FIRE MANAGEMENT ON CALM LANDS IN THE SOUTH-WEST OF WESTERN AUSTRALIA

Submission to the Ministerial Review Panel enquiring into CALM's prescribed burning policy and practices and wildfire threat analysis

FEBRUARY 1994

The Department of Conservation and Land Management

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DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

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CHAPTER 1

INTRODUCTION

The bushfire hazard in the south-west of Western Australia is arguably potentially more severe than in any other region of the world. This is because the south-west of Western Australia is the only region in the world that has extensive tall forests, which shed tonnes of highly inflammable material each year, and a Mediterranean climate. That is a climate which produces every year a three to six month drought with periods of high temperature and low humidity.

Fire is a naturally occurring element of south-west ecosystems; to the vegetation and the native animals, it is simply a powerful disturbance factor from which, in time, the natural systems recover, or in the presence of which they evolve. Fire can also be an agent of death and destruction to human assets and values, and large fires are extremely costly to the community.

Every year about 300 bushfires start on the public lands managed by CALM in the south-west of Western Australia. Every year, conditions occur under which some of these fires, if allowed to run, burn so fiercely as to be uncontrollable, even by well-equipped and highly trained firefighters. Every year, wildfires threaten or damage human life, property, environmental and ecological values and economic resources. Every year, CALM staff and volunteer firefighters are expected to stop the seemingly unstoppable - to protect the community and its valued assets from the ravages of intense summer bushfires in the forests, woodlands and heaths of the south-west.

Every year, debate about CALM's approach to fire management also surfaces. For just as fire is one of the greatest and most awesome of natural forces, so "fire management" (especially the use of fire to fight fire) is one of the most complex issues with which land managers are involved.

There are three fundamental responses CALM could take in response to the threat posed by bushfires.

- The suppression approach. Here, firefighters prepare for fire through training and provision of special equipment, wait for fires to start, and then go out and try to suppress them. This is the traditional approach taken in most urban and agricultural areas and by land managers in many parts of Europe and North America. It works when fires are accessible and relatively mild, or where few fires occur simultaneously, but it fails when intense fires develop under adverse weather conditions. It is sometimes dictated, when resources are unavailable for preventative work, or where there is insufficient technical know-how to undertake such work.

- The suppression plus prevention approach. Here firefighters, in addition to maintaining an effective suppression response, seek to mitigate potential fire behaviour by fuel reduction under controlled conditions and other preventative measures. This approach greatly improves the ability to handle fires under severe weather conditions or when there are many simultaneous fires and is the approach adopted for forest areas in Western Australia.

- A do-nothing approach, i.e. simply letting fires run and trying to pick up the pieces afterwards. This is not a morally or legally responsible approach, and has never been seriously considered for application in the south-west of Western Australia.

Both the first two strategies have been tried in Western Australian forests. The second approach was adopted following the failure of the first, in the years before 1961. It involves the deliberate use of fire for fuel reduction (in a process known as prescribed burning) in strategic areas of the forest, together with the maintenance of a highly effective fire detection system and the deployment of well trained and equipped firefighters throughout the south-west. No practical way of fuel reduction in Western Australian forests other than prescribed burning has yet been developed.

Although long practised by Aborigines, the deliberate use of fire in native bush lands is a controversial issue in modern Australian society. CALM believes that there are four main reasons for this: (i) some people, particularly the more vocal "green" extremists, consider fire to be "unnatural" and damaging to native ecosystems; (ii) fire is difficult to manage, and controlled burns occasionally become uncontrolled fires; (iii) the immediate aftermath of a fire is considered by most city or town dwellers to be ugly - green trees and shrubs are blackened or scorched - and the natural recovery processes cannot easily be visualised; and (iv) smoke from prescribed fires can contribute to air pollution in urban areas when it mixes with automobile exhausts and industrial emissions. In addition there are some people who do not regard fuel reduction as effective in mitigating fire behaviour; and there are others who, while not opposing some use of fire, argue that our knowledge of the subject is so tentative that it is better to do nothing than impose a fire regime which might be more damaging in itself.

Many people in the community, however, believe passionately in the value of prescribed burning, and do not consider enough of it is done. These tend to be people who have assets threatened by fire, or who are called upon to fight fires, but also includes many scientists and experienced land managers who understand that fire is a natural factor in the ecosystem and who are aware of the many problems associated with high intensity wildfires which are the inevitable consequence of unchecked litter accumulation.

CALM is caught up in these contentious issues. Our fire control responsibilities, our use of fire and our relationships with different sectors of the community with respect to fire, reflect the complexity of the issues and generate expectations of us from special interest groups.

Unfortunately the level of community support for the practice of prescribed burns is inversely proportional to the time since the last catastrophic bushfire.

CALM has a legal and moral responsibility to ensure that the public land which it manages does not pose a threat to human life and property as a consequence of uncontrolled wildfires. But the Department also has the responsibility of ensuring that the ecosystems on this land are sustained and that public use for a variety of purposes is optimised.

The Department believes that the use of prescribed fire is an essential component of the fire management system that is used to control wildfires in this State. While acknowledging that our knowledge of the effect of fire on ecosystems can always be improved and that prescribed burning practices will change as more information becomes available, the Department submits that there is no evidence that the prescribed burning regimes employed by the Department has any deleterious effects on the ecosystems of the south-west of the State.

This submission puts prescribed burning in a historical context, outlines annual practices and describes its effect on fire behaviour and ecosystems.

The submission focuses on the south-west forest regions of Western Australia - i.e. the area (approximately 2 450 000 hectares) broadly encompassed by the jarrah, karri, tingle, wandoo and tuart forests with their associated coastal heathlands. There are major fire management problems in other regions, particularly the South Coast, the Kimberley, the Goldfields and the spinifex grasslands of the deserts, but as little prescribed burning takes place in these areas, and they are more sparsely populated, they are not considered in this submission.

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CHAPTER 2

BACKGROUND

Any consideration of bushland fire must start with the three elements of "the bushfire triangle": weather, fuel and sources of ignition, and to look at these in their Western Australian context.

Fire Weather

The climate of south western Australia is strongly Mediterranean, i.e. comprises a cool, wet winter, followed by a warming and drying trend into spring, a hot and very dry summer, which in turn is followed by a cooling, dry autumn which is broken by the onset of winter rains. The "fire season" at Collie, for example, in the centre of the forest zone, normally runs from about mid-October to mid-April, although fires can and do occur occasionally in the winter months in all but the wettest of the south-west forests.

The south western fire season is highly reliable. Some summers are hotter and drier than others, but there is never a summer in which hot, dry conditions do not occur. Similarly, the onset of the winter rains in about May can be relied upon every year to signal the end of the fire season for several months. Unlike the south-east of Australia (Victoria and Tasmania) which experience occasional drought, leading to severe summer bushfire problems, the south-west of Western Australia experiences drought **every** summer.

Four consistent features dominate fire weather during the south western fire season:

- the regular passage of a series of high pressure systems from west to east across the southern half of the continent. These generate 7-10 day cycles of increasingly hotter weather, with dry continental winds backing into the north and north-west; after a few days these conditions are terminated by a cold front bringing a cool change, and south-westerly and south-easterly winds, and the cycle recommences.

- On average, seven or eight times each summer, the eastward movement of an anticyclone is blocked by stationary air masses in the Great Australian Bight. An intense low pressure trough then forms between the stationary high and the next incoming one. Occasionally this occurs at a time when there is a cyclone off the coast in the north of the State and the interacting systems produce gale-force north-easterly and north-westerly winds funnelling bone-dry air out of the centre of Australia into the south-west. This has occurred twice in the south-west in recent years - Cyclone Alby in 1978 and Cyclone Fifi in 1991.

- Thunderstorms occur regularly in the south-west region during the summer months. These frequently generate lightning which starts fires in bush lands and forests. Apart from occasional rain from thunderstorms or light showers associated with a cool change, the summers in the forest areas are generally rainless. Lightning has been the source of some of the most destructive fires which have occurred in Western Australian forests, including the worst fires in 1961.

- The vegetation, dry timber and the upper soil layers of the bush all progressively dry out as spring and summer progress, culminating at a point in autumn before the first rains. This drought (or cumulative fuel dryness) factor significantly effects fire behaviour - the dryer the fuels the more easily they ignite and the more intensely they burn - and difficulty of fire suppression, and overlays the day-to-day factors such as temperature, wind speed and relative humidity.

Table 1 shows the typical progression of key fire weather parameters over summer months in Perth.

Table 1 Perth Weather Conditions *

Month	*Av. Max T (°C)*	*Day >35°C*	*Rain (mm)*	*Rain Days*	*Sunshine hrs/day*
September	20.0	0	68	13	7.4
October	22.3	0	48	10	8.8
November	25.4	1	26	7	9.9
December	28.5	4	12	4	10.7
January	31.5	9	8	3	10.7
February	31.7	7	14	3	10.2
March	29.5	4	15	4	9.1
April	25.2	0	46	8	7.3
May	21.4	0	108	13	6.0

* Data supplied by Bureau of Meteorology

Tropical cyclones also have figured prominently in the weather records of the south-west of Western Australia, occurring on average every six years or so. Cyclones that inflicted major damage (including that associated with bushfires) occurred in 1843, 1872, 1915, 1937 1943, 1956, 1960, 1961, 1978 and 1991).

Summary: Land managers in south western Australia must take into account that there will be a fire season every year without fail; that there will be regular warming and cooling cycles throughout the summer, some of which develop into extreme fire weather conditions of heatwave and strong winds; that there will be natural sources of fire in the form of lightning; and that there will be a progressive curing of bushland fuels peaking in late summer or autumn.

Fuels

The amount and rate of heat release, or the intensity of a fire, is a measure of its damage potential, suppression difficulty and killing power. Fuel, consisting of ground litter, twigs, bark, sticks and live and dead vegetation, is the energy source of a bushfire - the amount (or tonnage) of fuel consumed and the rate of combustion directly affect the intensity of the fire.

The greater the tonnage of fuel and the higher the rate at which it burns, the more fiercely intense the fire.

Of all the elements of the bushfire triangle, fuel is the only one which can be managed.

Bushland in south western Australia has three important characteristics in relation to its capacity to fuel a fire:

- The vegetation itself is highly flammable. Leaves of most common species of trees and shrubs contain waxes and volatile oils which ignite easily and burn fiercely. As shrubs age, a greater proportion of the foliage dies and comes to consist of flammable, aerated fuel.

- Fine, flammable dry matter, such as leaves, twigs and bark, (collectively known by fire scientists as "litter") is constantly shed from living plants and accumulates over time. In the absence of fire, forest floor litter continues to accumulate. Figure 1 shows the litter accumulation that occurs over 40 years in karri forest stands.

- Many tree species (e.g. jarrah, marri, blackbutt) have stringy or fibrous bark which can be carried aloft as burning brands and embers in high winds, setting spot fires ahead of the main fire. "Spotting" and "hopovers" are very common features of West Australian forest fires, and are nearly always associated with heavy, dry fuels. They can extend hundreds of metres (sometimes kilometres) from the main fire edge, rendering useless narrow firebreaks or control lines. Jarrah trees in particular can accumulate thick and fluffy dry bark on standing trees in long unburnt areas which provide a ladder fuel by which a ground fire can rapidly develop into a crown fire.

The vegetation and litter in a forest becomes fuel when ignited. This fuel can burn in three different ways: (i) in a mild creeping fire, where the flames are confined to the dry leaves and twigs lying on the forest floor and to ephemeral grasses; (ii) a more intense fire with flames up to eight metres in height, which will consume the ground litter and the shrub layer and mildly scorch the tree canopy; and (iii) a high intensity fire which "crowns" - i.e. the fire leaps into the upper branches of the tall trees, and flames can be up to one hundred metres in height. A crown fire consumes all green and dry leaves in the tree and shrub layers and the litter, leaving only the large woody trunks standing. Under the same weather conditions, the higher the levels of fuel, the more intense the fire and the greater the likelihood of a fire moving from a creeping ground fire to a crown fire. Even under extreme weather conditions, a crown fire will not develop in areas of light fuels. This was demonstrated in the Dwellingup fires of 1961.

Crown fires in tall forest country cannot be directly attacked with current technology.

