Fuel Management—An Integral Part of Fire Management: Trans-Tasman Perspective

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Abstract—*Although Australia and New Zealand have quite different fire climates and fuels, the common understanding of fire behaviour underlies many facets of fire management in both countries. Fire management is the legal responsibility of various government land management agencies that manage public lands and individuals, local governments or corporations that manage private land. Volunteer bushfire/rural brigades have been formed throughout rural and peri-urban areas and are coordinated by rural and metropolitan fire authorities for specific activities such as fire suppression and fuel management. During the last two decades there has been an increasing interaction between Australia and New Zealand rural and land management fire agencies exchanging fire management practices, lesson's learnt, common incident command systems and more recently, through partnership in their research programs.*

Both countries face a similar array of challenges in meeting their fire management objectives and the task is becoming increasingly difficult. As overarching services provided by governments, fire management has been subject to financial pressures, resulting in staff reductions and erosion of traditional levels of fire management resources. Resources are declining at a time when demands for protection by the general community are increasing. Concurrently, the demands for ecologically appropriate fire management practices and concerns about the long-term impacts of prescribed burning have led to the suggestions that, in some areas, fire is adversely affecting biodiversity and long-term sustainability of natural ecosystems. These issues are overlain by debate about how fire can affect climate change, greenhouse gas balance at the landscape and national level, and whether such changes are being exacerbated by managed and/or wildland fires.

Australian Fire Environment

Bushfires have been part of Australia's environment for millions of years. Australia's natural ecosystems have evolved with fire, and the landscapes and their biological diversity have been shaped by both historical and recent patterns of fire. Because of the climatic variation across Australia, at any time of the year some part of the continent is prone to bushfires. Thus, bushfire occurs throughout Australia, although they may be very infrequent in some climatic zones, such as those dominated by rainforest or wet eucalypt forests. In any give year, the greatest extent of bushfires is in the tropical savannas regions of northern Australia; in some seasons these extend into the semi-arid and arid interior regions (Luke and McArthur 1978). Table 1 shows area of Australian burnt between 1997 and 2003 and percentage of total land area fire affected (Ellis and others 2004).

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Table 1—Approximate fire-affected areas across Australia, 1997 to 2003[a].

Calendar year	Area (million hectares)	Percentage of total land area fire affected	Percentage of fire-affected area that is tropical savanna[b]
1997	48.3	6.3	86
1998	26.3	3.4	92
1999	60.0	7.8	86
2000	71.5	9.3	65
2001	80.1	10.4	84
2002	63.8	8.3	63
2003	31.6	4.1	85

[a] Source: Western Australian Department of Land Information in Ellis and others 2004.
[b] Defined by the Department of Land Information, Western Australia, for the purposes of monitoring fire-affected areas, as being the area north of 21°S and east of 120°E.

Planned fires to achieve specific objectives (ecological, fuel reduction, etc) have been and remain a fundamentally important land management tool for Australia's land managers and firefighters. Australians who work with bushfires- indigenous Australians, farmers and pastoralists, fire fighters, public land mangers and scientists- recognise that there are good, as well as bad, bushfires. Good bushfires help to meet land management and fire mitigation objectives without adverse impacts on people, property or the environment; bad bushfires threaten lives, property or environmental assets and do so in ways that are difficult to control (Ellis and others 2004).

Since European settlement nearly 70 percent of Australia has been occupied by agricultural, forestry and livestock grazing enterprises resulting in the extensive modification and conversion of forest woodland, open woodland, shrubland and grassland systems (Thackway and Lesslie 2005). The native forests cover is classified into three classes by the density of their crown cover (National Forest Inventory 2001). Thus, there are:

- 118 million hectares of woodland (tree crowns cover 20 to 50 percent of the land area when viewed from above), including just under 10 million hectares of woodland mallee;
- 43 million hectares of open forest (51 to 80 percent crown cover), made up of 38 million hectares of what are commonly called wet and dry sclerophyll forests and 5 million hectares of open forest mallee; and
- 5 million hectares of closed forest (81 to 100 percent crown cover), made up of over 4 million hectares of rainforest and almost 1 million hectares of mangroves.

