principles

The following principles related to plantation fire suppression are derived, in part, from Cheney (1988).

- First attack requires direct suppression. The most effective is rapid application of large volumes of water or chemical retardant at high pressure..............
- Rapid head fire suppression in *P radiata* plantations can be achieved by delivering water at a maximum rate of around 500 litres per minute at a pressure of 1000 kpa through at least 60 m of 20 mm diameter hose.
- A range of tanker sizes is required for efficient initial attack. Small units of about 500 litres capacity have the advantage of speed and manoeuvrability. They are also usually deployed at daily work sites and are therefore available for immediate response. Large units of 4,000 litres and above have longer endurance but are often slow to deploy. A combination of units can ensure that water is continuously available. (See also Section 9.2.7)
- Regardless of the arrangements that are made for equipment or manpower, it is essential that there is permanent core of trained fire fighters who can make up the initial attack forces and can act in a supervisory capacity as crew leaders in extended fire fighting campaigns.
- Where the fire threat is from outside the plantation, and this is more often the case than not, the plantation suppression forces must be fully integrated with those of the surrounding rural community. Suppression forces designed to specifically protect the plantation must also be prepared to operate well away from the plantation itself if the plantation is to be afforded adequate protection.

- Management arrangements for fire suppression should be in accordance with Australasian Inter-service Incident Management System - Incident Command System (AIIMS ICS) (AFAC 2004).

10.2. Fire intensity and fire suppression

The capacity of a fire suppression organisation to control a wildfire will depend on many factors, with one of those being fire intensity. Some guides that give an insight to the difficulty or likelihood of controlling wildfires of given intensities are available, for example Table 8 from the Rural Fire Management Handbook. (NRFA, NZ 2002). A similar table from overseas is presented in Table 1, Appendix 5.

Table 8. Head fire intensity and fire suppression effectiveness

Fire Danger Class	Fire Intensity (kW/m)	Control Requirements
Low	0-10	Ground crews with hand tools
Moderate	10-500	Ground crews and back-pack pumps
High	500-2000	Water under pressure and heavy machinery
Very High	2000-4000	Head fire attack using aircraft and long-term retardants may be effective, but it may be too dangerous for ground crews.
Extreme	>4000	Head fire attack not likely to be effective, and it will be too dangerous for ground crews.

Source: Rural Fire Management Handbook (NRFA, NZ 2002).

10.3. Firefighter safety

Well-managed softwood plantations will, as we have seen, provide good access for firefighters and have firebreaks designed to help control wildfires that are of no more than moderate intensity. However, as Cheney (*pers comm.*) has noted, firebreaks may instil a false sense of security in firefighters using them to 'make a stand'.

Fogarty (1996) looked at the issue of firefighter safety in examining two wildfires that burnt under extreme conditions in New Zealand. Figure 5 from his report (reproduced as Figure 4) shows the radiation intensities that can be expected for given wildfire intensities at various distances from the flame front.

> *"When making a stand at severe wildfires, natural or man-made firebreaks need to be wide enough to ensure that the heat transferred from flames and radiant energy is dissipated to a level that it will not place firefighters at risk .... Some*

approximate levels of exposure of firefighters to radiation intensity (kW/m^2) for a range of fireline intensities and distances from the fire front are shown in Figure (5). *At the Montgomery Crescent Fire, where the fireline intensity was at least 25,000 kW/m, any firefighters closer than 27 m to the flame front would have been exposed to radiation intensity levels greater than 16 kW/m^2, causing burns that require medical treatment to skin exposed for more than 5 seconds .... These exposure levels do not incorporate the effects of flame roll-over at firebreaks, which have been observed to be between 10-20 m in New Zealand scrub fuels at fire intensities of 10,000-20,000 kW/m, and were 30-40 m at the Montgomery Crescent Fire. Therefore, it is anticipated that at this fire, a break of greater than 65-70 m would have been necessary for firefighters in rural attire to safely make a stand."*

Firebreaks of the width described earlier in this paper clearly do not provide sufficient separation from the flame front, even at moderate intensities, for firefighters to be on foot. Access to vehicles will obviously provide additional levels of protection, but the bottom line is – **be somewhere else** under these circumstances.

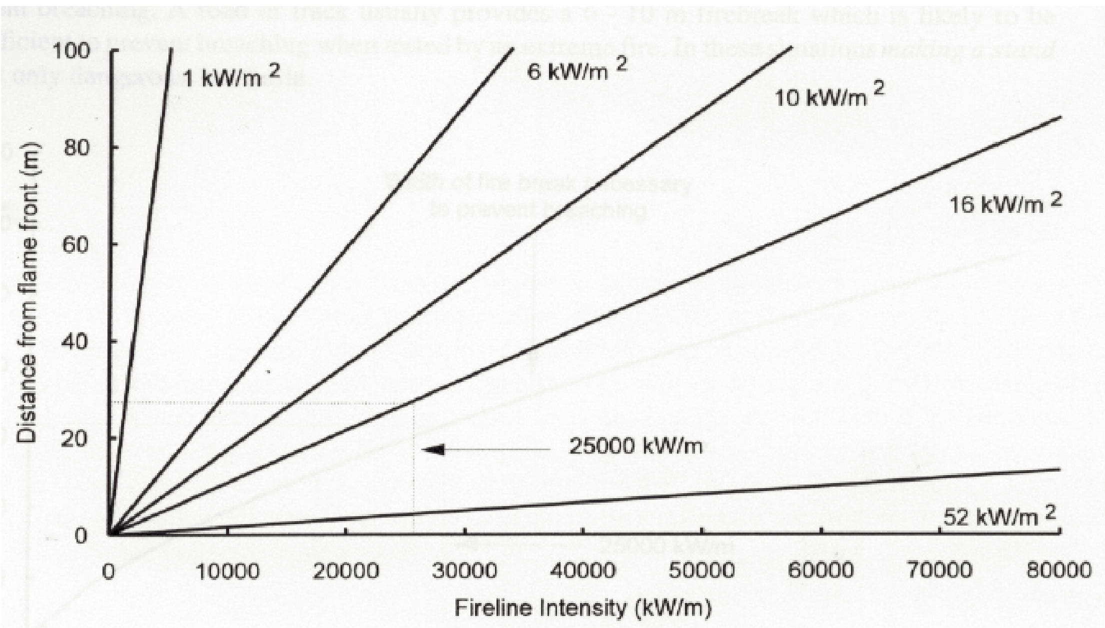

Figure 4. Radiation intensity and fireline intensity (Source: Fogarty (1996))

Approximate radiation intensity levels (kW/m^2) at different fireline intensities (kW/m), and distances (m) from the flame front (Figure 4), where each of the levels is as follows (from Drysdale 1985):

- 1 kW/m^2: the level where firefighters can withstand indefinite skin exposure;
- 6.4 kW/m^2: the level where pain will be experienced after 8 seconds on exposed skin;
- 10.4 kW/m^2: the level where pain will be experienced if the skin is exposed for 3 seconds;

- 16 kW/m^2: the level where exposed skin will blister after 5 seconds of exposure, and medical treatment will be required, and
- 52 kW/m^2: the level at which fibreboard will spontaneously ignite.

10.4. Fireline production in softwood plantations

"Under severe weather conditions, ... 10,000 – 20,000 litres per kilometre (10-20 litres per metre) (is required) *in the first 1–1½ hrs, and secure the edge, otherwise you can expect fires to exceed 40 ha in size. This equates to an overall effort of 200-400 litres per 20 metres per working minute. To achieve this, you need to have 90 litres/min flow at the nozzle."* (Forestry SA, 2004)
Forestry SA (2004) also provides some information on possible fireline construction rates in softwood plantations, as shown in Table 9.

Table 9. Some fireline construction rates in softwood plantations

Suppression Activity	Conditions	Line Construction (m/hr)
Canvas Hose Lay	Water delivery at 10 l/min	300 - 600
Canvas Hose lay	Water delivery at 20 l/min	300 - 600
Hand tools 6 man	Light fuel	1000 -1400
Hand tools 6 man	Moderate fuel	500 – 700
Heavy Dozer		800 – 1600
"Snow Plough*"		2000 – 3000

Source: Forestry SA, 2004
* "Snow Plough" = Small dozer with "V" blade

Fireline production rates will be influenced by how well the plantation has been managed, particularly at the time of establishment. *"Well prepared plantations have little residual large log material and softwood decays more rapidly than eucalypt generally making mop-up easier, although resinous stumps from thinning operations may burn for some time."* (Cheney *pers comm.*).