A view is held by a small number of people that regular prescribed burning actually promotes the development of additional forest fuels, which would not be there in the absence of fire. **Decades of research and field observation refutes this view.** Fuels are always lighter after a fire, and then accumulate in the post-fire period until a semi-plateau is reached (see Figure 2) In the higher rainfall areas fuel accumulates more rapidly; in the drier forests it may take two or three decades for fuel accumulation to start to level off. Measurement in karri stands unburnt for at least 40 years show litter quantities to range from 35 to 60 tonnes per hectare. Forest floor litter quantities in the 60 year old jarrah fuels in Amphion Block are currently of

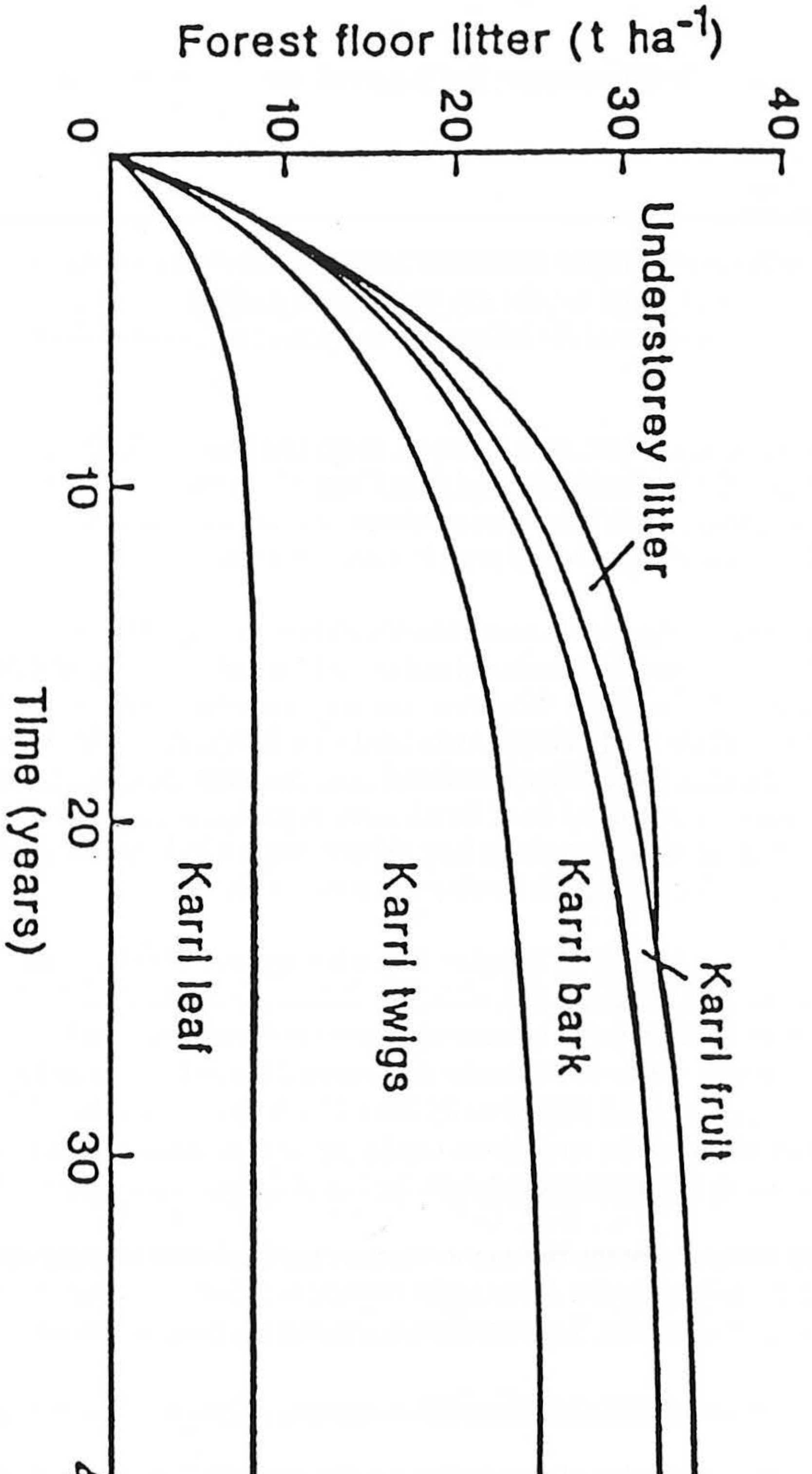
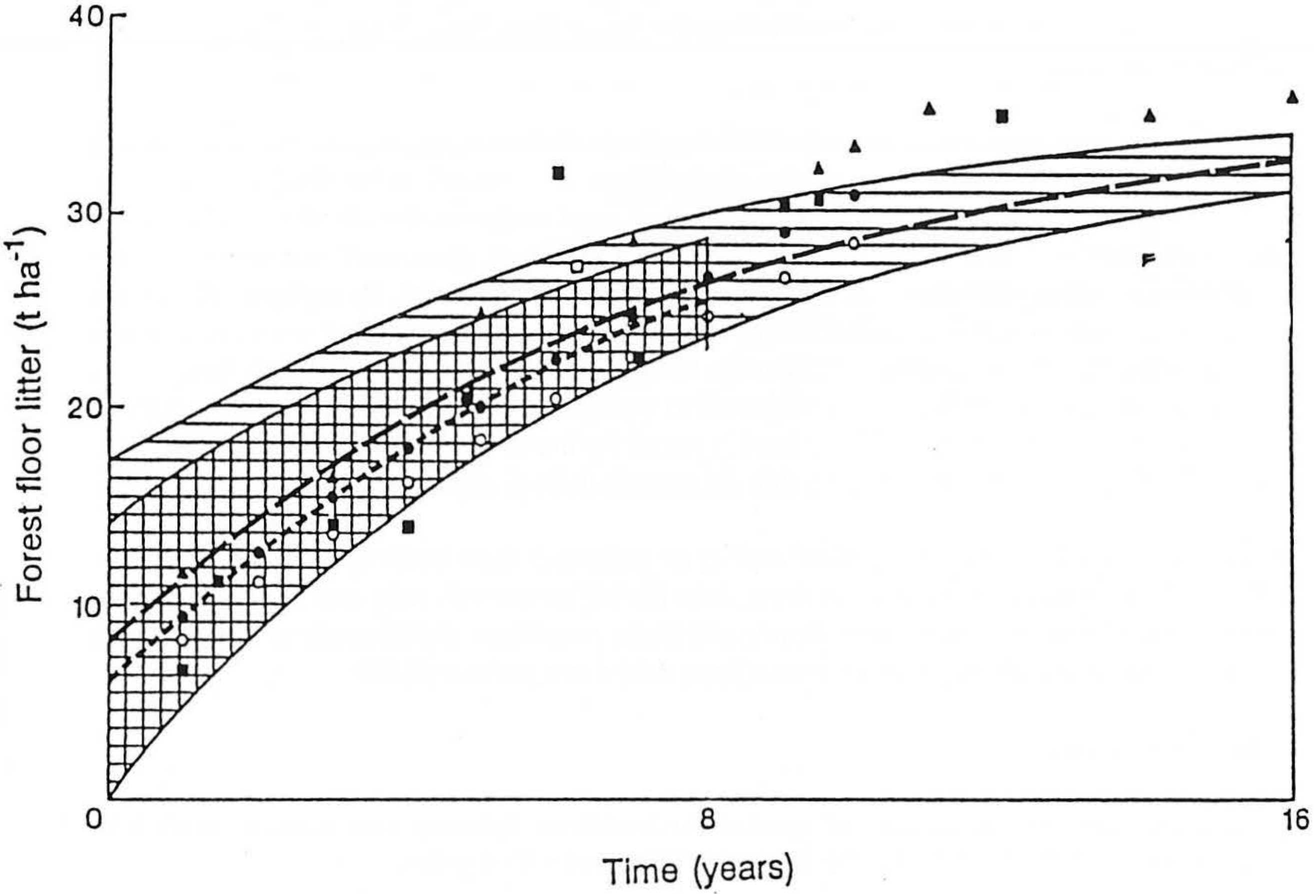


Figure 1 Predicted accumulation of forest floor litter based on measured rates of litterfall and decay constants for ten karri forest litter fractions. Accumulated understorey litter fractions have been grouped for clarity.



Predicted range of forest floor mass in relation to time of accumulation for karri stands burnt with fires which are assumed to consume between 50% and 100% of each of the litter factions. Measured values of accumulated litter from the following sources:

(■) O'Connell 1987; (□) Hingston *et al.* 1979; (O) Peet 1971 - 70% canopy cover; (•) Peet 1971 - 80% canopy cover; (Δ) Lonergan 1961.

From O'Connell (1991).

Figure 2 Comparison of predicted and measured litter accumulation in karri stands

the order of 25 to 32 tonnes per hectare. In addition, the litter and twigs components must be added to the heavy accumulation of blackboy skirts, dead, old banksias, and heavy, fluffy bark. These aerial components contribute greatly to fire spread and intensity to the extent that direct attack on fires in these fuels would not be possible on most summer days. The plateau is only reached at very high levels of fuel and the quantity of fuel which has accumulated is so high that wildfire even under moderately severe weather conditions is almost impossible to control. There is no evidence that rate of decomposition of litter and twigs is sufficient to cause any significant reduction in the quantity of fuel on the forest floor even during the 'plateau phase' of fuel accumulation.

Another misconception is that prescribed burning leads to the introduction of exotic grasses in the forest. This view possibly arises from observations of some urban bushland areas such as Kings Park, or of the grassy fuels which develop on road verges in the wheatbelt, where bush has been burnt very frequently and there are high sources of grass seed and fertiliser from neighbouring farm paddocks. Although there is some development of agricultural grasses along a very narrow (20-100 metres) fringe adjoining some farms in parts of the eastern jarrah and wandoo forest, this is not a problem in the main forest area. There are no sections of south-west forests which have been subjected to periodic prescribed burning over the last 30 years in which the native shrubs have been replaced by introduced grasses. Exotic grasses are well established in the tuart forest, but this did not result from regular prescribed burning.

Summary: *West Australian bushland carries or generates high levels of potential fuel for a fire. In forest areas this fuel progressively dries during summer months and in the absence of fire, accumulates for many years. Heavy, dry fuels contribute significantly to fire intensity and can lead to the development of crown fires, which are uncontrollable.*

Sources of Fire

There are basically two sources of ignition for bushfires: lightning and humans. Both have been features of the West Australian landscape for thousands of years.

Lightning is usually associated with thunderstorms, and these occur in every month of the year in the south-west, most frequently in winter, but with most devastating effect in summer. As soon as fuels on the forest floor begin to dry out as spring progresses, the chance of bushfires starting from dry lightning strikes rises.

Data are available on fire starts from lightning in south-west forests. Figure 3 shows the occurrence of lightning fires in the jarrah forest over three recent fire seasons. It is patently obvious that these are spread relatively evenly throughout the forest estate. Although these lightning caused fires occur from September through to May, most occur during December, January, February and March. Although the frequency of lightning-caused fires varies a great deal from year to year, on average, firefighters can expect up to 25 bushfires to be caused by lightning in south western Australian forests every summer. Since 1988 more than 210 lightning-caused fires have required suppression by CALM forces.

Humans are responsible for about 90 percent of all fires in Western Australia. Some fires are accidental (escapes from prescribed burning, camp fires etc.) but most result from deliberate arson. In recent years arson has been the most rapidly-increasing source of fire in Western

Australia, as it is world-wide. Deliberate fire lighting frequently occurs under severe fire-weather conditions, and arsonists often select the most difficult areas in which to operate.

Fires originating as escapes from CALM prescribed burning are a relatively insignificant percentage of total fires, averaging about five percent over recent years.