Most of the woodland and open forest areas of Australia, composed of fire-dependent and fire-adapted species and ecosystems, have evolved in the presence of a fire regime driven originally by natural sources of fire ignition (i.e. lightning) and by cultural practices of aboriginal people. The forests are a source of raw material for the forest industry, and a source of many tangible and intangible products and services including recreational and cultural opportunities for all Australians. In recognition of these values, forest protection efforts commenced in the early 1900s, and have steadily developed to the point where Australian State public land management agencies are recognized among the world's leaders in fire management.

Forest fire management in Australia is the responsibility of the State and Territorial governments. Fire management on public lands (e.g. State forests,

National parks, State parks, Crown lands, etc.) is the responsibility of the State agency charged with managing those areas. Fire suppression may be carried out by individual agencies or placed with one agency, e.g. in Victoria suppression on all State lands is carried out by the Fire Management Section of the Department of Sustainability and Environment. Fire management on private lands is carried out by volunteer bushfire brigades or industry brigades that are co-coordinated and supported by the State rural fire agencies. In recent years there has been an increase in the corporatisation of State-owned plantations and the fire management responsibility for these forests, along with new plantation forests established on private land, rests increasingly with the State rural fire authorities. This shift in fire responsibility has mainly occurred in South Australia and Victoria over the last five years.

Most of the States provide fire management directly as a government service, generally by the departments that manage lands, forests and other natural resources. Their fire management programs provide for varying levels of planning, fuel management (i.e. prescribed burning), detection, pre-suppression and suppression operations. The level and type of activity in each category varies with each agency's natural resource polices, protection priorities, financial resources and, in particular, the ecological and biogeographical conditions of the forest itself. Consistent with the statutory obligations and policies of public management agencies, their fire management objectives include:

- Protection of people from bushfire.
- Protection of buildings and facilities from bushfire.
- Prevention of bushfire burning onto neighbouring property.
- Conservation of natural and cultural values including:
  - Native plant and animal species, habitats and communities;
  - Soil and water resources;
  - Scenic and landscape values; and
  - Aboriginal and European heritage values.

All agencies deliver an organised detection program. Fire towers are the most common detection system offering regular surveillance of high-value areas and community assets. The used of fixed wing aircraft for detection has increased in the past 15 years. There are recent attempts to use satellite-based remote sensing as a tool for fire detection.

Suppression strategies use a mix of resources from the land management agencies with support from rural bushfire authorities. Ground crews using fire appliances (fire tankers), heavy equipment (dozers) and hand tools are the backbone of the suppression system. Aircraft for aerial suppression have been used in Victoria for more than thirty years, and over the past decade other land management agencies have increasingly used air attack on bushfires.

Different suppression strategies are used by the agencies, which are based on the nature of the forest and fire regimes that they deal with and, to some extent, on the organisational philosophy. Some agencies, such as those in Victoria and Western Australia, have relatively large full-time fire management organisations compared to those in other States.

New Zealand Fire Environment

Although not having one of the most severe fire climates in the world, New Zealand has as a long history of large and damaging wildfires. Northern and eastern New Zealand are characterized by a mix of flat and steeply

divided terrain, occasional drought, strong wind conditions and flammable grass and scrub fuels. New Zealand climate ranges from subtropical in the far north to cool temperature in the south, but the steep and divided relief causes dramatic variation along the length of the country. As frontal weather systems approach New Zealand, the winds preceding it often reach gale force and are force to rise over the Southern Alps resulting in hot dry fohn winds in the eastern part of the South Island. These regions in the South Island Canterbury Plains can experience extreme fire weather on more than 40 days per year (Pearce and Majorhazi 2003).

The approximate cover of different land uses in New Zealand is listed in table 2. Natural and plantation forests cover 23 percent (6.2 million hectares) and 7 percent (1.8 million hectares) of the New Zealand land area respectively (New Zealand Ministry of Agriculture and Forestry 2005). Areas of pastures, arable land and other non-forested land (tussock and scrub vegetation) cover approximately 70 percent (18.9 million hectares). These areas of tussock and scrub fuels are very flammable, and recent research results show that extreme fire behaviour will often occur under Low to Moderate forest fire danger conditions (Fogarty and others 1998).