However, at least within Australia, many plantations that were established on sites converted from eucalypt forest, and that may have been broadcast burnt or windrowed at the time of establishment, still retain heavy residual material that creates access and mop-up difficulties during fire suppression operations. Softwood plantations, particularly early in the rotation, may be invaded by exotic weeds that also make access and therefore firefighting more difficult. These difficulties are not necessarily being reduced significantly during the second rotation. Taylor[8] (*pers comm.*) in responding to questions about access issues during the first and second rotations in NSW says:

"Factors that continue to influence access for fire suppression purposes are:

- *Original broadcast cleared areas are starting to be worked through and in many cases access tracks for thinning provide some improved access for fire suppression.*

[8] C Talyor Forests NSW

- *Old logs and windrows are usually stacked again and burnt in preparing the second rotation crop, significantly improving access.*
- *Stumps and debris prevent access for vehicles in newly established 2R stands, thus in the event of a fire a bulldozer is essential if vehicle access is required. Stumps will rot down after crown closure.*
- *Blackberries are more established in 2R areas and can be a significant hindrance in younger stands up to say 10 years old, until crown closure is able to affect their vigour. Blackberry is also an issue in thinned stands as they quickly revive with reduced tree competition following thinning."*

In New Zealand, just as in Australia, a number of factors have contributed to the phasing out or cessation of burning as a site preparation tool. *"Some companies in New Zealand still follow a practice of "windrowing" logging slash, which concentrates flammable material into regular rows. This can exacerbate fire behaviour and add considerably to fire suppression time and cost."* (Cameron[9] *pers comm.*)

Unfortunately, comparisons of the rate of fireline construction in softwood plantations with those possible in other forest types are not available. There also appears to be very little information on the level of resource that should be made available to undertake fire suppression operations in softwood plantations within a particular fire climate. FESA (2001) in WA recommends minimum equipment standards for particular areas of plantation.

> *"Plantation growers must meet this increased need for firefighting equipment, either by providing the minimum equipment standards listed in Table 10, or by contributing to community-based equipment through an agreement with their Local Gover*nment."

Table 10. Recommended minimum equipment standards (Source FESA 2001)

Plantation Area (hectares)	**Fast Attack**	**2.4 (M/Duty)**	**3.4 (H/Duty)**
Less than 100 hectares	1		
100 to 1,000 hectares		1	
Greater than 1,000 hectares			1

Definitions:

Fast Attack: relates to a 1 tone 4x4 vehicle carry a minimum of 450 litres of water
2.4 (Medium Duty): relates to 4x4 vehicle carrying a 2.000 litres of water
3.4 (Heavy Duty): relates to a 4.4 vehicle carrying 3,000 litres of water

Source: FESA (2001)

There is no other consolidated information available at this stage on the levels of fire suppression resources that are considered appropriate for managing softwood plantation fire suppression operations within a particular region or jurisdiction.

10.5. Difficulty of suppression

In Section 7.2 we saw that grassfires will generally reach their potential rates of forward spread more quickly than wildfires originating in forest areas. This slower

[9] G Cameron, National Rural Fire Authority, New Zealand

development of forest fires can provide a window of opportunity for efficient fire suppression forces to achieve successful initial attack. *"This important difference in fire behaviour means that a fire starting in an established plantation can be easily suppressed during its growth phase before it reaches its potential rate of spread even under Very High to Extreme Fire Danger conditions."* (Cheney and Coleman 1988) However, if first attack fails fire suppression in a softwood plantation will become relatively more difficult than in grassland. *"Whereas fires in grasslands may be readily suppressed with water, particularly in light fuels, forest fires are more difficult. Suppression often requires the use of hand tools or machinery to create a bare-earth fire trail around the fire."* (Cheney and Coleman 1988)

Spotting characteristics also play a critical role in determining the ease of suppression in different fuel types. *"In forests, the factor which overwhelms suppression forces and determines the fire intensity at which suppression fails is the onset of severe spotting."* (Cheney and Coleman 1988).

10.6. Summary comments

- Aggressive first attack will give the best probability of success. Well-managed softwood plantations with good access should most often allow for effective first attack. However, in some locations, the original site preparation techniques mean significant access issues remain within the units enclosed by roads or tracks. Second rotation plantations in these areas may also still have poor access within enclosed units because of residual material from the initial establishment phase and clearfelling (including stumps), and exotic weeds.
- Because access is still usually much better than in native forests, 'wet' firefighting techniques are most successful. The capacity to deliver large volumes of water and/or foam directly on the fire edge will help to achieve early control.
- The safety of firefighters is paramount. Good access and wide firebreaks do not necessarily provide a safe working environment under all conditions. Radiation levels at which a firefighter will not be able to work effectively in the open, with normal safety equipment, are reached very quickly close to wildfires burning under conditions of even Moderate Fire Danger.
- Fireline construction with heavy machines in young plantation stands is very difficult, and established roads and tracks will usually have to be used as control lines if direct attack fails.
- Good firefighters can be undone by poor management arrangements for the provision of leadership, knowledge, planning and logistical support. AIIMS ICS should be used to help ensure the wildfire is quickly controlled while the welfare of firefighters also receives top priority.
- If first attack fails, wildfires in softwood plantations will generally be more difficult to suppress than wildfires in grasslands.
- There is little information available on the levels of fire suppression resources that should be applied to suppressing wildfires within softwood plantations.

11. Softwood Plantations and Protecting Communities from Wildfire

In the Introduction to this paper it was noted that:

> *'Although the fire climates in which softwood plantations are established vary considerably, and the risk of wildfire to a particular plantation may vary accordingly, what role should the fire climate play in determining the level of protection provided to adjoining communities? This is a key question that needs to be answered. We will see later that at least some of the planning tools that are used to determine the separation of a plantation from a community, or vice versa, provide for variable levels of fire protection based upon judgements of the 'local fire climate.'*

With those thoughts in mind, we should first look at what is known about how fires attack residences and the guidelines that are used to minimise the risk. We should also keep in mind that Tolhurst and Howlett (2003) indicate that about 7000 houses have been destroyed by bushfires across Australia since 1939. Although much smaller numbers have been lost in 'vegetation fires' in New Zealand (perhaps 20-30 since 1986, Baker[10] pers comm.), the protection of communities from wildfire must remain a high priority for every softwood plantation owner and relevant authority.

Recognition of this priority has caused government authorities to make specific reference to the steps that should be taken to reduce the potential losses. Some examples of these approaches are described below, and they should be read with the understanding that more specific land use planning rules may apply in different local government areas and regions.

11.1. Mechanisms of wildfire attack on properties

Tolhurst and Howlett (2003) examined the history of house losses related to wildfires in Australia and, although the work is not directly related to softwood plantations, it gives some perspective on what can happen next to a wildfire.

> *"Results of this research indicate that ember ignition poses the greatest threat to house ignition under a wide range of conditions for up to 600 metres from a fire edge. The threat from flame contact and radiation is only significant when forest fuels are within about 30 metres of the house, but the threat increases when houses are on steeper slopes. The threat from convective heating is generally only important on slopes steeper than 30 degrees.*

The mechanisms that are at play as a wildfire impinges on the urban environment are also described in Planning for Bushfire Protection 2001 (Rural Fire Service NSW, 2001).