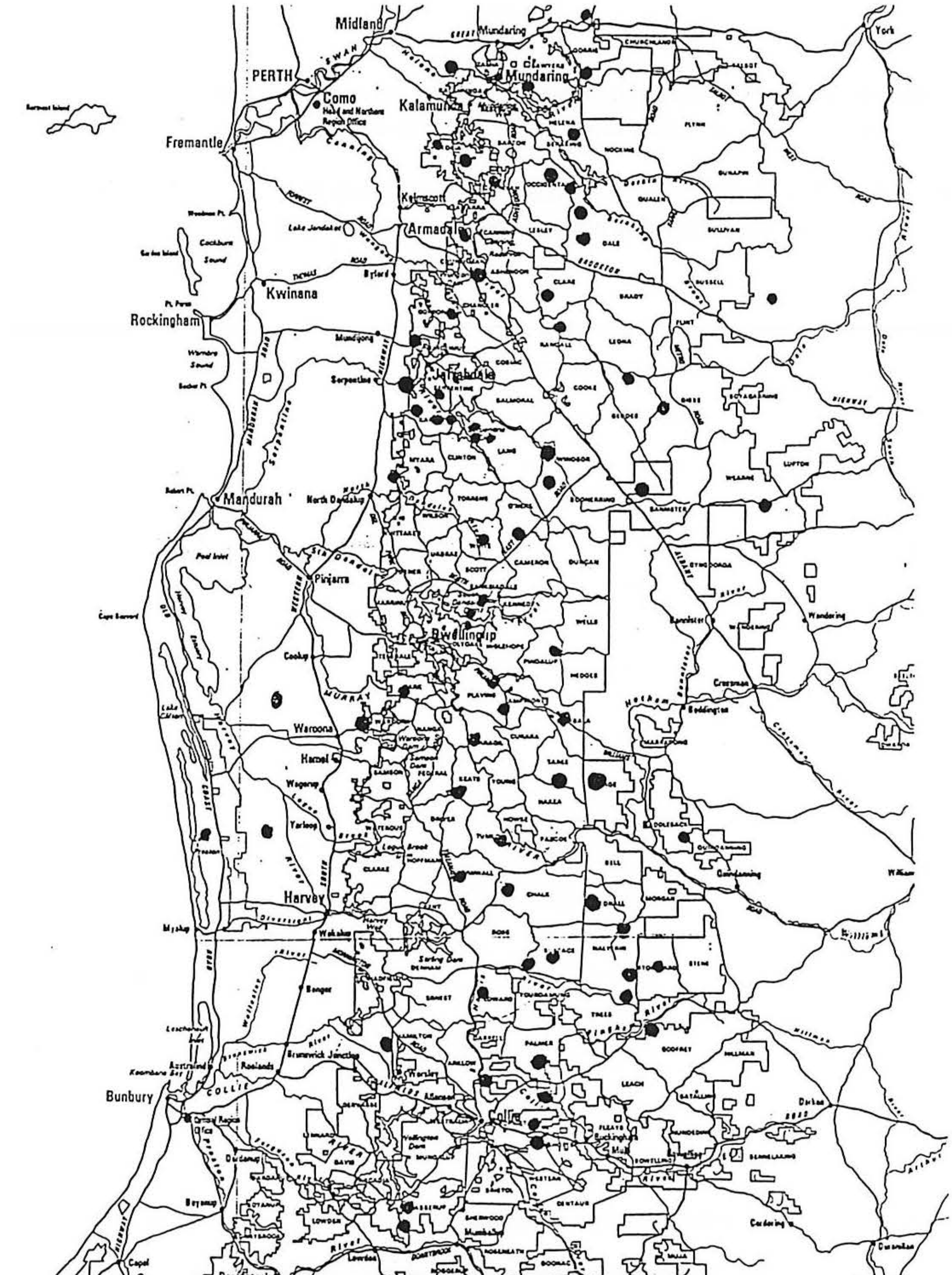


Figure 3: **Lightning-caused wildfires in northern jarrah forests in three fire seasons 1987/88, 1988/89 and 1991/92**

Table 2 shows fire causes in Western Australian forests over the last ten years by percentages.

Table 2 Causes of wildlires attended by CALM fire crews (percentages) 1984 to 1993

Cause	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93
Deliberately lit	35	40	40	39	36	45	49	41	52
Escapes from other burns	16	11	12	13	13	17	12	8	8
Accidental - Recreation (hunters, fishers etc.)	7	8	10	6	5	7	6	5	7
Accidental - other land	5	5	5	11	9.5	5	7	4	8
Lightning	11	7	4	11	21	12	11	26	10
Escapes from Dept. prescribed burns	14	16	9	9	5	7.5	6	5	3
Unknown	7	8	13	7	9	10.5	8	8	9
Miscellaneous other causes	5	5	7	4	1.5	1	1	3	3

Summary: *There will always be abundant uncontrolled ignition in the south-west of the State even if human caused ignitions, which the evidence indicates are increasing, could be eliminated.*

"Natural" or Pre-European Fire

Fire has been a naturally occurring element in the Australian environment for perhaps millions of years and many of our native plants and animals have developed unique relationships with fire. Certainly the present ecosystems of the south-west evolved in the presence of fire, or have co-existed with fire, especially since the arrival of the Aborigines at least 40 or 50 thousand years ago. Figure 3 demonstrates conclusively that even if human ignition sources were eliminated fire would occur in our south-west ecosystems.

There is an extensive literature on the question of pre-European fire occurrence in Australia. This is well-summarised in the book "Fire and Hearth" by the anthropologist Sylvia Hallam (1975); in Section One of "Fire and the Australian Biota" (Gill *et al.*, 1981); and in Chapters 5 to 9 of "Burning Bush" by fire historian Stephen Pyne. The generally accepted view is that there was a background mosaic of fires caused by lightning throughout most of Australia, onto which was superimposed widespread aboriginal burning. This deliberate firing of the bush by aborigines (known as "Fire Stick farming") was very regular in many parts of the country and was often well planned and managed. Fire was used to create hunting grounds, to regenerate desired plants, to clear thick country for easier access, to attack enemies and, more simply, to clean up the country.

The question of whether fire occurred periodically in south western ecosystems is not in debate - few serious students of the subject believe that it would be "natural" to totally exclude fire from forest areas permanently or for very long periods - e.g. hundred of years. However, there is considerable uncertainty about what constituted the "natural" fire regime (i.e. the combination of fire frequency, intensity, season of burning and area covered) for this area. It can no longer be fully reconstructed from historical evidence; to some degree, however, it can be inferred from the results of ecological and dendrochronological research.

Fire ecology (the study of the effects of fire on ecosystems) is a relatively new science in Australia, but it has grown quickly since its beginnings in the 1960s. The subject is an extraordinarily difficult one to study experimentally, because of factors such as:

(i) the wide range of variability in the effects of a single fire, depending on its intensity, season, time since a previous fire and weather conditions after the fire;

(ii) the wide range in response of different elements of the ecosystem - some plants and animals are scarcely affected by a fire, others may take several years to recover to their pre-fire status;

(iii) the difficulty of studying below-ground effects - e.g. effects of fire on soil micro-organisms, or soil stored seeds;

(iii) the high levels of interactions between elements of the fire regime and elements of the ecosystem, which tends to make single-species studies inconclusive.

Nevertheless, research to date, especially that conducted in the more mesic forest ecosystems, has produced a good understanding of the way in which native plants and animals cope with fire. This in turn has enabled inferences to be drawn about fire occurrence in pre-European Western Australia.

In summary, present understanding suggests:

- There are virtually no terrestrial ecosystems in south western Australia which would not have been burnt from time to time either by lightning-caused or Aboriginal-initiated fire. Some off-shore islands were not subjected to Aboriginal burning, but still were burnt occasionally as a result of lightning; and some plants grow out of bare rock or on scree slopes which may never have burnt under any conditions.

- There are no species which cannot survive or recover from periodic fire, either by regeneration *in situ,* or by migration into the area when suitable conditions re-occur. The native plants in particular display a wide range of highly effective traits which enable them to survive, or recover from bushfires of varying intensity, season and frequency.

- Different species are relatively favoured or disfavoured by different fire regimes. Some archaic (Gondwanan) plants and invertebrates and some ground-dwelling birds are favoured by long periods without fire, but are still capable of regenerating or recolonising areas after fire. Other species are "disturbance-opportunists" and flourish in the presence of frequent fire. Some species are unaffected by low-intensity fire, but are killed by high-intensity fire; some species will not regenerate except after a high intensity fire. Overlaying all these "natural" factors is the impact on native birds and mammals of introduced predators such as the cat and the fox and the interaction between fires, shelter, food and predation. There are no "general rules".......different species respond differently to the same situation, and the number of interactions is high.

- As far as the bulk of forest ecosystems go, fires can be of two types - high intensity fires which result in the complete destruction of the existing stand and open the way for a whole new succession; or lower intensity fires in which more or less of the original stand survive and carry through into the next generation. The more the existing system carries through into the post-fire situation, the less the impact of the fire, and the more rapidly the pre-fire situation returns.

The inference to be drawn from this information is that a wide range of fire regimes probably occurred naturally in south-west forests before European settlement. The native plants and animals are not only well adapted, it is unlikely that they would be there at all, if they did not have the capacity to survive periodic fire.

Analysis of fire scars on tree stumps or on partially burnt out old trees ("hollow-butts") (Rayner, 1993) and the examination of flowering records of species like *Xanthorrhea (*Lamont and Downes, 1979*)* are useful in suggesting the frequency of high intensity fires, but they suggest nothing about the frequency of low intensity fires. The latter can regularly burn through the forest without igniting the wood on standing trees or stimulating blackboys to flower.

The Coming of the Europeans

European settlement in Western Australia profoundly changed the bushfire situation in the bush lands of the south-west.

- For the first time, vulnerable permanent assets such as houses, buildings, fences, bridges etc. were constructed in and adjacent to the bush.

- For the first time, areas of native bush were cleared, and replaced with highly vulnerable crops and pasture;

- For the first time, timber cutting was carried out in the forests, raising the levels of fuels, and creating new assets in the form of young regrowth forests.

- The Aborigines were dispersed, and their traditional burning regimes ceased.

- New sources of fire were introduced - e.g. locomotives and clearing burns to assist with agricultural development.

For at least the first century of settlement there was no effective fire control on forest lands; in fact effective fire control did not come to the south-west until the 1960s.

After European settlement and up until the late 1960s, there was a significant increase in the number of intense wildfires in south-west forests. This is confirmed by dendrochronological analysis of fire scars on tree stumps (Burrows, 1991).

Early Fire Policies

Although bushfire ordinances were passed in the mid 1800s, there was little attempt to tackle the fire problem in the south-west until after the passage of the Forests Act and the establishment of the Forests Department in 1919.

The development of bushland fire policy saw opposing forces in conflict over the use of fire from the very beginning. The European-trained professional foresters who dominated the new Forests Department were opposed to prescribed burning; field foresters with long experience in the Australian bush were in favour of it.

During the 1920s and 1930s fire management involved:

- Subdivision of the forest into areas which had been cut over for timber and regenerated, and those which had not. The former were completely protected from fire. Some prescribed burning, mainly of "firebreaks" (narrow strips of forest between two tracks), was undertaken in the remainder of the forest, but most of it simply burnt from time to time in wildfires, at least in the early years.

- The development of the infrastructure for fire management: ranger stations, fire lookouts, communications systems, maps, roads, training and liaison with neighbours were all put into place.

- Programs of community education, plus law enforcement helped to reduce illegal or irresponsible fire lighting.

The policy of restricting the use of broad scale burning and improved fire suppression saw heavy fuels accumulating in most forest areas by the 1940s. From the late 1930s onwards, fires had started to become very large and difficult to control. There were major fires in the jarrah forest in 1949/50 (Wallace, 1965) and in the jarrah and the karri forests in 1937 and in 1950/51. In the long protected compartments fires became uncontrollable once they exceeded about a hectare in size, even under quite mild weather conditions.

The situation in the northern jarrah forest in the decade after World War II has been graphically described by Havel (1987) who was a forestry worker at Gleneagle at the time:

> *"The Gleneagle bush (like most of the jarrah forest) at this time had been fully protected from fire for over two decades, and the resultant accumulation of leaf litter and debris was so immense, that firefighting in summer was almost hopeless. Even the newfangled bulldozers the Department brought in after 1950 could make little impression. Once a fire started in these heavy fuels it was almost impossible to make a stand against it. Usually we had to hold our attack until the hours between midnight and dawn, when the temperature dropped - but if a strong easterly, or a no'wester was blowing, you could forget about it. The firefighting strategy of the time was thus retreat and then more retreat, often for days and nights at a time, until the cool change came through from the west and a massive containment and mop-up operation could be mounted.*

The prescribed burning of those days was concentrated on gulleys and buffers between the protected compartments. Even this operation was extremely chancy. No matter how mild the day, the long unburnt forest we were trying to protect always burnt much better than the fuel-reduced buffer strips we were trying to burn, so that every hop-over rapidly became an emergency."

Also at about this time there were massive fires in the southern forest national parks, notably the Walpole-Nornalup park, where whole hillsides of karri trees were killed. The remnants of these dead trees, and the regrowth forests which developed under them, can still be seen near Nornalup today.

In 1953 there was a change in Forests Department policy and broadscale prescribed burning for fuel reduction was introduced. Because of the massive fuels in most of the areas to be burnt, implementation of the policy was cautious and slow at first. Most of the initial burning in the northern jarrah forest was actually done in the winter. There were also technical deficiencies, especially lack of fire behaviour information on which to base burning prescriptions, and a lack of trained staff to undertake the work. Little effective burning could be undertaken in the dense southern forests, principally because of lack of access and problems with predicting fire behaviour in complex karri and karri-tingle fuels.

The early development of fire policies and their implementation is summarised by McCaw and Burrows (1989).