New Zealand native vegetation consists of species that are not specifically adapted to fire, but there are xeromorphic elements thought to be adapted to disturbance from longer term climatic fluctuations. Margins of beech (*Nothofagus* spp.) and podocarp forest are sensitive to fire and after fire or other disturbance (e.g. landslides), flammable species (e.g. *Leptospermum* spp. and *Dracophyllum* spp.) invade the site such that the potential for decline and fragmentation by fire is increased (Fogarty and Pearce 1995).

New Zealand experiences approximately 3,000 vegetation wildfires each year and these fires are attended by the Department of Conservation, forest companies or local government Rural Fire Authorities make up of both permanent (land management) staff and volunteer fire fighters. These fires are primarily human-caused and many continue to occur as a result of escapes from (both permitted and unauthorised) prescribed burning activities and increasing arson (Pearce and Majorhazi 2003).

The number of hectares that are burnt annually by wildfires varies considerable being driven predominantly by the weather conditions during the summer season. The summer of 1946 represents the most disastrous fire year in New Zealand history when, following periods of drought in the north east central regions of the North Island, over 200,000 ha of indigenous forest, exotic plantations, cutover forest, tussock and scrub were burnt. More recently, the 1998/99 fire season resulted in 18,000 ha being burnt. Since 1988/98 there has been an annual average of 7,000 ha of rural lands (including forestry) have been burnt (Fogarty and Pearce 1995).

Large and devastating bushfires occur relatively infrequently in New Zealand when compared with Australia, Canada and USA. However, the

Table 2—Different land uses in New Zealand.[a]

	Hectares (millions)	% of total
Pasture & arable land	11.8	44%
Natural forest	6.2	23%
Other non-forested land	7.1	26%
Plantation forest	1.8	7%

[a] Source: New Zealand Ministry of Agriculture and Forestry, 2005.

potential exists in most parts of the country for significant events to occur (Pearce and others 2004, Fogarty and others 1998). Like Australia, New Zealand will face an increase in the severity and impact of bushfires in the next decade and beyond. The increasing trend in the expansion of the rural-urban interface is one of the major factors contributing to increased future risk from wildfires. Also, changes in forestry and land management practices may increase the likelihood of major wildfire events. This includes potential changes in long-term fire danger such as those associated with projections of future global warming and climate change (Pearce and others 2005; Hennessy and others 2006).

Fuel Management Strategy

The damage caused by wildfires and the ability of suppression forces to control them is strongly linked to fire intensity, which is governed by fuel, weather and topography. Of these factors, only the fuel level can be manipulated, and fuel management is the basis of wildfire prevention throughout much of Australia. New Zealand is beginning to consider use of fire to manage fuels (for fuel reduction or ecosystem management) despite a long history of using fire as a land management tool for land clearing and forest establishments. In the natural landscape, this requires the periodic removal of part of the surface litter and understorey vegetation. This can be achieved by manual, mechanical, or chemical methods or through the use of fire.

Prescribed burning is defined as the burning of vegetation under specified environmental conditions and within a predetermined area to achieve some predetermined objective. The objective may include habitat management for native fauna, species regeneration, maintenance of specific eco-types or hazard reduction, etc.

Studies conducted by McArthur (1962), Peet (1965), and others since the 1960s (Cheney and others 1992) have provided the technology for fire to be used effectively to manage fuels. These studies enable the behaviour of fires that are lit under given conditions to be predicted. A range of operational procedures provide a high level of security against fire escape. Due to the improvements in techniques and the application of fire behaviour knowledge, prescribed burning has become a reliable fuel management tool. To date the only effective way of reducing fuels over large areas is through the use of low-intensity prescribed fires and, in Australia, this is generally synonymous with broad-area fuel reduction. In most of the eucalypt forest the aim of fuel-reduction programs is to keep the load of fine fuel (fuels less than 6 mm in diameter) on the forest floor to less than 10 tonnes per hectare (t ha^{-1}). This will prevent the development of crown fires in medium to tall forests and will limit the rate of spread and damage done by wildfires. The frequency of burning is determined by litter accumulation rates so that burning rotations to manage fuel reduced areas are normally between 5 and 10 years.