> *"Bushfire attack takes essentially five forms; wind, smoke, ember, radiant heat and flame........... Evidence indicates ember attack is responsible for most bushfire*

[10] P Baker National Rural Fire Authority, New Zealand

> *related house fires. However, strong winds resulting from severe bushfires will drive embers into vulnerable areas of a building....... To effectively protect a building, strategies must be adopted that separate the dwelling from the hazard and reduce the intensity of bushfires to minimise the impact of ember, wind, flame and heat attack."*

Ellis and Sullivan (2003) quote work by Ahern and Chladil (1999) which indicates that *" .... for a number of catastrophic bushfire events, about 85% of houses were lost within 100 m of the bush-urban interface ....."* They also indicate that *"the density of the swathe of firebrands may be extremely high close to the firebreak, perhaps hundreds per square metre, but* (that it) *decreases sharply with distance ... The swathe may extend more than 200 metres from the firebreak ...."*

One of the reasons this document has been prepared was the concern that perhaps the tragic losses of life and property in the ACT fires of January 2003 were, at least in part, related to the proximity of some *P radiata* plantations to urban areas. Ellis and Sullivan (2003) examined the mechanisms of house loss caused by the wildfire and conclude, in part:

- *"Firebrands directly ignited residential gardens, houses and other structures, urban parkland, access lanes and roadside belts.*

- *We did not find evidence that any residential properties were ignited or damaged by direct flame contact or radiant heat from flames in the pine forest, bushland or grassland outside the suburb perimeter roads. We do, however, consider it possible that this mode of attack occurred in some instances.*

- *The fires that ignited within the suburbs then spread via surface fire, including radiant heat, direct flame contact, and by lofted firebrands, into urban parks, access lanes, roadside belts, residential gardens (including trees and mulch), structures, stored flammables including vehicles, and houses. Wooden or brush fences apparently facilitated spread between properties and, where close to structures, contributed to their ignition.*

- *We consider it likely that more than 50% of house losses occurred as a result of spread through urban fuels, including between residential properties. Penetration of houses by firebrands was apparently facilitated by window breakage and other structural damage.*

- *We found that garden condition and layout were strongly linked to the loss or damage of properties."*

So, while the wildfire obviously provided the initial direct source of ignition of houses or their surrounds in most instances, the fuel loads around and between houses also played a role in determining the overall loss. The steps taken by individual landowners and fire suppression agencies make it difficult to distinguish the relative contribution of the wildfire in softwood plantations to the losses from the wildfire in the grassland areas. However, if we look again at Section 7.1.2 we see Cheney quoted as saying that " *under low humidities the bark is flammable and produces abundant firebrands in the form of bark plates."* Under the conditions experienced on 18 January 2003, the softwood plantations were a significant contributing factor to the ember attack experienced in the urban areas. Were they better or worse in this regard than the wildfire in grassland? There is no objective evidence but, subjectively, given the propensity of softwood plantations to produce massive short distance spotting under very low relative humidities, the answer is that they were probably worse.

Whatever the right answer might be, Bartlett (2004) explicitly recognises, in his response to the January 2003 wildfires, that a new perspective at the issue is required:

> *"In the Duffy area, buffer zones of 40-55 metres (between private property and plantation), when coupled with high fuel loads in suburban gardens and urban open spaces, were insufficient to preclude significant house destruction. Improving protection to residential assets on the downwind side of a plantation will require a co-operative approach from both the plantation owner and the residential owner. In the ACT, a decision has been made to establish a variable width Bushfire Abatement Zone around Canberra and to preclude commercial pine plantations from this zone."*
>
> And:
>
> *"The set back distances between plantations and residences in the Canberra suburbs were at least 40 to 55 metres. They were sufficient to prevent direct flame contact with houses, but insufficient to prevent substantial ember attack on the residences."*
>
> And:
>
> *"In future cleared buffer zones should be 50-70 metres wide on the northern and western sides of residences and supplemented by fuel management measures for a further 50-100 metres within the plantation."*

11.2. Separating softwood plantations and residences/communities

In the earlier discussion about external firebreaks, it was noted that, while firebreaks properly constructed and maintained were important in significantly increasing the level of protection for a plantation, those same firebreaks alone did not meet the standards required to help protect built assets adjoining the plantation.

When determining standards for the separation of plantations from residential dwellings and communities, a number of factors need to be considered including the plantation type and size, the slope of the land, the construction standard of the dwellings to be protected, and the proximity and nature of combustible materials (including gardens) on the dwelling site.

Typically the objective of separating residences from plantations is to provide sufficient separation between an existing rural dwelling and a proposed plantation (or between a proposed dwelling and an existing plantation) such that radiant heat and flames propagating in the plantation do not cause building ignition or window glass breakage.

Whilst ember attack is recognised as the chief vector by which residential structures catch alight during bushfires, it is not usual or practical to establish plantation/dwelling separation distances based on possible ember attack ranges as these can be several hundred metres for pine plantations or several kilometres in the case of eucalypt plantations. The separation distances based on preventing dwelling ignition from radiant heat and/or direct flame impingement allow opportunities for appropriately prepared homeowners and firefighters to extinguish ember ignitions after the main fire front has passed and radiant heat conditions around the dwelling have reduced to a level that allows safe access to the house perimeter for extinguishing of embers.

Planning for Bushfire Protection 2001 (Rural Fire Service NSW, 2001) provides a very comprehensive approach to determining appropriate protection measures for residences and communities. The basic approach is to define Asset Protection Zones (Figure 5) of variable width, based upon the location of the property with respect to slope and the adjoining fuel type.

> *"...Asset Protection Zones (APZ), are required for any building development* (in NSW) *adjoining a bushfire hazard area. The broad intent of an APZ is to provide separation between the development and the hazard to prevent structure ignition from radiant heat/direct flame impingement and to provide 'defensible space' in which home owners/firefighters can safely defend against ember attack ignitions after the passage of the fire front."*

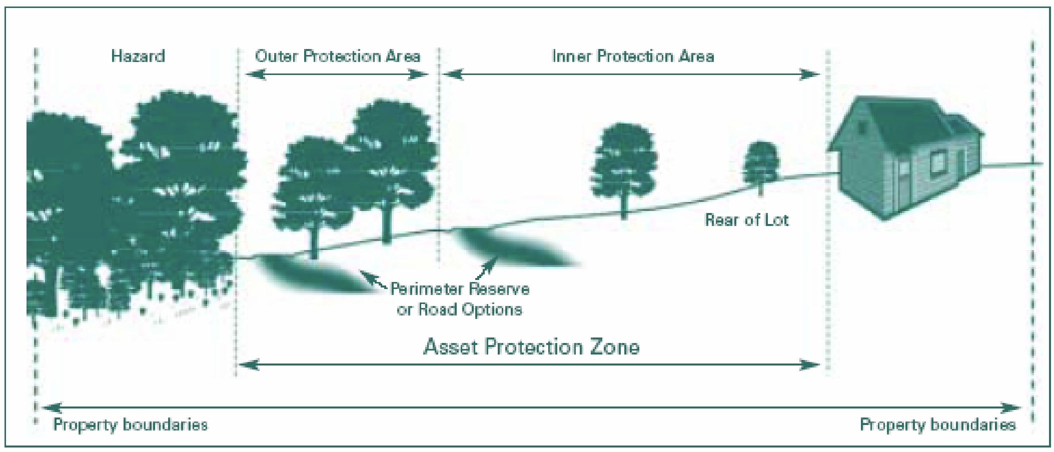

Figure 4.1 Components of an Asset Protection Zone

Figure 5. Asset Protection Zones – NSW (Source: Figure 4.1 in Rural Fire Service NSW, 2001).

Figure 6, also derived from Planning for Bushfire Protection 2001, indicates the category of bushfire attack that may be faced next to a Forest, the definition of which includes softwood plantation, compared with a grassland for different slope classes.

Distance from vegetation	Less than 20m	From 20m but not greater than 30m			Greater than 30m but not greater than 50m			Greater than 50m but not greater than 80m			Greater than 80m but not greater than 100m		
Slope	All slopes	Greater than 15°	Greater than 5° but not greater than 15°	0 to 5°	Greater than 15°	Greater than 5° but not greater than 15°	0 to 5°	Greater than 15°	Greater than 5° but not greater than 15°	0 to 5°	Greater than 15°	Greater than 5° but not greater than 15°	0 to 5°
Vegetation	Category of Bushfire Attack												
Forest	FZ	FZ	FZ	Ext	FZ	Ext	High	Ext	Ext	Med	Ext	High	Low
Grassland	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Figure 6. Bushfire Attack Categories – NSW (Source: Rural Fire Service NSW (2001) Bushfire Attack Categories: Low, Medium (Med), High, Extreme (Ext), Flame Zone (FZ). These categories are described in Table 2, Appendix 5.