The Dwellingup Watershed

The culmination of early fire policies for West Australian forests came in the summer of 1960/61. Massive fires swept through the forests of the south-west. The town of Dwellingup was burnt, as were the smaller settlements of Holyoak, Nanga Brook and Karridale. There were serious losses of pasture, stock and fencing. Fortunately no one died in the fires, but many were injured, and the cost to the community was enormous.

A brief summary of the fires is given in Stewart (1969), from which the following extract is taken:

"........after weeks of hot dry weather, on a "dangerous" day on 19 January with a temperature of 104^{o}F, a series of lightning strikes occurred between 5.30 and 6.00 pm dispersed over some 20 000 hectares of State forest within 15 to 32 kilometres of Dwellingup. Six fires were reported that evening and a further four between 5.15 am and 1.15 pm the following day. Strikes also occurred in Gleneagle and Harvey Divisions.

Gangs were promptly despatched and most fires were held, but by the time the tenth fire erupted, about 1.15 pm on 20 January in century temperatures with an easterly wind, all gangs were committed. It was out of control before emergency forces could launch an attack, and made a run of six kilometres by 6 pm, throwing spot fires ahead. That night a further series of lightning strikes occurred in Dwellingup, Collie and Harvey Divisions, thus requiring retention of forces in the two latter divisions which could otherwise have assisted at Dwellingup.

Despite reinforcements from southern divisions, timber industry personnel and farmers, there were insufficient resources over the next few days to contain the numerous outbreaks which eventually linked into one vast burn with an extremely long and irregular perimeter. With 'dangerous' weather again on Tuesday 24, a temperature of 106^{o}F and freshening wind from the north and north-west, many breakaways occurred and units were recalled to Dwellingup for regrouping.

The wind had dropped towards evening and with a fire front two miles north of the town, forces were deployed on threatened flanks and throughout the village although no immediate danger was then apparent. About 8 pm winds of gale force from the north showered burning debris on Dwellingup long before the ground fire reached the town perimeter. Numerous fires were set both in the open and to buildings. Women and children were quickly assembled in bare open spaces........

.....The Dwellingup fires covered 146 200 hectares, destroyed 132 dwellings, a hospital, two sawmills, two service stations, three general stores, offices, outbuildings and 74 motor vehicles to a total value of some $2 million."

In the wake of the 1961 fires, a Royal Commission was held. The report of this Commission (Rodger, 1961) contains numerous recommendations concerning measures necessary to prevent and control bushfires. From the point of view of the Forests Department, recommendation 20 was the most significant. It read:

"The Forests Department [is to] make every endeavour to improve and extend the practice of control burning to ensure that the forests receive the maximum protection practical consistent with silvicultural requirements."

This did not represent a redirection of policy for south-west forests, rather it unambiguously endorsed the policy which had been adopted in 1953.

The Royal Commission's recommendations were adopted in full by the Government of the day, and have not been rescinded over the intervening years. The recommendation only applied to the Forests Department. The other government agencies involved in management of forests in the south-west, i.e. the Fisheries and Fauna Department and the National Parks Board, were not directed to follow the same path as the Forests Department. The areas of land they managed in the south-west at the time were relatively small. Nevertheless, both agencies undertook prescribed burning for fuel reduction in the areas they managed, as their meagre resources permitted.

Operational and Research Developments in the Wake of the Dwellingup Fires

The decision to use fire to fight fire in Western Australia generated a wide range of scientific work and technical development. Major progress was made in the following areas:

- ***Fire behaviour research and prescribed burning guides***

  Over a period of about 30 years, forest research scientists have developed a profound understanding of fuel accumulation rates and the effects on fire intensity and rate of spread of different temperatures, wind speeds, relative humidity, fuel dryness and slope for the jarrah and karri forests. This information was incorporated into a fire behaviour prediction system and a prescribed burning guide which is used by field staff in planning and implementing prescribed burns. (The information is also used when planning wildfire suppression strategies, but is less reliable, i.e. the current model tends to underestimate rate of fire spread at higher intensities, because of lack of experimental data in this range.)

- ***The rationale for prescribed burning***

  In conjunction with the work on fuels leading to improved prescribed burning techniques, a quantitative assessment of the relationship between fuel loading and ease of fire suppression was developed. Using a combination of knowledge of fire intensity and flame heights and the practical experience of expert firefighters, threshold levels of fuels have been set for the main forest types, and these represent the rationale for cyclic prescribed burning. *The threshold levels of available fuel for the jarrah forest have been set at eight tonnes/hectare and for the karri forest at 17 tonnes/hectare.* These limits are set because: (i) they represent the level of fuels above which headfires cannot be successfully attacked under average summer conditions; (ii) they are the upper limit of fuel quantities beyond which fire intensity will cause unacceptable damage to young trees and will generate crown fires and spotting.

  These threshold fuel levels are also used as the basis for setting prescribed burning return times ("rotations") for the forest where fuel reduction for wildfire mitigation is the policy. The time taken for fuels to build up to eight tonnes per hectare in the jarrah forest or 17 tonnes per hectare in the karri forest varies considerably, depending on climate, site fertility and forest structure. The average is five to seven years in the jarrah, 7-10 years or more in the eastern jarrah/wandoo and six to eight years in the karri forest. (Incidentally, the rate of fuel accumulation after fire is much more rapid in the karri than in the jarrah forest. Conditions are also more mesic in the karri forest, and the fire season is shorter and generally much less severe. This is why a higher threshold level for fuels is considered acceptable; to maintain fuels below eight tonnes per hectare in the karri forest would require a two to three year burning rotation, which would be impractical and probably unacceptable ecologically).

  In practice, prescribed burning rotations are determined by actual measurement of fuel accumulation, not years elapsed since last burn.

- ***Fire effects studies***

  Studies into the effects of fires on soil physical and chemical properties, flora, fauna, water resource values and forest regeneration commenced in the early 1960s and have continued ever since. This work has resulted in a major increase in knowledge about forest ecosystems and their response to fire disturbance. This work is described in more detail later in this submission.

- ***Aerial burning***

  During the late 1950s and early 1960s, it became apparent that available resources of staff and number of suitable days were insufficient to enable the prescribed burning policy to be implemented by the traditional method of strip burning by gangs walking through the forest. As a result, a technique for lighting prescribed fires in jarrah forests from aircraft was conceived and pioneered in Western Australia. This work was done jointly by the Forests Department and the CSIRO, and it reduced the cost and increased the effectiveness of prescribed burning. In the late 1960s this technique was extended to the karri forest, the delay being caused by the need for further research into karri scrub classification, fuel drying rates and fire behaviour.

Other Developments

The high profile of CALM's prescribed burning policy has tended to obscure the fact that prescribed burning is only one of the measures employed in attacking the wildfire problem in the south-west forests.

In parallel with the developments described above, a number of other related and very significant fire management developments took place in Western Australia in the aftermath of the great 1961 fires. These included:

- the development of highly reliable prediction systems of fuel moisture content, fire behaviour and fire effects parameters;
- the replacement of the old "bush telephone" and HF radio system with VHF and UHF radio systems;
- the introduction of spotter aircraft to augment and partly replace the fire detection system based on lookout towers;
- the use of fire retardants to help with fire attack and mopping up, thus greatly increasing the efficiency of fire fighters;
- the first inter-agency agreements for cooperative fire management with Shires, Bush Fire Brigades and other organisations;
- formal and structured fire training systems for CALM staff and volunteers;
- the development of structured and pre-planned fire command systems (the "Large Fire Organisation", "Red Action" and, most recently the Interagency Incident Control System which is standard for all bushfire authorities in Australia) aimed at ensuring that arrangements and procedures for responding to and coping with fire emergencies are effective, timely and appropriate;
- the introduction of computers for mapping, fire behaviour computation and for aiding decision-making and fire management planning;
- provision of an updated vehicle and pumper fleet in the field;
- development of aerial and ground function systems for the safe, accurate and cost-effective function of planned burns;

- the development of Wildfire Threat Analysis as an objective way of identifying, ranking and mapping values to be protected so that priorities and procedures for fire prevention and fire suppression works can be agreed on and implemented with the resources available;
- the identification of "strategic buffers" in the forest - areas where fire protection would take priority over other forest uses, and incorporated through integrated planning across tenures.

Taken as a whole, in conjunction with the use of fire to reduce fuels in the forest, these measures provided a total approach to fire management on crown land forests in the south-west. In addition, good working relations with Shires and the Bush Fires Board have been achieved to ensure integration of CALM's approach with the approach taken on neighbouring lands.

The Formation of CALM

Prior to 1985 there was a significant inefficiency in Western Australia in that three separate agencies existed with responsibility for crown land forests in the south-west. These were the Forests Department which controlled State forests, the National Parks Authority which controlled national parks and the Department of Fisheries and Wildlife, which controlled nature reserves. Each agency had a different fire policy, a different approach to fire suppression and were operationally independent, although all used prescribed burning to some extent as a wildfire mitigation measure.

In March 1985 the three agencies were amalgamated (a new Department of Fisheries also being formed). The new Department of Conservation and Land Management had responsibility for all crown land forests in the south-west, irrespective of tenure - but no responsibility for vacant Crown land or for forests on private property.

For the first time, the new arrangement of agencies allowed a consolidated fire policy to be adopted, an integrated approach to fire planning and control to be applied across different tenures in the forest, and major efficiencies in terms of equipment, detection, maps, computers and other fire management infrastructure. With the exception of Victoria, this arrangement is unique in Australia.

Contemporary Issues

Despite the significant advantages of operating as an integrated agency, CALM (along with most Government agencies in Western Australia) has had to deal with a serious problem of declining funding and human resources during the late 1980s and early 1990s. This has been exacerbated by the increase in the CALM estate (especially through transfer to CALM management of vacant Crown land) without an increase in budget, but with a clear public expectation for improved management. These issues have affected the capacity of the Department to implement fire management programs and to carry out fire research studies. A number of new constraints has also emerged. For example:

(i) There has been increasing criticism from some sections of the community of CALM's prescribed burning policies which is then translated into lobbying of senior politicians.

(ii) CALM seeks to minimise the movement of smoke from prescribed burns to urban areas, and this greatly reduces the number of days on which burning can be undertaken in any season;

(iii) CALM has supported a substantial expansion of conservation reserves on areas which were formerly State forest. Within these reserves large sections containing Fire Exclusion Areas or areas of extended burn frequencies have been set aside. This has reduced the area available for regular fuel reduction burning; and

(iv) there has been a major change in demography in the south-west over the last 15 years. This has seen a decline in land ownership by traditional farmers and their replacement by "hobby farmers" and environmentalist communities, many of whom are strongly opposed to prescribed burning on neighbouring forests.

All of these factors have resulted in a significant decline in the area subjected to preventative fire management by CALM from the situation which prevailed in the 1970s and early 1980s.

CHAPTER 3

THE CURRENT APPROACH

Current Policy

CALM introduced its Fire Management policy in May 1987 (see Appendix I), and while regularly reviewed, this document is still in force. The policy has two objectives: (i) to protect community and environmental values on lands managed by the Department from damage or destruction by wildfire; and (ii) to use fire as a management tool to achieve land management objectives, in accordance with designated land use priorities.

The policy is based on eight premises:

- Fire has occurred naturally from time to time in practically all lands managed by CALM. Fire has therefore played some part in determining present vegetation structures and composition.
- Under natural conditions, practically all ecosystems are made up of a mosaic of vegetation associations and structural stages which vary according to their fire histories. The scale of the mosaic varies in different ecosystems.
- Fires from natural causes (e.g. lightning) will inevitably occur. Fires resulting from human activities, either deliberate or accidental will also occur, but may be reduced by effective public education and awareness, and by legislation.
- In Western Australia, weather conditions occur every year under which fires can be so intense as to be impossible to contain with currently available technologies and resources. Such fires can threaten human lives, and resources valued by the community, and their control involves considerable public expenditure and risks to firefighters.
- The speed and intensity at which fire burns is related to the quantity of accumulated dry litter or other fine plant material. In the majority of the vegetation types occurring in the south-west, accumulated fuel loads can be reduced by prescribed burning. This significantly reduces the likelihood of intense fires even under extreme conditions, and markedly improves the capacity for firefighters to safely control a fire.
- Within each major fuel type there is a recognised weight of dry fuel above which firefighting forces are not likely to be able to contain wildfires burning under normal hot summer conditions.

- Much of the public land managed by CALM, particularly in the south-west, has a common boundary with well developed private assets such as towns and farms, the protection of which reduces the flexibility for fire management.

- Information about the long-term effects of different fire regimes, including fire exclusion on many ecosystems is continually evolving, and any management policy must be under constant review and accompanied by research and monitoring programs.

- The Department has a moral and legal obligation to comply with those provisions of the Bush Fires Act, and CALM Act relating to fire prevention and control of wildfires on or near CALM lands.