Prescribed fire is also used in native forests to remove slash accumulations and to prepare a seed bed for the regeneration of native forest species, and more recently to regenerate understorey species and manipulate vegetation to provide suitable habitat for native fauna. Although these operations also remove fuels, they are generally of higher intensity than low-intensity prescribed burning specifically for fuel reduction and the intensity prescribed is determined by the requirements for good regeneration.

Hazard reduction burning—Hazard reduction burning will reduce the total load of fine fuel and is also effective in reducing the height and flammability of elevated fine fuels such as shrubs and suspended dead material. Burning is the only practical way of reducing the fibrous bark on trees, which is the prime source of firebrands that cause spotting. Hazard reduction reduces fire behaviour by:

- reducing the rate of development 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 does not provide a panacea, nor does it work in isolation. It must be used in conjunction with an efficient fire fighting force.

Hand crews can suppress a fire up to a maximum intensity of 1000 kilowatts per metre (kW m^{-1}) (Loane and Gould 1986). If the fuel load is greater than 15 t ha^{-1} (which is typical of dry eucalypt forests between 8 to 15 years since the last fire) this intensity will be exceeded under low to moderate fire danger conditions. If the fuels are reduced to 10 t ha^{-1}, fires will not develop an intensity of 1000 kW m^{-1} until fire danger gets into the moderate to high range. This means that the range of weather conditions that fire fighting with hand tools is effective is increased and more time is available to bring the fire under control. If the fuels are reduced further to less than 7.5 t ha^{-1} then suppression with hand tools is effective under weather conditions of very high fire danger. Under extreme conditions, provided there is sufficient fuel to carry fire, fire suppression by any means is virtually impossible because the strong dry winds associated with conditions will cause burning embers to breach any fireline. Nevertheless, the result of the lighter fuel load will reduce the rate of spread of the fire and the area burnt so that the fire suppression task will be easier when the weather conditions ameliorate.

Silvicultural burning—Silvicultural burning is usually a moderate-intensity prescribed burn carried out after a partial-cut logging operation designed to remove logging slash, prepare the seed bed and stimulate regeneration and/or the growth of rootstock regeneration. Silvicultural burning is conducted in the jarrah forest of Western Australia and the silvertop ash forests of New South Wales.

Ecological burning—The main aim of using fire for ecological management is to provide an appropriate fire regime (of specific fire frequency, intensity, seasonality and patchiness) to meet specific goals for the management of a particular species, populations or communities (e.g. as part of a recovery plan for a threatened species). Since fire has a fundamental role in the development of forest ecosystems, it follows that fire has a place in maintaining them. Good (1981) indicated that because fire is the major and only environmental factor over which some control can be exercised, and many native species depend on fire for their continued existence, and the use of fire will always have a place in ecological management. Fire has a place in both flora and fauna management but its effective application in Australia has been infrequent.

Application of prescribed burning—There is a perception among people unfamiliar with fire management that prescribed burning is simply lighting fires to burn-off the undergrowth and that this can be carried out with only a basic understanding of fire behaviour. Indeed, where burning-off has been carried out in this way the results have been less than optimal and have resulted in escapes, injury and/or death (e.g. Kur-Ring Gai National Park, New South Wales 2000). Like any land management operation, prescribed burning requires the setting of clear priorities and objectives, planning and the application of technical guidelines to meet those objectives. In general terms the process of conducting a prescribed burn is as follows:

- Set the objectives and desired outcome for the fire.
- Determine the fire intensity and the associated heat pulse that is required to meet that objective (in forestry and for fuel management this may be determined by an acceptable height of scorch of the overstorey canopy or an acceptable level of heat damage to the cambium of regenerating trees).
- Determine the level of fire behaviour (for example flame height, intensity) that will produce this heat pulse for the particular fuel type.
- Determined the weather conditions and the ignition pattern that will produce this fire behaviour.
- Light the fire in a planned way when prescription conditions are met and confine it to a predetermined area.