The extent to which a property or asset is seen to be under threat, according to the Bushfire Category determined, is then used to determine the configuration of APZ's. Adjoining forest areas, the width of APZ's range from 40-100 m if the asset is upslope of the hazard, and 20-75 m if it is downslope of a hazard.

In Western Australia, the FESA (2001) guideline indicates:

> *"No plantation trees shall be planted within 50 metres of any existing or proposed structure (i.e. house, shed, etc) and a further 50 metres of plantation should be pruned and have ground fuels reduced so as to provide a minimum of a 100 metre low fuel area immediately surrounding the structure."*
>
> And:
>
> *"In addition to measures employed close to local development, fuel reduction should also be an objective for defined plantation areas located up to 1 km from any local development. Such fuel reduction is the responsibility of the plantation manager. Fuel reduction measures to minimise fire hazards in such areas can include:*
>
> - *Low and high pruning of pines.*
> - *Removal of pruning debris.*
> - *Strictly controlled grazing.*
> - *Application of special harvesting methods.*
> - *Broad scale fuel reduction burning.*
> - *Herbicide spray weed control.*

In the Green Triangle the FOC (2003) recommends:

> *"Setback of plantation edge from habitable dwellings existing at the time of plantation establishment shall generally be:*
> - *A minimum of 50 m combined with fuel reduction works within the plantation to provide a total of 100 m for the Northern and Western sides of dwellings*
> - *A minimum of 35 m combined with fuel reduction works within the plantation to provide a total of 50 m for the eastern and southern sides of dwellings."*

The National Rural Fire Authority, New Zealand (2003) advocates *"defensible space requirements around a house .... (near) ..... steep slopes and/or heavy fuels"* of 30-50 m towards the direction of the prevailing wind.

The fire climate will help to determine the risk to a plantation and therefore the level of risk to adjoining communities. The problem is that, even in a relatively benign fire climate, significant wildfire events are still possible. The evidence from the ACT wildfire and elsewhere is that a fuel break 50 metres wide should prevent the possibility of direct flame contact with an adjoining residence. However, unless steps have been taken to reduce fuels around the house, the house will in all likelihood be burnt by ember attack. Even if the house surrounds are well maintained, does 50 metres provide sufficient space within which a well-equipped rural firefighter could 'make a stand?' If we look at the work presented by Fogarty (1996) in Section 10.3 then the answer to that question is 'no'. To operate effectively under conditions of Extreme Fire Danger, a minimum distance clear of fuel that will carry a fire of 100 m would seem to be a reasonable approach. If mass short distance spotting from softwood plantations is likely to occur, then further work to manage fuel loads and fuel arrangements for a distance in from the plantation boundary will substantially increase the likelihood of properties surviving.

11.3. Summary comments

- External boundary firebreaks, as discussed earlier, will not provide adequate separation of a plantation from residences or rural/urban communities.
- Depending on the location of the plantation with respect to the critical assets outside the plantation, the width of the area on which fuels should be removed or reduced significantly should be a minimum of 100 metres.
- Even at these distances, significant ember attack will occur under conditions of Extreme Fire Danger. However, properties should be able to be defended by properly home owners, if properties have also been appropriately managed to reduce the chances of a fire igniting and spreading in their surrounds.

12. Overall Summary and Challenges

Before presenting a summary of the available evidence, and indicating what that evidence might mean for the protection of softwood plantations and adjoining communities from wildfire, the four important contextual issues raised at the outset of this paper need to be prominent in our thinking. The four issues are:

1. *Although the benefits and costs of investing in various fire prevention and fire suppression strategies are important considerations for plantation managers, and the communities within which they operate more generally, discussion of this issue falls outside the scope of this paper.*
2. *The size of a plantation unit, and the size and scale of the plantations owned by an individual, company or government agency, will have a significant influence on the capacity of the owner to undertake or participate in fire prevention and fire suppression programs in, or adjoining, the plantation.*
3. *The climates in which softwood plantations are established in New Zealand and Australia vary enormously, and the risk to a softwood plantation from wildfire may vary significantly from region to region. The actions required to protect a particular plantation will vary with the risk that is considered to be present in the region concerned.*
4. *Although the fire climates in which softwood plantations are established vary considerably, and the risk of wildfire to a particular plantation may vary accordingly, does that mean that the fire climate should also be considered in determining the level of protection provided to adjoining communities? This is a key question that needs to be answered.*

What, in summary, does the evidence of research and experience tell us about the relationship between wildfires and softwood plantations?

- Planning for the protection of a softwood plantation from wildfire should commence prior to establishment. Removal of heavy fuels from the site, the location and extent of access roads, tracks and firebreaks and the positioning of water supplies will all help to determine if a plantation can be protected from wildfire. Silvicultural treatments throughout the rotation should be planned to link with fire protection requirements whenever possible.

- Most wildfires that have originated in large well-managed softwood plantations have been restricted in size because they have had good access allowing for the implementation of very effective ‘wet’ firefighting first attack methods. This pattern could change dramatically if emphasis on managing softwood plantations to help protect them from wildfire decreases, and the availability of skilled and well-equipped firefighters also diminishes.

- Wildfires in softwood plantations will generally have rates of forward spread that are equivalent to the rates of forward spread in eucalypt forests, although the fire behaviour that is exhibited will vary with the age of the plantation and the manner in which it’s silvicultural history has impacted on fuel loads and fuel arrangement.

- While rates of forward spread may be similar to those encountered in eucalypt forest, the potential for medium and long distance spotting is markedly reduced in comparison with the potential for medium and long distance spotting in eucalypt forests. The maximum recorded spotting distance from a softwood plantation fire was 2.6 km in Western Australia. Spotting distances during wildfires in eucalypt forest are often up to 10 km, with much longer distances possible depending on the forest type and wildfire intensity.

- Significant short distance spotting can be a feature of fires in eucalypt forests at even Low Fire Dangers. The differences in bark type mean that short distance spotting in softwood plantations is generally insignificant at Low to Moderate Fire Dangers compared with fire in eucalypt forests. However, at low relative humidities, significant short distance spotting does occur during wildfires in softwood plantations. The source of the spotting is the small bark plates that flake off as the fire increases in intensity.

- At the top end of Extreme Fire Danger, wildfires in softwood plantations will generally have rates of forward spread that are about 30%-40% less, under the same weather and topographical conditions, than wildfires burning in grassland, or other fuel types where the prevailing wind can impact directly on the flame zone. This differential will increase at lower levels of Fire Danger.

- Wildfires in softwood plantations will behave differently, under the same weather and topographical conditions, in accordance with the age of the plantation and the silvicultural and fuel modification treatments it has received. If there is a significant gap between the surface fuels and the crown fuels, the transformation from a surface fire to a crown fire may occur very rapidly and without warning.

- Crown fire formation can cause the rate of forward spread to increase by as much as two to three times. This sudden change in fire behaviour obviously has significant implications for fire suppression operations, particularly in terms of firefighter safety.

- Wildfires of even moderate intensity will generally kill or so severely damage the plantation that salvage and/or re-establishment will be necessary. However, low intensity fires do not adversely affect the major softwood plantations species provided that heavy fuel moisture contents are at levels where they will not burn. Fuel reduction burning is therefore a management option in the major species from about the age of 11-12 years in stands that have been low pruned, and properly planned and managed from the time of establishment.

- In addition to fuel reduction burning, mechanical treatments, such as pruning, thinning and crushing of slash can also significantly reduce the level of hazard. Although it is not possible to treat all plantation areas this way, effective fuel modification programs in strategic areas based on combinations of fuel reduction burning and mechanical or silvicultural treatments, is beneficial.

- The level of work undertaken to protect a softwood plantation from wildfire will necessarily depend on the fire climate in which the plantation is located, and the capacity of the plantation owner to afford the work concerned. Small plantation owners will be faced with high unit costs, and they are unlikely to have the capacity to undertake fire protection works that will significantly add to the protection of the plantation itself. For these and other reasons, small and isolated softwood plantations will probably be impossible to defend from a significant wildfire advancing on a broad front.