Three aspects of the policy are particularly relevant to this submission. These are:

- The policy deals holistically with the fire issue. It covers fire preparedness and suppression, scientific research, public liaison and education as well as prescribed burning. (There have been claims by some critics that CALM's fire management policies do not involve strategies other than prescribed burning.)

- The policy imposes specific constraints on the use of fire. In particular, fire may be used only in accordance with an approved management plan, or to protect a designated priority land use; prescribed fires must be properly planned and proposals approved by a senior officer; conservation of biodiversity is to be promoted in conservation reserves; frequency of fire must be governed by fuel build-up as well as risk to human values, and the sensitivity to fire of plants and animals.

- The policy recognises that although knowledge is incomplete and that there must be constant reviews of policy in the light of research and monitoring, we do not have the luxury of doing nothing until there is a perfect understanding of the effect of fires on ecosystems.

CALM's Fire Policy has been endorsed by the Department's controlling bodies, the National Parks and Nature Conservation Authority and the Lands and Forest Commission.

Implementation of Policy

The translation of policy into operations on the ground requires a major management and organisational effort. The principal components of this are:

- ***The Wildfire Threat Analysis***

  Limited resources, limited time, competition for attention, and a range of social and environmental factors which are spatially and temporally dynamic, requires land managers to make exceedingly difficult decisions about priorities on how to spend their "fire control dollar". The decision support system, called a Wildfire Threat Analysis (Muller 1993), has been developed to assist decision making by land managers (Appendix II).

WTA provides an objective and repeatable means of integrating the key factors that contribute to a wildfire threat to a specified value. These factors are the risk of a fire starting, the suppression response which can be mounted and the likely fire behaviour at the site of the fire. These factors can be mapped and ranked, so that in the end it is possible to determine which values are most at risk.

WTA forms the basis of CALM's fire management planning in the south-west of Western Australia (and is being routinely used in other areas as well). Not only does it highlight the problems and therefore the priorities for fire prevention and pre-suppression work, it can be used to design a range of ancillary fire services and requirements, such as the detection system, the suppression response plan, standby arrangements and interagency work.

- *Master planning in districts*

The land managed by CALM in the south-west is subdivided into three regions, each of which in turn is further subdivided into districts. The districts look after an area of about 200 000 hectares. For each of the regions there is a Regional Management Plan which sets out the tenure of various forest areas and the strategies for management. Arising out of the Regional Plan, each CALM district in the south-west (there are 12) prepares a master fire management plan for the area managed. This is based on the WTA, and looks many years ahead, but is revised annually in the light of burning programs achieved, fires which have occurred and review of values and priorities.

The district fire management master plan is a key planning tool.

Firstly, it allows a map-based presentation of the integrated wildfire threat analysis, demonstrating the various values and ignition risks, the full range of the suppression task, and the fire behaviour which is likely to occur at any given site.

Secondly, the master plan is the document in which fire management is integrated with all the other things occurring on the land CALM manages. Logging coupes and regeneration areas, softwood and hardwood plantations, mining areas, archaeological sites, recreation sites, research plots, special catchment zones, power lines and dieback quarantine areas for example are identified, mapped and considered in fire planning for the area.

Thirdly, the master plan provides the basis for ranking the fire control effort, in particular the prescribed burning effort. On the basis of the WTA, each district is zoned into three priority areas. Priority One areas are those with the highest values to be protected and the greatest risk of fire. In these areas district staff attempt to maintain at least 90 percent of the forest at "standard" fuels or better. In Priority Two zones the aim is 75 percent and in the Priority Three Areas it is 50 percent, or better.

Fourthly, the master plan is the place in which Strategic Buffers and Fire Protected, or Fuel Datum Areas are defined. The former are areas where fire protection policy takes precedence over other land uses. They are moved about, depending on areas available, but the main intention is to stop the run of major fires. In the jarrah forest the Strategic

Buffers are designed with an "acceptable loss" (i.e. fire size) of 4000 hectares in mind; in the karri forest the figure is 2500 hectares.

"Fuel Datum Areas" are areas set aside for No Planned Burns. The intention is to have a sample of "control" areas located throughout the forest where prescribed burning does not occur and where every effort is made to keep fire out. These areas are valuable for research in the future. The current distribution and location of these areas in the south-west is described by Russell Smith (1993).

Finally, the master plan is the place where fire regimes are set down. In areas to be prescribed burnt, the plan shows which areas will be burnt in spring and which in autumn, as well as the frequency of burning. This is the principal mechanism by which diversity is achieved.

- ***The Annual Burning Plan***

An annual burning program is drawn up each year for each district. This is derived from the Master Plan, which in turn was derived from the Wildfire Threat Analysis. In the annual plan, individual "jobs" are identified, numbered, ranked in priority, and listed either for an aerial or a hand burn. The final program is adjusted according to available resources, with priority being given to the most strategically important burns.

- ***Area Management Plans for Conservation Reserves***

Management plans for specific areas within districts are progressively being drawn up and published as required in the CALM Act. These mostly apply to national parks, but also to some nature reserves. Examples are the management plans for Yanchep National Park, John Forrest National Park, Lane Poole Reserve, Leeuwin-Naturaliste National Park, Shannon D'Entrecasteaux National Park and Walpole Nornalup National Park.

These plans contain specific directions on fire management. Access roads are specified, fire exclusion areas nominated and special fire regimes designated.

Area fire management plans are not necessarily integrated into district master plans, nor are they "negotiable" at the district level. Although draft plans are prepared by CALM staff, final plans are strongly influenced by public and local community interest groups and are eventually approved by the National Parks and Nature Conservation Authority and the Minister.

In some parks and reserves Interim Management Guidelines (IMG) are prepared to guide CALM managers until a formal management plan is prepared. These also designate the fire management scheme to be adopted so as to maintain park and reserve values. In general there is a high degree of integration of the IMGs with district master plans.

- ***The Fire Control Working Plan***

In addition to the master plan, each district produces each year a Fire Control Working Plan (FCWP). These are prepared to a standard format to ensure ready familiarity for officers transferred from one area to another, or for staff coming in at the time of a fire to relieve local staff.

The FCWP is the primary operational document used by CALM field staff to prepare themselves for fire at the start of each fire season. It establishes the objectives for different forest zones, and provides a full inventory of all the human and other resources available locally for fire-fighting. It details the Standing Orders - i.e. the action to be taken in the event of a fire, the detection and standby arrangements and provides all the contacts with other firefighting agencies and brigades.

- ***The Fire Operations Manual***

This is a compendium of all the instructions and standards which must be applied by field staff in their fire control operations. It is the "legal rule book", in that it contains all the legislative and official departmental requirements, plus it is the unofficial guidebook, in that it contains a distillation of decades of field experience in fire planning, fire suppression and prescribed burning operations translated into standing orders or Fire Protection Instructions.

Copies of the fire operations manual are held by fire managers in each of the districts, and it forms the basis of training programs.

- ***Prescribed Burning prescription and checklists***

Well in advance, each proposed burn is surveyed in detail. The assessment includes (i) an environmental audit, in which the possible impacts of the burn are evaluated, carried out according to a comprehensive checklist; (ii) a safety check to identify all persons, assets, properties or operations which might be put at risk by the burn; and (iii) a stratified random fuel assessment to identify and map fuel types, fuel quantities and any areas susceptible to flame scorch.

A detailed prescription is then prepared for each proposed burn. This comprises a set of objectives, a calculation of the fire behaviour which will meet these objectives, the weather and fuel moisture conditions which must occur on the day of the burn and the lighting pattern to be adopted. Each prescription is checked by a senior and experienced officer.

Finally before a burn is commenced, the boundary tracks are cleaned up, and other essential preparatory work undertaken. In some cases, dangerous dead trees adjacent to the burn edge are felled and moist gullies or karri types are scrub rolled. If extensive road maintenance is necessary this is usually done in the preceding summer or autumn in dry soil conditions, so as to minimise any concerns about spreading dieback disease.

Districts also notify neighbours of proposed burns; in the case of aerial burns, all property owners within three kilometres of the boundary of the burn are notified. Warning signs are placed on all access roads and walking tracks in the area, and announcements about the proposed burn are made on ABC radio on the day of the burn.

- ***Implementation of burning proposals***

As spring replaces winter and the weather begins to warm up and fuels in the forest begin to dry, burning commences. In the district office each morning, staff compare the predicted fire behaviour for the day (on the basis of the weather forecast and known fuel moisture conditions in the field) with the prescribed conditions for the various proposed jobs on the burning program. If the conditions match, guidelines for smoke dispersion are then checked. If these are acceptable, staff and crews are assigned, and the burn goes ahead. In the case of aerial burns, it is also necessary to consult with the regional controller, who decides on aircraft priorities for the day.

The first step in some burns is "edging". This is done late in autumn or early in spring. A very light fire is run in for 20-40 metres all the way along the edge of the job and then allowed to go out. This burnt edge makes for easier control of the main burn later, and minimises mopping up costs.

Most prescribed burns in the jarrah forest are completed in one or two days. In the karri forest, the task is far more complex, because of the range of different vegetation and fuel types which occur in a single burn. These fuels dry out progressively over several weeks. This means that a single burn can require five or six lightnings, and can take three months to complete. Flare ups along the edges of partially completed karri prescribed burns as fuels dry out are the most common cause of escapes from CALM burning. This is a major concern, but short of not burning at all, or resorting to a massive road construction program to surround all the different vegetation and fuel types with fire breaks, no infallible solution to the difficulty has yet been identified.

Burning is generally undertaken during the Restricted Burning Period, as determined by the Local Government Authority and the Bush Fires Board. Occasionally the Department will seek an extension of this period into the Prohibited Period to allow completion of a burn, or to undertake a special burn which must be done at that time of the year. Extensions require the approval of the Shire and the Bush Fires Board.

At the completion of every day's burning, edges are inspected, and essential mopping up undertaken. In some cases, night patrols are mounted to ensure the safety of the burn. A final inspection is made by a senior district officer before a burn is deemed to be safe and completed.

- ***Fire records***

All completed prescribed burns are inspected and compliance with the prescription is checked. The checklists, fuel assessment sheets, and prescriptions themselves are filed. Details of areas burned are recorded on maps, which are also filed in the district office. Comprehensive records of past prescribed burning is recorded on microfilm at the Department's Operational Headquarters at Como.

- ***The fire training program***

CALM operates one of the most intensive and systematic fire training programs in Australia. Fire courses are competency-based whereby training needs are identified for individuals and where officers in the field must demonstrate competence, or be trained before they can assume prescribed roles or duties. In addition, CALM's training is integrated with the Incident Control System training which had been adopted Australia-wide.

Centrally organised training is provided for all Level 1 field staff, and then for various specialised fields such as fire controllers and operations officers, fire logistics, planning, strategy, leadership and prescribed burning. At the district centres, hands-on training in fireline control is provided for CALM firefighters and for timber industry contractors.

- ***Interagency agreements***

  Over the years CALM has established a number of mutual-aid agreements with different agencies and organisations. The aim is to share fire management tasks and costs in an agreed way, and to determine this well before the event. Examples of organisations with which CALM currently has inter-agency agreements are Alcoa, Worsley Timber Company, Bunnings Tree Farms and Worsley Alumina. An example of a wider agreement which focuses on a particular area is the Denbarker Fire Protection Scheme, which incorporates agreement between CALM, the Bush Fires Board, local Shire councils and local Bush Fire Brigades, and deals with the protection of an area of over 70 000 hectares of State forest, conservation reserves, private farmland and vacant Crown land.

Constraints to Prescribed Burning

The prescribed burning program undertaken by CALM is subjected to a wide range of constraints. These include:

Legal constraints

The Bush Fires Act lays down a series of conditions which must be complied with before a burn can be undertaken, or during a burn. These include a requirement that prescribed burning cannot be commenced when the Fire Danger for the area is Very High or Extreme and the restriction of burning to The Restricted Burning Period without specific approval from the Bush Fires Board.

Environmental constraints

Smoke management guidelines, which have been agreed to by CALM and the Environmental Protection Authority, must be complied with; burns cannot be lit which will deposit ash on water supply dams; declared rare flora and threatened fauna must be considered and the burn modified if there is a risk of permanent damage; fire is minimised in and around granite outcrops where many important "relictual" species occur; wherever possible areas containing important wetlands are burnt early in the spring while the wetlands are submerged or too damp to burn; and aesthetics along roadsides must be considered (burning is limited to only one side of a main road in the one summer)

Operational constraints

The occurrence of weather conditions which are suitable for safe prescribed burning is a major constraint. In any summer there are only a few days on which burning can take place because of weather. In general there are far fewer suitable days in autumn than in spring. Other operational constraints include limits to funds and manpower, the problem of penalty pay rates for staff who are engaged in burning after hours and on weekends, and the need to avoid special research areas, stands of young trees and areas scheduled for dieback photography.