The key to conducting the operation is a good fire behaviour guide that predicts fire behaviour in the selected fuel type. In Western Australia, the Department of Conservation and Land Management has been conducting prescribed burning to meet fire protection, forestry and ecological objectives in a scientific way since mid-60s. The planning process starts seven years in advance of each prescribed burn. Individual burning guides have been developed through empirical research for all their major fuel types including dry jarrah forest, tall wet karri forest, conifer plantations and mallee shrublands (for example Sneeuwjagt and Peet 1998).

In the eastern states prescribed burning is largely carried out using rules of thumb based on a McArthur's original burning guide for dry eucalypt forests produced in the 1960s (McArthur 1962). However, in one case a new burning guide has been developed and that was for burning under young regeneration of silver top ash in New South Wales State Forests (Cheney and others 1992). Clearly, if prescribed burning is to be conducted in a more professional way in there is an urgent need for new and better burning guides that can be applied to a whole range of different fuel types.

Advances in fuel management—The development of more sophisticated burning guides requires a better understanding of fire behaviour in fuels of different structure and composition. Recent work undertaken by CSIRO and Department of Conservation and Land Management Western Australia as part of Project Vesta (Cheney and others 1998, Gould and others 2001, McCaw and others 2003) has identified the importance of fuel structure in determining fire behaviour and has developed a system for quantifying fuel structure with a numerical index that can be used as a fuel predictor variable to replace fuel load.

Although fuel structure is difficult, if not impossible, to measure reliably and consistently, all natural fuels can be divided into easily recognisable layers. It is the characteristics of these layers that determine the particular fuel type and its characteristic fire behaviour and the difficulty of suppression. For

example, the simplest fuel type is annual grassland like wheat. This is a single layer of relatively uniform compaction. The main factor that determines rate of spread is the continuity of the grass. Although height of the sward the affects the flame height, and thereby the suppression difficulty, it has only a minor effect on the rate of spread. In contrast dry eucalypt forest with a tall shrub understorey has fuels that can be identified into several layers of different compaction. These are in order of decreasing compaction:

- Compacted surface litter bed of leaves twigs and bark that makes up about 60 percent of the total fuel load,
- Near surface layer above it of the low shrubs containing suspended litter and bark,
- Elevated layer of tall shrubs,
- Intermediate layer of small trees,
- Fibrous bark of the overstorey trees, and
- Canopy of the overstorey trees.

All of these layers make an important contribution to the fire behaviour and each layer becomes progressively involved in fire as the intensity increases. A visual hazard rating system is being developed (Gould and others 2001) takes into account the height, continuity and fraction of dead flammable material in each layer. The latter that appears to be most important in determining fire spread is the near surface fuel layer and the best fuel variable for predicting the rate of spread is an index based on the hazard score and height of the near surface fuel layer (Gould and other 2001, McCaw and other 2003).

Effectiveness of fuel reduction over time—The period of time over which fuel reduction remains effective in assisting suppression depends upon the number of fuel layers involved, the rate of accumulation of fuels and the time that it takes for the key layers to build up to their full potential hazard for the site. This may be a relatively short time for fuels with a simple structure or take many years in more complex fuel types (table 3).

Table 3—Period that fuel reduction burning will assist suppression activities and the main factors that contribute to difficulty of suppression.

Fuel type	Persistence of reduced fire behaviour (years)	Factors contributing to difficulty of suppression
Annual grass	1 (year of burning)	
Tussock grassland	5	Development of persistent tussock fuel
Tall shrubland	10 to15	Height of shrubs accumulation of dead material (ROS, flame height)
Forest, short shrubs, gum bark	10 to 15	Surface fuel, near-surface fuels structure (ROS flame height)
Forest, tall shrubs, stringybark	15 to 25	Near-surface fuel, shrub height and senescence, bark accumulation (ROS, flame height, spotting potential

Although the effect of prescribed burning may persist for a considerable time, most fire management agencies consider that sufficient fuels have accumulated after 5 to 8 years to warrant re-burning.