- Existing guidelines on the distances that should separate softwood plantations from residences and communities are generally based on judgements of fire climate, and the likely influence on wildfire behaviour of local fuel and topographical conditions. The question needs to be asked if this is a viable approach. Even in a relatively benign fire climate, very severe wildfires may occur. The frequency of such wildfires may be less, but when they do occur the losses may be very high if fire protection measures are inadequate. Consideration needs to be given to a risk management approach. Whatever approach is finally adopted, the evidence shows that a severe wildfire in a softwood plantation will produce massive ember attack on closely adjoining communities. It also shows that a properly equipped rural firefighter, operating from outside a vehicle, needs to be of the order of 100 m away from the edge of a severe wildfire to be able to work in safety. On this basis, and the fact that house loss from ember attack diminishes rapidly at distances of greater than 100 m from the wildfire, a standard 100 m firebreak should be the starting point for further consideration of the fire protection needs of adjoining communities. Additional fuel modification works within the plantation itself would obviously add to the level of protection to the community.

- Softwood plantations are an important part of the economies of both New Zealand and Australia. Provided that they are sited appropriately with respect to adjoining communities, and the communities recognise the need for effective fire protection actions in their own environment, properly planned, well-managed plantations, together with well trained, well equipped and well managed fire suppression resources, they pose no greater threat to our communities than other forest or fuel types.

- The recent experience in the ACT has been well documented. Softwood plantations played a role in the tragedy that occurred. Whether that role was more significant than the wildfire advancing through the grassland and the open eucalypt woodland is not clear. What is clear is that more can be done as the ACT has already recognised.

Continuing observation and experiment will improve our understanding of wildfire behaviour and the application of suitable fire protection measures in and adjoining softwood plantations. However, understanding alone is not enough, and softwood plantation managers, communities and relevant fire and other authorities need to ensure that:

- *There is a continuing strong focus on strategic planning of softwood plantations that recognises the risk of wildfire to the plantation as well as its neighbours.*

- *There is a continuing strong focus on management of plantation fuel.*

- *Fire suppression agencies are well equipped in terms of resources, knowledge and leadership to respond rapidly and effectively in an integrated manner, irrespective of changes in ownership of the plantation resource and shifts in legislative responsibility for fire protection activities.*

- *Authorities recognise and manage the protection and risk to both the plantations and the communities. Effective partnerships are required to ensure effective fire protection. .*

- *Finally, are we willing to continue to take the risks associated with an approach to protecting communities based largely on varying levels of protection based on judgements of the fire climate? Perhaps a new approach based on a minimum standard should be examined.*

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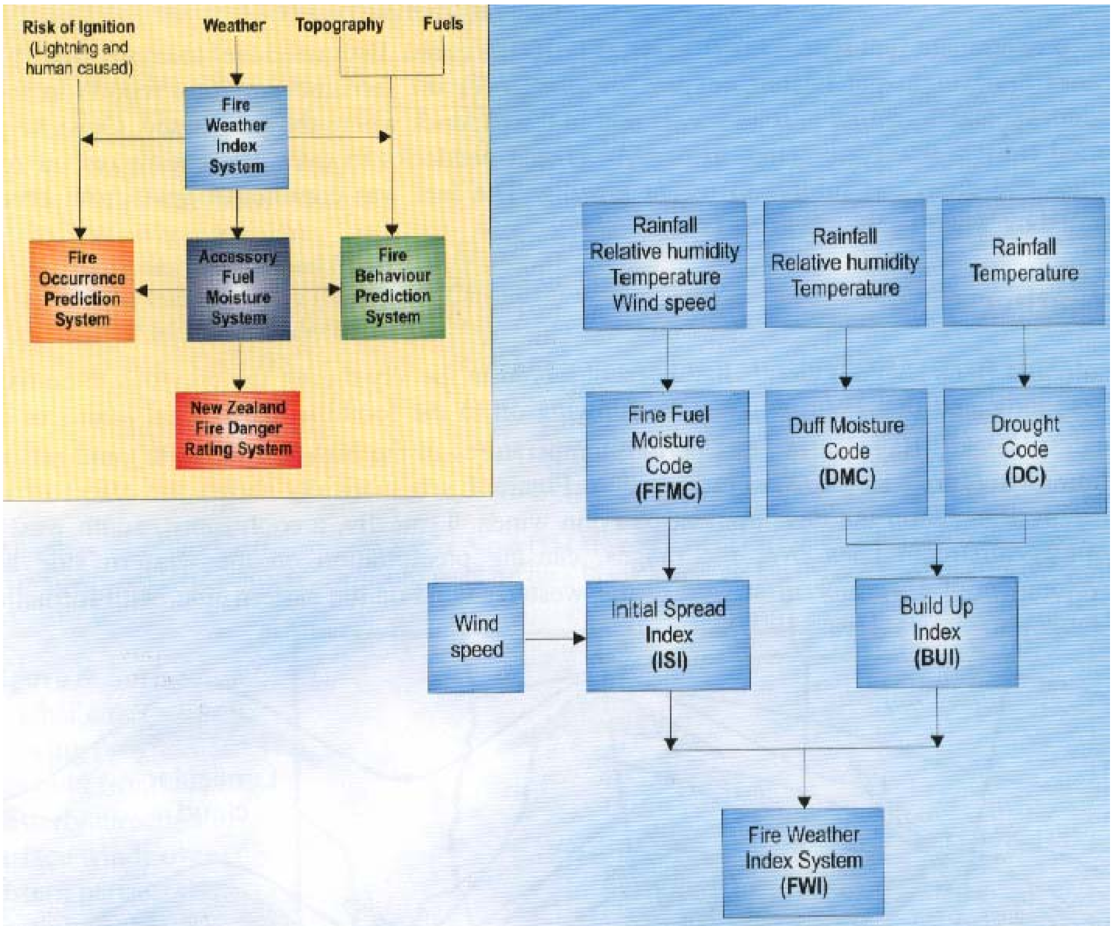
Appendix 1. The New Zealand Fire Danger Rating System

1. Diagrammatic Representation of the NZFDRS



FFMC	A numerical rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and flammability of fine fuels.
DMC	A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium sized woody material.
DC	A numerical rating of the average moisture content of deep, compacted layers. This code is a useful indicator of seasonal effects on forest fuels, and amount of smouldering in deep duff layers and large logs.
ISI	A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread without the influence of of variable quantities of fuel.
BUI	A numerical rating of total amount of fuel available for combustion, that combines DMC and DC.
FWI	A numerical rating of fire intensity that combines ISI and BUI. It is a suitable index of fire danger.

2. NZFDRS Fire Danger Classes

Fire Danger Class	Description of Probable Fire Potential and Implications for Wildfire Suppression†	Nominal Max. Flame Height
Low	New fire starts are unlikely to sustain themselves due to moist surface fuel conditions. However, ignitions may take place near large and prolonged or intense heat sources (e.g., camp fires, windrowed slash piles) but the resulting fires generally do not spread much beyond their point of origin and if they do, control is easily achieved. Mop-up or complete extinguishment of fires that are already burning may still be required provided there is sufficient fuel and it's dry enough to support smouldering combustion.* Colour code is GREEN.	no visible flame
Moderate	From the standpoint of moisture content, fuels are considered to be sufficiently receptive, to sustain ignition and combustion from both flaming and most non-flaming (e.g., glowing) firebrands. Creeping or gentle surface fires activity is common place. Control of such fires is comparatively easy but can become troublesome as fire damages can still result and fires can become costly to suppress if they aren't attended to immediately. Direct manual attack around the entire fire perimeter by firefighters with only hand tools and back-pack pumps is possible. Colour code is BLUE.	up to 1.3 metres
High	Running or vigourous surface fires are most likely to occur. Any fire outbreak constitutes a serious problem. Control becomes gradually more difficult if it's not completed during the early stages of fire growth following ignition. Water under pressure (from ground tankers or fire pumps with hose lays) and bulldozers are required for effective action at the fire's head. Colour code is YELLOW.	1.4 to 2.5 metres
Very High	Burning conditions have become critical as the likelihood of intense surface fires is a distinct possibility; torching and intermittent crowning in forests can take place. Direct attack on the head of a fire by ground forces is feasible for only the first few minutes after ignition has occurred. Otherwise, any attempt to attack the fire's head should be limited to helicopters with buckets or fixed-wing aircraft, preferably dropping long-term chemical fire retardants. Until the fire weather severity abates, resulting in a subsidence of the fire run, the uncertainty of successful control exists. Colour code is ORANGE.	2.6 to 3.5 metres
Extreme	The situation should be considered "explosive" or super critical. The characteristics associated with the violent physical behaviour of conflagrations or firestorms is a certainty (e.g., rapid spread rates, crowning in forests, medium- to long-range mass spotting, firewhirls, towering convection columns, great walls of flame). As a result, fires pose an especially grave threat to persons and their property. Breaching of roads and firebreaks occurs with regularity as fires sweep across the landscape. Direct attack is rarely possible given the fire's probable ferocity except immediately after ignition and should only be attempt with the upmost caution. The only effective and safe control action that can be taken until the fire run expires is at the back and up along the flanks. Colour code is RED.	3.6 + metres

†THE ABOVE SHOULD NOT BE USED AS A GUIDE TO FIREFIGHTER SAFETY AS FIRES CAN BE POTENTIALLY DANGEROUS OR LIFE THREATENING AT ANY LEVEL OF FIRE DANGER.