Neighbour-related constraints

Some neighbours to CALM lands object to prescribed burning and seek to have burns cancelled. Because CALM wishes to maintain good relations with neighbours, but also wishes to minimise the risks of wildfires moving across boundaries (either into or out of CALM land) this causes difficulties and often results in burns being deferred or cancelled.

In some instances neighbours have "referred" proposed CALM burns to the EPA - even burns prescribed in an approved management plan. This process causes significant delays and reduces CALM's capacity to schedule and implement a burning program.

Constraints imposed by area management plans for conservation reserves

Demands imposed on districts to implement the fire management operations required in the fire management plans of national parks seriously affects the works programs that can be achieved in the other sections of the forest regions. For example, the prescribed burning expenditure by Dwellingup District on the complex fire prevention program within the Lane Poole Reserve constitutes approximately 40 percent of the district's budget even though the Lane Poole Reserve covers less than 12 percent of the Dwellingup District area.

Similarly, the fire management programs within Leeuwin-Naturaliste National Park, D'Entrecasteaux/Shannon National Parks and Walpole-Nornalup National Park demand an inordinately high percentage of each of the districts' fire protection budgets.

The fire management plans for these parks require large areas within these parks to be kept fire free, or be burnt at long intervals. Some of these areas had previously been burnt on a regular rotation to protect them from damaging wildfires. Recent instances of wildfires burning in these heavy fuels have amply demonstrated the severe difficulties that fire controllers face, and the inability to contain these damaging fires to relatively small sizes. In addition, firefighters face greater risks of serious injury and even death when exposed to the intense and erratic fire behaviour that occurs within such heavy fuel accumulations.

Smoke Management

One of the most obvious products of fire is smoke. In most cases the light smoke from low intensity prescribed burning dissipates rapidly in the atmosphere. However, under some weather conditions, smoke from prescribed burns as far as 350 km south of Perth can be blown into urban areas such as Perth and Bunbury. If this event coincides with a low-level atmospheric inversion, highly visible smoke haze results. This usually occurs during night time hours and most often the haze dissipates during the early morning hours.

CALM is well aware of the need to minimise the incidence of such events and has been implementing procedures to prevent smoke accumulation in the metropolitan area originating from the northern jarrah forest within 100 kilometres of Perth for nearly 20 years. Based on smoke distribution studies conducted by the CSIRO (Vines *et al.* 1971) a computer model was developed to allow predictions to be made about the fate and concentration of smoke plumes from proposed prescribed burns. Guidelines have been developed from the smoke model.

Stringent application of these guidelines resulted in only very rare instances when smoke from burns in the northern forests entered the Perth metropolitan area.

In 1991 CALM extended its smoke management system to the rest of the forest lands in the south-west. This was in response to concerns by the Environmental Protection Authority that smoke haze originating from southern forest burns, 250-350 kilometres south of Perth, was exceeding the 20 kilometre visibility standard in Perth. There were seven or eight of these events each summer, mostly occurring at night.

CALM has now identified the factors that influence the incidence of smoke haze in Perth (Smith 1991, 1992). A new set of smoke management guidelines has been developed and adopted. These take into account the following contributory factors: atmospheric stability, temperature inversion, wind direction at altitude, forecast of sea breeze, location and size of burns, concentration of burns, aggregate areas burnt, burn priority and history of burning, availability of resources, and the incidence of burning by other agencies or landowners.

To assist fire managers to coordinate these complexities a decision model has been developed and was applied in 1992/93 and in 1993/94 burning seasons (Sneeuwjagt 1993). This has resulted in a steep decline in the number of incidents of smoke haze entering Perth from CALM burning from seven or eight to two or three times per year.

The approach is highly successful, but not infallible. The main difficulty is that it is not yet possible to always forecast the weather reliably for several days ahead, and low-level inversions are highly unpredictable.

Although contributing to a decrease in the incidence of hazy days in Perth, the adoption of the smoke management guidelines has severely restricted the potential number of available burning days each summer. In the northern jarrah forest the number of suitable days has been reduced by about 80 percent; in the remainder of the forest it is of the order of 30 percent. Figure 4 demonstrates the reduction in the number of suitable burning days at Mundaring required to minimise smoke blowing into Perth. This impact will increase dramatically if it is decided that smoke management guidelines must also apply to regional centres such as Busselton, Mandurah and Manjimup.

Wildfires also generate smoke, and the more intense the fire, the denser the smoke. Some of the worst air pollution ever seen in Sydney occurred in the wake of the 1994 wildfires in adjacent bush lands. The effect of this was incomparably worse than that of the light smoke from well managed prescribed burning which occasionally affects Perth. Significantly more smoke is produced in Perth by wood-fired potbelly stoves.

Details of the Department's smoke management program are given in Appendix III.

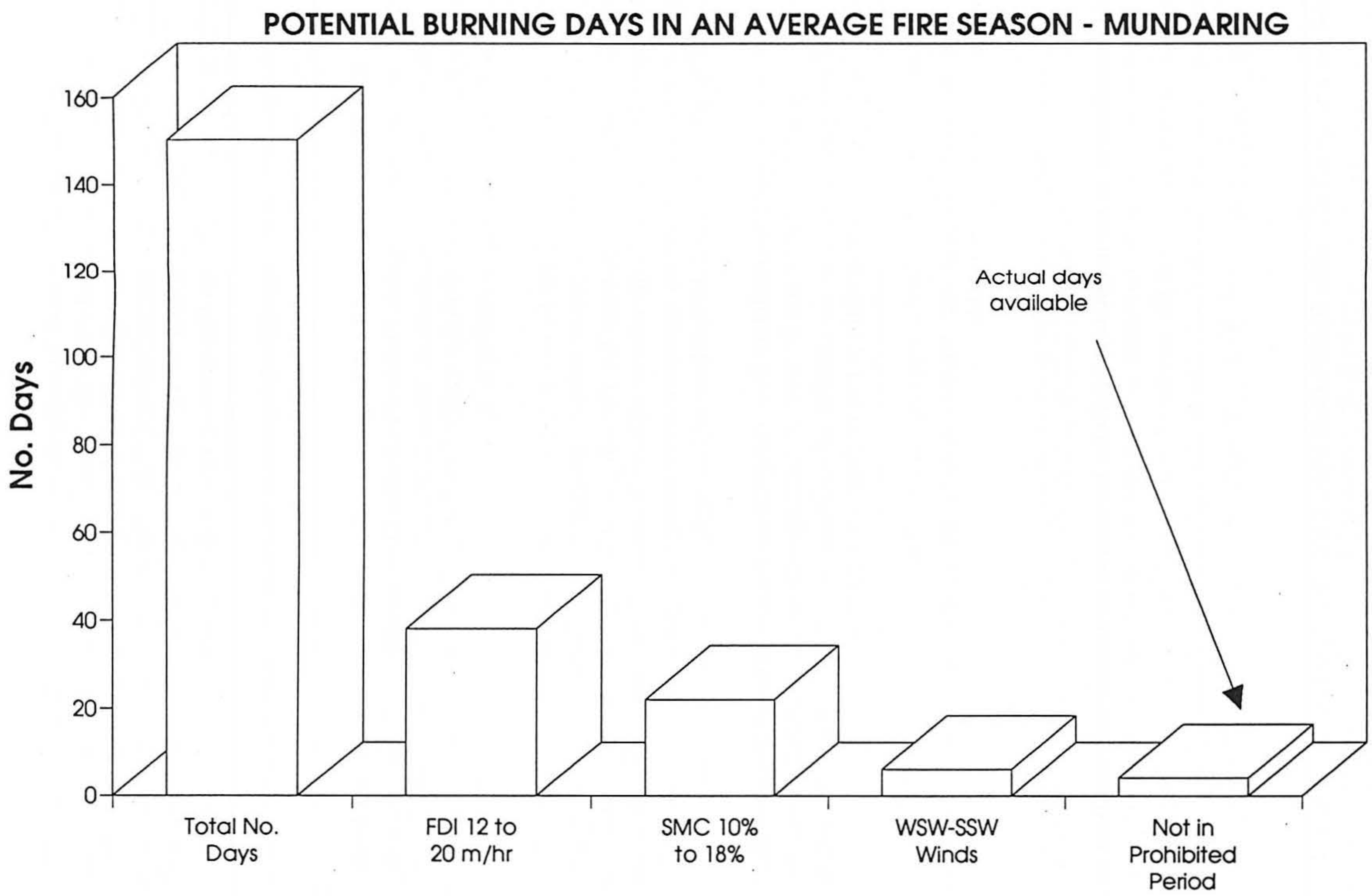


Figure 4 **Potential burning days in an average fire season - Mundaring**

The Use of Fire for Regeneration and Habitat Management

Fire is also used in Western Australian forests for regeneration and habitat manipulation. In the karri forest, regeneration burns are lit in areas where timber harvesting has occurred for the dual purposes of reducing the volume of logging debris and preparing seedbed for the re-establishment of karri. Similarly, post-logging burns are carried out in jarrah forests where gaps have been created in which advanced growth saplings can be released, or in shelterwood areas for the purpose of establishing lignotuberous advance growth; and in the wandoo forest to create ashbeds for wandoo regeneration.

These operations have become well established over many decades, and are carried out by district staff as part of the annual burning program. Similar planning and controls apply.

Burning for habitat manipulation is not yet widely practised, but the techniques are developing progressively as special requirements are identified. The most common use of this approach is in the regeneration of Heartleaf Poison or *Acacia* thickets in some lower rainfall forests and woodlands where these provide essential shelter for threatened mammals such as Tammar Wallabies and Woylies.

Regeneration and habitat manipulation burns also reduce fuels, so that they add to the mosaic of fuel-reduced areas within the forest, even though this is not their primary purpose.

Recent Decline in Areas Prescribed Burnt

The impact of the numerous constraints to prescribed burning in south-west forests (especially smoke management) has resulted in a decline in the area burnt each year over the last eight years. Forty-six percent of the estate managed by CALM in the south-west is now carrying fuels which are six years old or older. The figure is as high as 66 percent in conservation reserves.

Of concern is the build-up of fuels in areas designated as strategic buffers in the forest. To operate effectively, fuels within buffer strips should be generally six years old or less. At present only 48 percent of the area within strategic buffers carries less than 6 year old fuels.

Figure 5 shows the pattern of prescribed burning in hardwood forests since 1979.

As a result of the decline in burning there has been an apparent tendency towards larger wildfires and the higher costs of fire suppression. This is illustrated by the fact that average fire size in 1988 was 14 hectares but it is now (1992/93 summer) 46 hectares, and by the increase in the number of fires greater than 400 hectares occurring in forest districts since 1981, as illustrated in Figure 6.

The percentage reduction in expenditure on prescribed burning has paralleled the overall decline in the Department's budget over this time. The "5-year rolling average" for expenditure on prescribed burning is shown for the period 1986/87 to 1992/93 in Figure 7.

In the past three years the Wildfire Threat Analysis has been used to identify the most important areas requiring protection through provision of strategically located burn buffers. This has meant some reduction in the overall fuel reduction burn program has been possible without a significant increase in the risk of damaging fires. It is estimated that this strategic approach to the prescribed burning program will enable the overall burn program in the forest regions to be set at about 200 000 hectares per year. This compares with the average program achieved in the mid 1980s of about 250 000 hectares, and the current annual achievement (in 1992/93) of 150 000 hectares.