Trans-Tasman Partnership

Australia and New Zealand have had a long history of sound fire management through a number of coordinating organisations. Building on this history and accumulated relevant fire management expertise, fire managers in Australia and New Zealand have been able and will continue to contribute the technical capacity of fire management in Australasia and internationally. In addition to the obvious positive economic and environmental outcomes from fire management their contributions have complementary social benefits to both countries. The major Trans-Tasman co-ordinating bodies include:

Forest Fire Management Group (FFMG)—is a committee of Australian and New Zealand land management agencies with responsibility for forest fire management together with representatives from research, education and the forest industry. FFMG reports to the federal government Forestry and Forest Products Committee (FFPC) which is comprised of the heads of federal, state, and territory and New Zealand government forestry agencies. The FFPC is a sub-committee of the Primary Industries Ministerial Council. FFMG's aims are to provide a centre of expertise on forest fire management and control, and particularly to:

- Provide a high level of technical and policy advice on fire management and fire control matters to the Forestry and Forest Products Committee through the Primary Industries Standing Committee;
- Assist interstate and international liaison and consultation between fire controllers and managers; and
- Assist in the development of effective fire management and control philosophy and proficiency.

Australasian Fire Authorities Council (AFAC)—is the peak representative body for fire, emergency services and land management agencies in the Australasian region. It was established in 1993 and has 26 full members and 10 affiliate members. AFAC's mission is to improve collaboration between the fire, emergency services and land management agencies in the Australasian region, particularly in the exchange of strategic information and the sharing of expertise.

As the national peak body, it is also committed to:

- Developing national standards for the fire industry;
- Advocating to State and Federal government on behalf of its member agencies;
- Creating national policies on a range of issues;
- Acting as an industry peak body on issues of national importance.

Research partnership—The resources of Australia's and New Zealand's pre-eminent forest research organisations has come together in a world leading joint forest research venture. Ensis- the joint venture between Australia's CSIRO Forestry and Forests Products and New Zealand's Scion (formerly Forest Research) - combines and enhances the breadth, depth and scale of Australasia's bushfire research and development capability. This research capability is also enhanced by the research partnership with the Bushfire Cooperative Research Centre (Bushfire CRC). The integrated Ensis bushfire

research group created a strong Australasian bushfire science capability with significant benefits to end users in Australia and New Zealand, including:

- Gaining critical mass, economies of scale, and enhanced overall capability, with immediate benefits in the areas of bushfire science.
- A significant increase of expertise available to New Zealand in terms of fire behaviour, fuel assessment and suppression research. Integration of the bushfire research groups has increased its research capabilities in the Bushfire CRC.
- An increased capacity to quickly deal with the various activities generated from major wildfire events which in most cases assume top priority.

Conclusion

Australia and New Zealand have quite different fire environments and diverse land cover but the importance of understanding fire behaviour is recognised in both countries as an aid to fire management. Fire management agencies in both countries face a similar array of challenges in meeting their fire management objectives and the task is becoming increasingly difficult. As a government service, fire management has traditionally been combined with other forest management skills, notably sustainable timber production. Financial pressures and changes in policy relating to timber production from native forests are resulting in staff reductions and erosion of traditional levels of the fire management skills base and resources. Resources are declining at a time when demands for protection by the general community are increasing. Concurrently, the demands for ecologically appropriate forest management practices and concerns about the long-term impacts of prescribed burning practices have led to the suggestion that, in some areas, fire is adversely affecting biodiversity and long-term sustainability of forest ecosystems. It is also widely recognised that there will be increase in the severity and impact of bushfires in the next decade in the Australasian region. This includes potential changes in long-term fire danger such as those associated with projections of future global warming and climate change. These issues are overlain by debate about how fire can affect climate change, greenhouse gas balance at the landscape and national level, and to whether these changes are being exacerbated by managed and/or wildland fires.

Accurate interpretation of the effect of fire management practices on forest management requires not only accurate measurement of area burnt but also the classification of all fires by vegetation type and burning conditions, the measurement of the fuel dynamics and equilibrium fuel loads for each type and the measurement of consumption rates under a wider range of burning conditions than is currently available. Also, fuel management using prescribed fire has an important role in protection of forests, community assets, other valued resources and biodiversity. Forest and rural landscapes in Australia and New Zealand are becoming increasingly more fragmented because of human activities, is also having an impact on the fire management practices that could contribute more to the amount of area burnt by wildfires. The critical role of fire management and using fire as a management tool for fuel management requires a better understanding of fuel characteristics and fire behaviour leading to the development of improved guides for prescribed burning in different fuel types.

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