*General rule(s) of thumb: certainly when Drought Code (DC) exceeds about 300 and/or Buildup Index (BUI) is greater than around 40 one can generally expect ground or subsurface fires. Please note however, these benchmark values are for moderately well-drained sites but in actual fact they will vary according to soil type and drainage conditions and should be determined locally on the basis of past wildfire suppression and/or prescribed burning experience.

Appendix 2. Softwood Plantation Fire Statistics

This table has been drawn from a variety of sources and, sometimes, different sources have provided different areas for the same fire. It is also usually not clear if the areas listed are net or gross areas of plantation burnt. In other words, treat the data with caution, even though it does give an indication of the frequency of significant plantation fires in each jurisdiction.

Table 1. Significant(1) Softwood Plantation Fires

Jurisdiction	Location	Date	Year	Area of Plantation Burnt (ha)	Species	Source
ACT	Uriarra		1939	1100	P radiata	Bartlett A. (2003)
ACT	Mt Stromlo	5 February	1952	316	P radiata	Bartlett A. (2003)
ACT	Unknown – Two fires, area possibly inaccurate		1983	320	P radiata?	CSIRO (1989)
ACT	Pierces Creek		1991	400	P radiata	Bartlett A. (2003)
ACT	Mt Stromlo		2001	342	P radiata	Bartlett A. (2003)
ACT		18 January	2003	10500	P radiata	Bartlett A. (2003)
New Zealand	Eyrewell, Canterbury		1940	469	Exotic plantation	NZNRFA(3)
New Zealand	Tahorakuri, Taupo		1946	30738	Exotic plantation and other	NZNRFA(3)
New Zealand	Balmoral, Canterbury		1955	3152	Exotic plantation	NZNRFA(3)
New Zealand	Mawhera, West Coast		1970	400	Exotic plantation	NZNRFA(3)
New Zealand	Slopedown, Southland		1971	295	Exotic plantation	NZNRFA(3)
New Zealand	Allanton, Otago	6 September	1972	139	P radiata	Fogarty LG, Jackson AF and Lindsay WT (1996)
New Zealand	Rankleburn, Southland		1972	422	Exotic plantation	NZNRFA(3)
New Zealand	Ashley, Canterbury		1973	194	Exotic plantation	NZNRFA(3)
New Zealand	Mohaka, Hawkes Bay		1973	368	Exotic plantation	NZNRFA(3)

New Zealand	Waimea, West Coast		1975	370	Exotic plantation	NZNRFA[3]
New Zealand	Hanmer, Canterbury		1976	798	Exotic plantation	NZNRFA[3]
New Zealand	Wairapukao, Bay of Plenty		1977	432	Exotic plantation	NZNRFA[3]
New Zealand	Balmoral, Canterbury		1981	170	Exotic plantation	NZNRFA[3]
New Zealand	Hira, Nelson		1981	1972	Exotic plantation	NZNRFA[3]
New Zealand	Dunsandel, Canterbury		1988	185	Exotic plantation	NZNRFA[3]
New Zealand	Southbridge, Canterbury		1990	150	Exotic plantation	NZNRFA[3]
New Zealand	Berwick	26 February	1995	181	P radiata	Fogarty LG, Jackson AF and Lindsay WT (1996)
New Zealand	Berwick, Otago		1995	255	Exotic plantation	NZNRFA[3] Same fire as above??
New Zealand	Mohaka, Hawkes Bay		1996	>100	Exotic plantation	NZNRFA[3]
New Zealand	Aupori, Northland		1997	260	Exotic plantation	NZNRFA[3]
New Zealand	Harakeke, Nelson		1997	535	Exotic plantation	NZNRFA[3]
New Zealand	Para Road, Marlborough		2001	102	Exotic plantation	NZNRFA[3]
New Zealand	Aupori, Northland		2003	240	Exotic plantation	NZNRFA[3]
NSW	Woodburn	28 October	1968	139	P radiata, P elliotti, P taeda	Dawson (1982)
NSW	Jervis Bay	23 December	1972	122	P radiata	Dawson (1982)
NSW	Unknown		1979	244	Unknown	CSIRO (1989)
NSW	Nowra	30 September	1980	777	P radiata	Dawson (1982)
NSW	Woodburn	25 September	1980	130	P radiata, P elliotti, P taeda	Dawson (1982)
NSW	Bathurst		1983	1667	P radiata	CSIRO (1989)
NSW	Bombala		1983	6457	P radiata	CSIRO (1989)
NSW	Canobolos		1985	2439	P radiata?	CSIRO (1989)
Queensland	Warwick	30 September	1977	115	P radiata	Hamwood[2]
Queensland	Warwick		1978	260	P radiata	CSIRO (ca. 1989)

Queensland	Kelly Range	21 October	1981	222	P elliottii	Hamwood[(2)]
Queensland	Maryborough	29 September	1982	129	P elliottii	Hamwood[(2)]
Queensland	SE Coast		1982	>200	P elliottii	CSIRO (1989)
Queensland	Landsborough	29 September	1984	243	P elliottii P caribaea	Hamwood[(2)]
Queensland	SE Coast		1985	>200	P elliottii	CSIRO (1989)
Queensland	Toolara, Gympie	22 September	1991	902	P elliottii	Hamwood[(2)]
Queensland	Beerburrum	6 November	1994	3600	P elliottii P caribaea	Hunt S, Hamwood R and Ollerenshaw S (1995)
Queensland	Beerburrum	27 September	1994	1200	P elliottii P caribaea	Hunt S, Hamwood R and Ollerenshaw S (1995)
Queensland	Beerburrum	7 October	2001	650	Mixed	Kleinschmidt[(2)]
South Australia	Wandilo	5 April	1958	320	P radiata, P pinaster	Dawson (1982)
South Australia	Kongorong	29 March	1971	328	P radiata	Dawson (1982)
South Australia	Glencoe	30 January	1974	370	P radiata	Dawson (1982)
South Australia	Caroline	2 February	1979	3244 (163 ha in Victoria)	P radiata	Geddes DJ and Pfeiffer ER (1981)
South Australia	Millbrook	8 March	1980	Not in report	P radiata	Pratt J (1990)
South Australia	Central & South-east Regions – 8 fires.	16 February	1983	21000	Approx 90% P radiata	Keeves & Douglas (1983)
Tasmania	Queenstown		1976	207	P radiata	CSIRO (1989)
Victoria	Longford	17 November	1962	111	P radiata	McArthur AG (1965)
Victoria	Blanket Hill	3 March	1965	324	P radiata	Dawson (1982)
Victoria	Creswick	25 January	1966	200	P radiata	Dawson (1982)
Victoria	Creswick	12 February	1977	258	P radiata, P nigra	Dawson (1982)

Victoria	Bright	24 November	1982	332	P radiata, P ponderosa	Watson N, Morgan G and Rolland D (1983)
Victoria	Deans Marsh/Lorne	16 February	1983	973	P radiata mostly	Rawson RP, Billing PR and Duncan SF (1983)
Victoria	Macedon	16 February	1983	1326	P radiata and other	Rawson RP, Billing PR and Duncan SF (1983)
Western Australia	Bridgetown		2003/2004	634 State 348 Private	P radiata	McCaw L (pers comm.) Report in preparation.
Western Australia	Cyclone Alby	4 April	1978	1114	P radiata?	Van Didden (1978)
Western Australia	Grimwade	2 March	1984	60+60 of pine slash	P radiata	Forests Department Fire Protection Branch Report
Western Australia	Nannup Folly Plantation	March	1988	209	P radiata	CALM Annual Report
Western Australia	Myalup	21 April	1991	260	P pinaster	Smith R (1992)
Western Australia	Yanchep	30 January	1991	250	P pinaster	CALM Annual Report
Western Australia	Gnangara	30 December	1994	850	P pinaster	Burrows N, Ward B & Robinson A (2000)
Western Australia	Ross's FPC Sharefarm	4 January	2003	~100	P radiata	McCaw L (pers comm.)