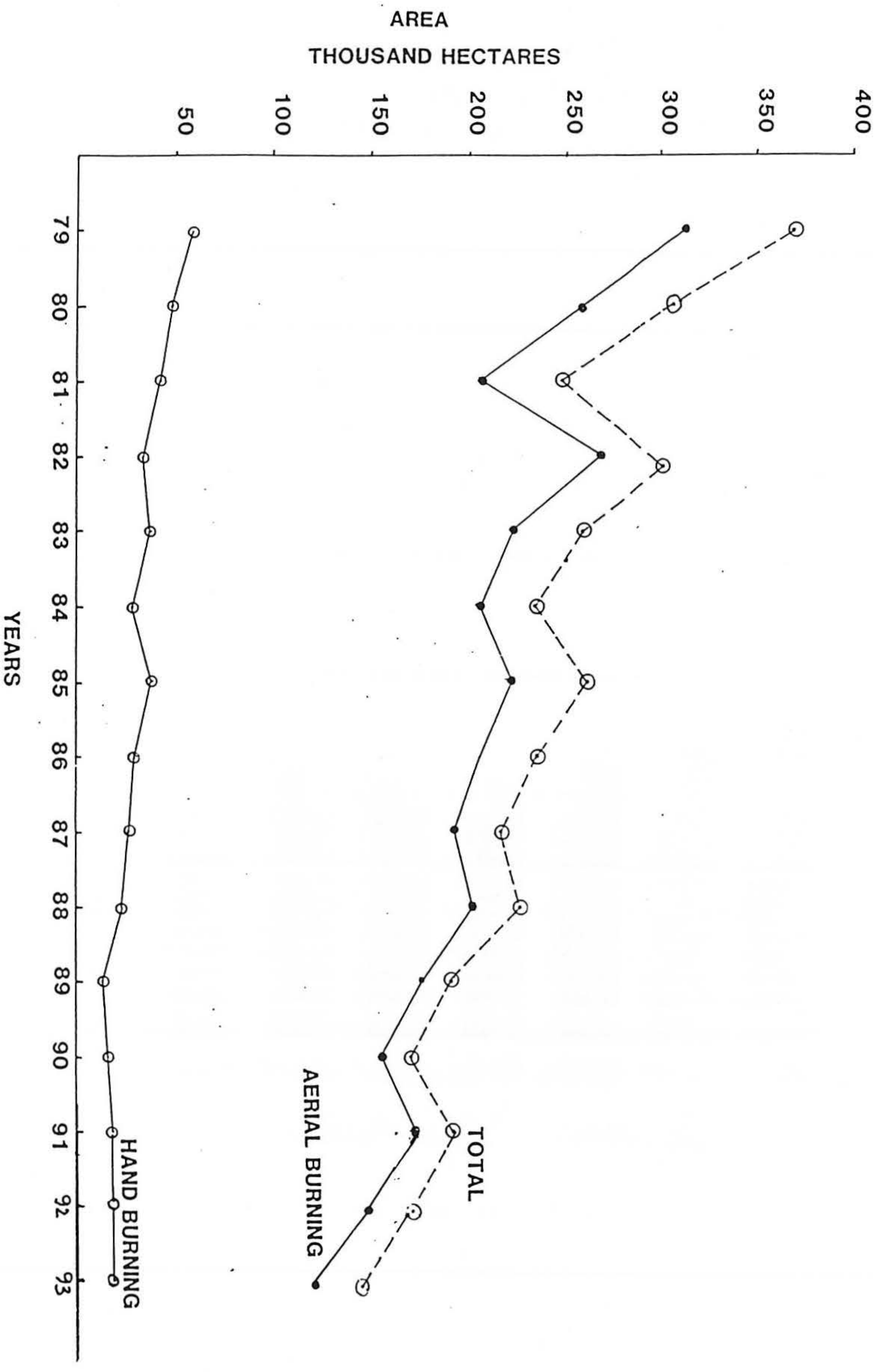


Figure 5 **Prescribed burning (hardwood) forest areas**

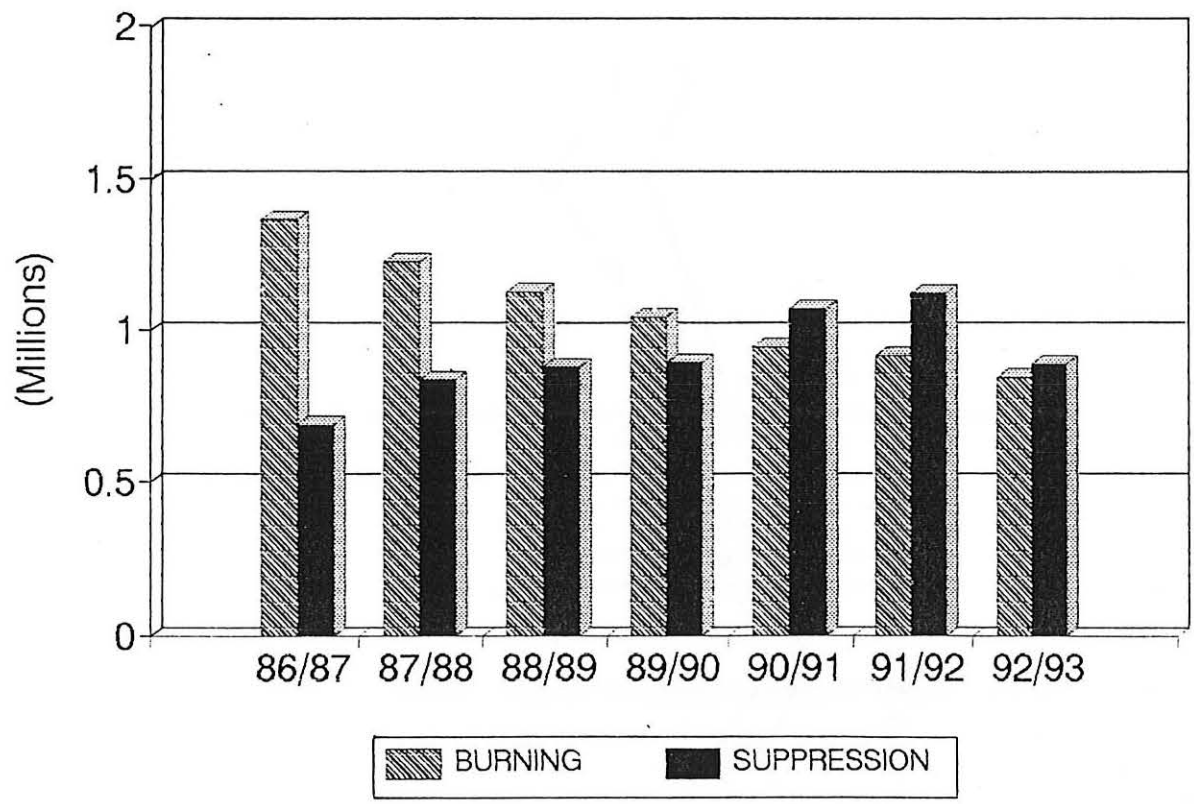


Figure 6 **Five year rolling average expenditure on fire protection in forest regions**

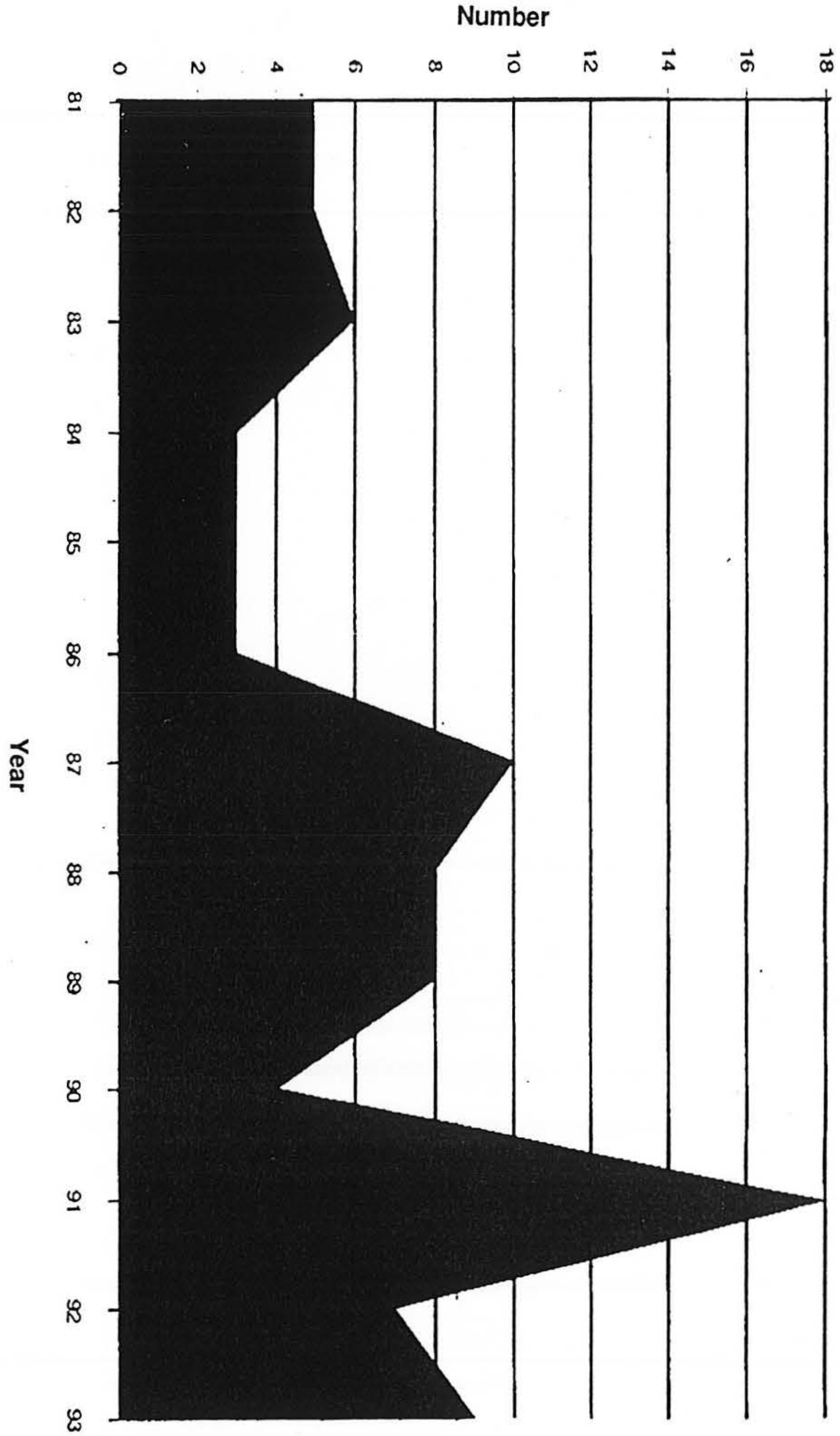


Figure 7 **Fires >400 hectares in forest districts**

CHAPTER 4

PRESCRIBED BURNING EFFECTIVENESS AND IMPACTS

Fire is inevitable in the Australian bush. It will be started either by lightning, or by humans. Also inevitable is the probability that from time to time there will be a coincidence of fire ignition, dry fuels, hot windy weather, and human assets. When this happens (as it did in NSW during January 1994) it is too late to start thinking about a fire prevention or fire damage mitigation policy. Effective bushfire control, and minimising bushfire damage can only result from two things: (i) advance planning and hazard reduction well before the event; and (ii) a total package incorporating prevention, pre-suppression, preparedness, detection, suppression and organisation.

Of all of the pre-suppression or hazard reduction approaches adopted, prescribed burning for fuel reduction is the most controversial. Critics of prescribed burning advance three main arguments to support their view: firstly that it is causes ecological damage, secondly that it is ineffective; and thirdly, that prescribed burning is itself the major cause of wildfires in the forest. These points are discussed below.

(NOTE: In this submission, the term "prescribed burning" is used to describe the practice used by CALM in Western Australian forests - i.e. relatively mild fires set on a return time of five to nine years.)

THE ECOLOGICAL IMPACT OF PRESCRIBED BURNING

Any and every fire which burns through bush lands has some environmental and ecological impact. This is because every fire consumes some part of the vegetation (living or dead) which is currently being used for food or shelter by some organisms; it consumes some of the organisms which feeds on or pollinates or helps to germinate some plant or other; it may bare the soil and stimulate seed fall; it may consume or create habitat; and fire emits smoke and ash which is carried into the atmosphere or is redistributed to some other part of the landscape.

At the same time, disturbance is a dominant process in natural ecosystems. Moderate disturbance over the long-term allows maintenance of biological diversity. One of the advantages conferred on an ecosystem by a high degree of biological diversity is an increased buffering against severe disturbance and an increased capacity to recover speedily from disturbance.

The degree to which a site is disturbed by a fire, and the rate of recovery from the disturbance depends on the intensity of the fire, the season in which it burns, the size of the fire and the time since the previous fire. Thus it is insufficient to consider merely the impact of a single fire. It is also necessary to consider the cumulative impacts of more than one fire and the varying effects of different fires.

There is a long history of fire effects research in Australia, in particular in Western Australia. This work has focused on the impacts of fires on nearly every element of the ecosystem, including the vascular plants, the vertebrate and invertebrate animals, the soil and litter micro-organisms, reptiles and amphibians, soil nutrients and air quality.

Although the research base is incomplete (there will always be a need for additional work on the long-term cumulative effects of different fire regimes), a relatively clear picture has emerged.