1. Plantation fires where the area of plantation burnt was 100 ha or greater, or a significant report on the behaviour of the fire within the plantation is available**.**
2. Internal report available.
3. New Zealand National Rural Fire Authority.

Comments on Specific Areas in NSW - from Forests NSW (2003) - are:

"In terms of historical losses in plantation areas as compared with non-plantation areas....................... there is no evidence that house/agricultural infrastructure losses are greater in plantation areas than in non-plantation areas............ Large plantation fires, which emerge from plantations into agricultural areas are very rare."............the following record shows just how rare:

- ***Walcha Plantation Area****: no recorded house/structure loss from plantation fires. Ten fires have burned in or into plantations in the 22 years from 1979 to 2002, burning a total of 40 ha.*

- ***Macquarie Plantation Area**: no recorded house/structure loss from plantation fires. 138 fires have burned in or into plantations in the 22 years from 1979 to 2002, burning a total of 4244ha (6.5% plantation area). Of the 4244ha burnt, 3410ha (80%) was burnt in two large plantation fires.*
- ***Hume Plantation Area**: no recorded house/structure loss from plantation fires. On average less than 0.01% of this regions plantation estate has burnt on any given year. In the 22 years from 1979 to 2002, no single fire has burnt more than 20ha. During this period, no fires have escaped the plantation estate onto private land.*
- ***Bombala Plantation area:** no recorded house/structure loss from plantation fires. 178 fires have burned in or into plantations in the 22 years from 1979 to 2002, burning a total of 6551ha (6.5% plantation area). Of the 6551 hectares burnt, 6475ha (98.8%) was burnt in one extreme fire event."*

Appendix 3. Some Characteristics of Major Wildfires in Softwood Plantations

This table started out as an attempt to see if there were enough reliable data to provide some analysis of fire spread related to plantation type. It is clear that the data to achieve this are not available. The data that can be obtained from the reports identified are provided below, although they should be treated with caution. Any further analysis should be done after referring to the report cited in the table. Note that data relevant to the ACT wildfires of January 2003 is presented in Table 7 in the main body of the report.

Jurisdiction	Location	Date	Area of plantation burnt (ha)	Main Species Burnt	Stand Ages (yrs)	FFDI	Max ROS/ Max ROS of Surface Fire (m/hr)	Max ROS of Crown Fire (m/hr)	Max Spotting Distance (m)	Reference
New Zealand	Berwick	26 Feb 1995	181	Mixed	Mixed	VH	2800 not all pine)			Fogarty LG, Jackson AF and Lindsay WT (1996)
Queensland	Toolara	22 Sept 1991	902	P elliottii	20/21, pruned, thinned, prescribed burnt?	VH	900			Alexander ME (1991)

Queensland	Beerburrum (3 fires)	27/28 Sept & 6/7 Nov 1994	4800	P elliottii		VH/E	1600-3600		Significant Distance?	Hunt S, Hamwood R and Ollerenshaw S (1995)
South Australia	Wandilo	5 April 1958	320	P radiata P pinaster	23-24	VH	600	1200-1600	Up to 2000 after the fire storm	McArthur AG, Douglas DR and Mitchell LR (1966)
South Australia	Glencoe	2 April 1966	40	P radiata	8-12	VH/E	600	1200	400-600	Woods and Forests, South Australia (1990)
South Australia	Kongorong	29 March 1971	328	P radiata	29, 5-11, some slash	VH	500-600 in 29 yr old stand		100-200 through canopy 800 as a result of a whirlwind	Woods and Forests, South Australia (1990)

South Australia	Glencoe	30 January 1974	370	P radiata	Mature, but generally poor quality forest	VH	600-1200		800	Woods and Forests, South Australia (1990)
South Australia	Caroline	2 Feb 1979	3244	P radiata	8-11 14-19	VH/E	4000	4000	Multiple short distance spotting.	Geddes DJ and Pfeiffer ER (1981)
South Australia (see notes below)	Central & South-east Regions	16 Feb 1983 Ash Wednesday	21000	90% P radiata	Mixed ages and treatments	>100 for a number of hours	12000-14000			Keeves A and Douglas DR (1983)
Victoria	Longford	17Nov 1962	111	P radiata P pinaster	9-10	Extreme	600		300	McArthur AG (1965)
Victoria	Bright	24 Nov 1982	332	P radiata Some P ponderosa	.Mixed	VH/E	1100		1800	Watson N, Morgan G and Rolland D (1983)
Western Australia	Burrows Trial	1988	NA	P pinaster	17, unthinned, unpruned	H/VH?	160-200	280-1440	50-100	Burrows N, Ward B and Robinson A (1988)
Western Australia	Myalup	21 April 1991	260	P pinaster P radiata	Mixed	VH	1300		2600	Smith R (1992)

Western Australia	Gnangara	30 Dec 1994	850	P pinaster	30-43	VH/E	>2000		200-400	Burrows N, Ward B & Robinson A (2000)
Western Australia	Bridgetown	2003/04	982	P radiata		Extreme	4000			McCaw L pers comm.

Appendix 4. Fuel Reduction Burning Guides

1. Victorian Guides

Table 1 is taken from Woodman and Rawson (1982), after Thomson (1978). Thomson examined low intensity fire behaviour, in spring, in three stands of *P radiata* in north-eastern Victoria.

Table 1. Fuel Reduction Burning Prescriptions for Radiata Pine Stands

Stand Age (Years)	BKDI[1]	Needle Fuel Moisture (%) Surface Needles	Needle Fuel Moisture (%) Elevated Needles	Wind Speed[2] (km/hr) Mean	Wind Speed[2] (km/hr) Maximum
11	<50		15-22[3] 12-22[4]	0-4	7
16	<100	14-20[3] 12-20[4]		0-4	7
26	<30	16-20[3] 12-20[4]		0-4	7

1 The Byram Keetch Drought Index measured in points.
2 Wind speed recorded at 1-2 m within the stand.
3 Moisture limits for a lighting pattern which relies on headfire, i.e. fires allowed to spread with the wind, or upslope.
4 Moisture limits for a lighting pattern which relies on backfire, i.e. fires spreading into the wind or downslope.

Table 2 is also taken from Woodman and Rawson (1982) after Billing (1979). The prescription is derived from experimental burning in 14 month-old first thinning slash in a 15 year old *P radiata* stand that had been low pruned. The elevated fuels from thinning were up to one metre high. Temperature, relative humidity and wind speed measurements were taken inside the plantation, and spread rates under the conditions described should be less than 40m/hr.

Table 2. A fuel reduction burning prescription for first thinning slash.

BKDI	Moisture content (%) Duff Layer	Needle Fuel Moisture (%) Elevated Needles	Wind Speed (km/hr)	Temp (^oC)	RH (%)
<70	>40	17-21	<5	<20	>50

"The prescription is similar to that shown in Table 1 *except that maximum temperature and minimum relative humidity have been specified. This has been done to emphasise the importance of selecting mild conditions if stem damage and crown scorch are to be minimised. Although not included in his prescriptions, Thomson's*

results indicated similar temperature and relative humidity limits were desirable." Woodman and Rawson (1982)

A Fuel Reduction Burning Prescription for "Aerial Fuels"

In young unpruned *P radiata* stands, significant quantities of dead needles can collect in the branches of the lower crown, providing an important path to crown fire formation. Billing (1979) showed that these fuels could be burnt after first thinning, and before the thinning slash itself was burnt, when the fuel moisture levels in the "aerial fuels" were quite high.

"Because they are extremely well aerated the aerial fuels can sustain burning at moisture contents up to 45%, and the range 25-35% is most suitable for this type of operation. Under these conditions during winter and spring the moisture contents of the elevated slash fuels and litter and duff layers should be too high to sustain significant fire spread. Temperatures less than 15 ^{o}C, relative humidities greater than 70% and wind speeds within the stand of less than 5 km/hr are desirable." (Woodman and Rawson 1982, after Billing 1979) (See also Billing and Bywater 1982)

2. Western Australia Guide

Table 3. Prescribed conditions for pine underburning

Type of Burn	**Needlebed SMC**	**Needlebed PMC**	**AFF**	**Temp (^{o}C)**	**RH (%)**	**Ground Wind (km/h)**	**SDI Limit**
Needlebed Burn *P radiata*	15-22	>60	0.3-0.6	<22	45-60	2-6	<250 or fall of 500 from summer maximum
Needlebed Burn *P pinaster*	20-30	>60	0.3-0.6	<20	50-70	2-6	<250 or fall of 500
Slash Burn *P radiata*	18-24	>60	0.2-0.4	<22	50-65	0-3	<250 or fall of 500
Slash Burn *P pinaster*	28-35	>60	0.2-0.4	<20	60-75	0-3	<250 or fall of 500

Source: Forest Fire Behaviour Tables of Western Australia, 1985

SMC: Surface moisture content
PMC: Profile moisture content
AFF: Available fuel factor
SDI: Soil dryness index

Appendix 5. Fire Suppression and Wildfire Intensity, Bushfire Attack Categories

Table 1. Generalised limits of fire suppression effectiveness in relation to fire intensity,

Fire Intensity (kW/m)	Control Requirements
<500	Ground crews with hand tools
500-2000	Water under pressure and/or heavy machinery
2000-4000	Helitankers and airtankers using chemical fire retardants
>4000	Very difficult, if not impossible, to control

Source: From Pearce (2004), after Alexander and De Groot (1988); Alexander and Lanoville (1989).

Table 2. Bushfire attack categories and expected fire behaviour,

Category of Attack*	Expected Fire Behaviour
Low	Insignificant ember attack, radiation no greater than 14.5kW/m, or is greater than 100 metres from all woody vegetation.
Medium	Significant ember attack, radiation heat greater than 14.5 kW/m, and no greater than 16kW/m.
High	Significant ember attack, possible flame contact, radiation heat greater than 16kW/m, and no greater than 21kW/m.
Extreme	Significant ember attack, possible flame contact, radiation heat greater than 21kW/m and no greater than 31kW/m.
Flame Zone	Within the Flame Zone and/or radiation greater than 31kW/m.

* Categories of Bushfire Attack are based upon a Fire Danger Index (FDI) of 80 and fuel loads for NSW vegetation.
Source: Rural Fire Service NSW (2001)

Appendix 6. Glossary

This Glossary has generally been drawn from Cheney (1993).

Backfire (Backing Fire)	A prescribed fire or wildfire burning into or against the wind or down the slope without the aid of wind; characterised by the flames leaning over the burnt area.
BKDI or KBDI	The Byram-Keetch Drought Index measured in points or millimetres. A relative number which reflects the dryness of the large components and deep organic layers of forest fuels.
Convective Activity, Convection Column	Thermally produced ascending column of gases, smoke, ash particulates and other debris produced by a fire. The column has a strong vertical component indicating that buoyant forces obstruct the ambient surface wind and can form a *Wake Zone* in the lee of the column.
Crown Fire, Passive Crown Fire, Active Crown Fire	A Crown Fire is a fire that advances from top to top of trees or shrubs more or less independently of the Surface Fire. Sometimes Crown Fires are classed as either running (Active) or dependent (Passive), to distinguish the degree of independence from the Surface Fire.
Crown Scorch	Browning of the needles or leaves in the crown of a tree or shrub caused by heat from a fire.
Duff Layer	The matted, partly decomposed organic surface layer of forest soils.
Fine Fuels, Flash Fuels, Litter Fuels	1. Fuels such as grass, leaves, dropped pine needles, fern tree moss and some kinds of slash that ignite rapidly and are consumed rapidly when dry. 2. Fuels burnt in the continuous flaming zone of a fire – often defined as those fuels <6mm diameter.
Fire Behaviour	The manner in which a fire reacts to the variables of fuel, weather and topography.
Fire Danger	The sum of constant and variable fire danger factors affecting the inception, spread and resistance to control of a wildfire
Fire Danger Index (FDI)	A relative number denoting an evaluation of rate of spread or suppression difficulty for specific combinations of fuel, fuel moisture and windspeed.
Fire Danger Rating	A fire management system that integrates the effects of selected fire danger factors into one or more qualitative or numerical indices of current protection needs.
Fire Hazard	1. A fuel complex, defined by volume, type, condition, arrangement and location, that determines the degree both of ease of ignition and of suppression difficulty. 2. A measure of that part of the fire danger contributed by the fuels available for burning.

Fire Intensity (Byram's Intensity)	The product of the available heat of combustion per unit area of ground and the rate of spread of the fire. The primary unit is kilowatts per metre (kW/m) of fire edge.
Fire Load	The number and size of fires historically experienced on a given unit over a given period (usually one day) at a given index of fire danger. The combination of the probable number of wildfires in a given period, the number of existing wildfires, and their anticipated difficulty of control.
Fire Management	All activities associated with the management of fire prone values, including the use of fire, to meet land management goals and objectives.
Fire Prevention	All activities concerned with minimising the incidence and damage from unplanned fires.
Fire Protection	All activities to protect an area from damage by wildfire.
Fire Suppression	All the work and activities connected with fire-extinguishing operations, beginning with discovery and continuing until the fire is completely extinguished.
Firebrand	Any burning material originating from one fire that could start another fire (eg. Commonly bark, but also leaves, embers, sparks, cones).
Firefighter	A person whose principal function is fire suppression.
Fireline	1. A loose term for any cleared strip used in control of a fire. 2. That portion of a control line from which all flammable materials have been removed 3. A line cleared around an actionable fire, generally following its edge to prevent further spread of the fire and effectively controlling it.
Fuel Break	A generally wide (>30m) strip of land on which the vegetation has been permanently modified so that: • Fires burning into it can be more readily controlled • It gives *(some)* protection to firefighters; and • It allows easy access for suppression forces
Fuel Moisture, Fuel Moisture Content	The water content of a fuel particle expressed as a fraction of the oven dry weight of the fuel particle.
Fuel Reduction Burning	A fuel treatment that reduces the load of available fuel by burning.
Head Fire	That portion of a fire edge showing the greatest rate of spread (ie. generally to leeward or upslope).
Heavy Fuels, Coarse Fuels	Fuels of large diameter, such as logs and large branchwood, or of a peaty nature, that ignite and burn more slowly than fine fuels.
Needle bed	The entire layer of fine fuel created by needle fall.
Plantation	The National Forest Policy Statement definition of a timber plantation is: *'Intensively managed stands of trees of either native or exotic species, created by the regular placement of seedlings or seeds.'*
Prescribed Burning	Controlled application of fire to natural or modified fuels under specified environmental conditions, that allow the fire to be confined to a predetermined area and, at the same time, to produce the intensity of heat and rate of spread required to attain planned resource management objectives.

Rate of Spread	The relative activity of a fire in extending its horizontal dimensions – expressed either as rate of increase of the fire perimeter, as a rate of increase in area, or as a rate of advance of its head (rate of forward spread), depending on the intended use of the information.
Spot Fire	Fire ignited outside the perimeter of the main fire by flying sparks, embers or larger firebrands.
Spotting	Behaviour of a fire producing firebrands that are carried by the wind and start new fires beyond the zone of direct ignition by the main fire.
Spotting Distance	The distance over which new fires are started by spotting activity. • Short distance - <1 k • Medium distance - 1-6 k • Long distance - >6 k
Surface Fire	A fire that burns only surface litter, other loose debris of the forest floor and small vegetation.
Surface Fuel	The loose surface litter on the forest floor, normally consisting of fallen leaves or needles, twigs, bark, cones and small branches which form a compact layer with individual components oriented horizontally.
Wake Zone	A zone of light and variable wind downwind of a strong convection column caused by the column obstructing the ambient wind.
Wildfire	Any uncontrolled fire burning in forest, scrub or grassland.