A comprehensive review of the effect of fire on south-west Western Australian ecology has been carried out by Christensen and Abbott (1989). They examined pre-European fire regimes, the effect on soils of low intensity and moderate to high intensity fires, nutrient cycling in the jarrah and karri forest, the effects of fire on micro-organisms, vascular flora, jarrah and karri trees, forest understorey plants, the establishment of exotic plant species, soil and litter invertebrates, birds and mammals.

On the basis of their review, Christensen and Abbott concluded that there is irrefutable evidence that fires occurred periodically in the jarrah and karri forests over many thousands of years. There is less certainty about the frequency of occurrence, the intensity and season of pre-European fires, but they considered it likely that a combination of lightning fires and burning by aborigines would have achieved a mosaic pattern of fire ages and fire intensities through the forest.

Christensen and Abbott also found no evidence of any decline in plant species richness after several cycles of spring/autumn burning, and they concluded that the forest had a high capacity to cope with the changes associated with periodic fire and to return to the pre-fire situation.

Christensen and Abbott went on to postulate a general pattern describing the response to fire by living organisms in an ecosystem:

- There is a reduction in numbers and sometimes in species of organisms immediately after fire.

- There is a recovery in numbers and species of organisms after fire. This recovery is often characterised by the appearance of species which were rare before the fire or were present in the ecosystem only as stored seed in the soil.

- Changes may occur in species dominance and relative density after fire. These changes are often spectacular (e.g. fire weeds) but are almost always transient.

- Recovery from fire is achieved almost totally by propagation from within the burnt area, although recovery of vertebrates is often assisted and sometimes is achieved entirely from unburnt areas.

- The rate of post-fire recovery of animal species depends largely on vascular plant recovery patterns which are in turn influenced by the intensity and season of the fire, and by the length of intervals between fires.

- Each species of organism has a well-defined response to fire. This response is flexible, allowing organisms to react across a wide range of possible fire regimes. Nevertheless, there are limits to responses, associated with individual life history strategies.

Fire Intensity

Forests

The impact of a forest fire is dramatically influenced by the degree to which elements of the pre-fire ecosystem are carried through into the post-fire ecosystem. A very high intensity fire may consume almost the entire above-ground vegetation of the forest leaving behind bare ground and dead tree trunks. At the other extreme a mild, patchy fire leaves a high proportion of the pre-fire (or "parent") ecosystem unscathed. A very significant ecological advantage of low intensity over high intensity fire is that the former maximises the threads of continuity, or biological legacies, from the parent to the succeeding ecosystem. On the other hand, there are some elements of a forest ecosystem which will gradually decline without the regenerative force of a high intensity fire. Nature provided for both sorts of fire to co-exist over time for these reasons.

The intention of prescribed burning is to help firefighters reduce the number and size of high intensity wildfires. Prescribed burns are lit under carefully selected conditions of air temperature, fuel moisture content and wind, so that the rate of spread and the intensity of the fire, are at the lower end of the scale. Occasionally a burn will be hotter than prescribed, especially if forecast conditions are exceeded, and autumn burns tend to be more all-consuming than spring burns. In general, in a spring burn, a proportion of the pre-fire ecosystem (e.g. the tree canopy, the tree trunks, the tall shrubs, the moister gullies and damplands and patches of litter) survive the fire unscathed. The ecological impact is therefore relatively low.

Heathlands

Many areas adjoining the forest along the south and west coastline, or interspersed through the stands of jarrah and karri, are treeless plains. These are variously known as coastal heaths, swamps, flats, wetlands. They vary in size from a few hectares to several hundred hectares.

Heathland generally comprises a dense single story vegetation of shrubs and grass, but occasionally (especially on the recently consolidated sand dunes along the south coast) has a scattered low overstorey of peppermint (*Agonis flexuosa*) banksia (various species) or yate (*E. cornuta*).

Dense single-layered heathlands have a completely different fuel structure and fire behaviour to multi-layered forest: and when they burn the whole vegetation complex is consumed at once in a very fierce fire. The option to run mild fires through these areas generally doesn't exist. On the other hand, their powers of regeneration are very great. Usually within days of a fire new shoots have emerged and the dense mat of roots found in these ecotypes ties the soil together securely.

Frequency of Burning

The interval between successive prescribed burns is determined by the rate of fuel accumulation. CALM's fire management objective is to not let jarrah forest fuels accumulate beyond about eight tonnes per hectare and karri fuels beyond about 17. These weights convert to an interval of approximately six years for most jarrah forest and eight years for most karri forest - shorter intervals apply in some localised strategic areas, but none shorter than four years, and longer intervals apply in others. To minimise any ecological impact of repetitive burning, it is necessary to ensure that sufficient time elapses between fires for all plant species to flower and seed, especially the "obligate seeders" - i.e. those plants which do not resprout after fire and which depend on soil or plant-stored seed to regenerate.

The fate of flowering plants in areas subjected to rotational burning in Western Australian forests has been studied by Muir (1987) and Burrows *pers. comm.*

Among the species he studied, Muir was not able to identify a single one growing in the forest zone which did not flower and seed within five years of a fire. Burrows has studied several hundred jarrah forest species considered to be threatened. He has developed a flowering calendar for 255 species and has described the post-fire regeneration strategies and age to first flowering of 187 species. All understorey species studied reached flowering age within three years of fire.

The research is continuing; however, to date no plants have been identified which are threatened by the fire frequencies being employed by CALM in Western Australian forests or heathlands.

Season of Burn

One of the most contentious aspects of CALM's prescribed burning program is the debate concerning spring versus autumn burning.

The relative effects of spring and autumn burning an ecosystem is still incomplete but there has been extensive research which is summarised below.

Soils and litter

- Hatch (1959) found no significant difference in pH, macro and micro nutrients between jarrah forest burnt in spring every three years for 15-25 years and forest long unburnt (25 years). Abbott *et al.* (1984) reported similar findings.
- Soil surface temperatures during spring fires are considerably lower than those measured in autumn (Shea *et al.* 1979, Burrows 1987) but in both cases, is highly variable (Christensen and Kimber 1975). O'Connell and Menage (1983) found that the fire history of three jarrah forest sites had an insignificant effect on litter decomposition.
- Fuels are considerably drier during autumn so autumn fires tend to consume a higher proportion of the forest litter (leaves, twigs and logs) than spring fires (Burrows 1987). Spring fires tend to leave unburnt patches, particularly wetlands, damplands and around rock outcrops, while autumn fires tend to be all-consuming.

- Although there is no research to support the fact, field observation indicates that soil erosion is more likely following autumn than spring burns, since spring burnt areas tend to have more advanced regeneration at the time of the onset of winter rains, mainly associated with the regrowth of coppicing species ("resprouters"), and autumn burns tend to expose the surface soil while spring burns leave part of the litter bed intact.

Micro-organisms

There is little published work on this group and nothing published which compares spring and autumn fires. Malajczuk and Hingston (1981) and Malajczuk *et al.* (1987) have shown that numbers of ectomycorrhizal root types in jarrah forest were highest in a stand unburnt for 45 years and lowest in a stand burnt one year previously.

Vascular plants

Jarrah and karri forest ecosystems comprise plants which have evolved a variety of adaptive traits which enable them to survive fire, or regenerate after fire. About 70 percent of the species in the jarrah forest are resprouters; the remainder depend on soil or canopy stored seed (Bell and Koch, 1980). These adaptive traits cut in to ensure the survival of the plant species irrespective of the season in which are fire burns.

In general, autumn fires (even those of relatively low rate of spread) cause considerably more physical crown and bole damage to trees and shrubs than low intensity spring fires (Burrows, 1987). During autumn fires, heavy fuels such as logs and limbs are dry and ignite, causing damage to nearby trees. Hollow-butt and fire-injured trees often burn down in autumn fires, but persist in spring fires. Eucalypt tree crowns scorched by spring fire recover more quickly than those scorched by autumn fire (Kimber 1978, Peet and McCormick 1971, Burrows 1988 unpubl.), because eucalypts flush their leaves during summer.

Low intensity fires (spring or autumn) have no long-term effects on the survival or growth of jarrah (Peet and McCormick 1971, Abbott and Loneragan 1983).

No changes in the number of understorey species were recorded by Christensen and Kimber (1975) and by Abbott (1984) following a series of low intensity fires in spring and autumn. This is supported by Bell and Koch (1980).

A study of the long-term effects of frequent (spring and autumn) fire on plants in high rainfall forest near Manjimup has shown no significant change in species numbers. Only four species showed significant changes in numbers; three species increased under an autumn burn regime and one species increased under a spring burn regime (Christensen unpubl.).

Legumes which rely on soil stored seed for regeneration following fire increase in numbers following an autumn fire under dry soils. Repeated spring burning under moist conditions can reduce the number of above-ground plants, although the soil store of seed from which plants can regenerate does not appear to be affected (Shea *et al.* 1979, Skinner 1984, Christensen and Kimber 1975, Christensen and Skinner 1978). Frequent (two to three years) repeated autumn burning would diminish above-ground plants and the store of seed in the soil.

Repeated high intensity summer fires, or high intensity autumn fires would also diminish the regenerative capacity of resprouters.

A study of seedling regeneration of understorey species following spring and autumn fires in jarrah forests near Nannup revealed no significant difference in number of species, but significant difference in numbers of individuals. One year after fire, numbers of individual seedlings were higher following an autumn burn (Burrows unpubl.).

Species which require ashbed for seed regeneration, such as *Eucalyptus wandoo*, are favoured by autumn fires under dry conditions for their regeneration.

Both spring and autumn fires disrupt flowering. About 70 percent of plants flower in spring. Almost all forest plants flower within three years of fire (Muir 1987, Burrows unpubl.). Most forest areas are burnt on a cycle of five to seven years or more, thus allowing adequate time for plants to flower and seed.

The plant species most vulnerable to "frequent" fire are those which rely on canopy-stored seed for regeneration, and which take a relatively long time to mature. These species tend to be found in moist sites which rarely burn in spring fires, but can burn ferociously in the autumn.

Infrequent autumn fires are necessary to regenerate some thicket forming species which rely on capsule stored seed (e.g. *Melaleuca viminea*). These thickets often form important animal habitat (Christensen 1980).

Higher intensity fires in summer or autumn can sometimes induce flowering in some species (e.g. *Xanthorrhoracaea*), whereas mild spring fires do so only rarely. Both spring and autumn fires can stimulate massive and synchronised seed release and simultaneously provides ideal seedbed conditions for the germination and survival of seedlings (Bell *et al.*, 1989).

Invertebrates

Research has shown no consistent pattern. Some taxonomic groups are temporarily favoured by spring burns, some by autumn and some by no fire at all. Further research is needed on the long-term effects of various fire regimes on invertebrate taxa (Christensen and Abbott 1989). The recent outbreaks of jarrah leaf miner have been examined to determine whether prescribed burning is implicated (Abbott 1993). There is no indication that spring burning is the cause of an outbreak, but the severity of outbreak may be reduced by high intensity autumn fires which scorch the jarrah crowns and lead to complete crown replacement the following summer.

The Yellow Bellied Frog

Geocrinea vitellina, the Yellow Bellied Frog, is one of the rarest vertebrate animals in Australia. It occurs mainly in moist seepages near the Blackwood River in the southern jarrah forest, but moves out into the dry uplands during late summer and autumn. This species is almost completely unaffected by spring burning, but could be eliminated by autumn burning (or summer wildfires) in the area where it occurs.

Birds

Kimber (1974) found an immediate, temporary reduction in the bird populations after a spring fire followed two years later by an increase. Similar responses were observed by Christensen *et al.* (1986), Tingay and Tingay (1984) and Wooller and Brooker (1980) for both spring and autumn fires. All workers report that the level of disturbance to the bird population is proportional to the level of vegetation scorched or damaged by fire and the rate of vegetation recovery. Low intensity spring burns only affected birds utilising the ground and low shrubs, whereas autumn burns which scorched the entire forest profile, affected most bird species.

There is some mortality of nestlings following spring fires, especially of those species which nest near the ground. However, 70 percent of breeding is completed by the time spring fires are set. Also, parent birds are highly mobile, and the lengthy breeding season in the south-west allows disturbed birds to nest elsewhere. More than 80 percent of the forest is unburnt in any year, and over half the forest is always more than three years unburnt.

Mammals

Mammals are affected according to the impact of fire on their food and shelter. Impact is greatest when fires are large, intense and frequent. In most spring burns, the individual spot fires move less than 30 metres in an hour. Mammals are able to easily move out of the way of these slow, low intensity fires. Spring fires also cause less damage to live and dead vegetation (including hollow logs and trees) than do summer or autumn fires. Spring fires are usually patchy, with moist gullies and areas carrying light fuels remaining unburnt. Autumn fires tend to burn the entire forest. In the presence of foxes, some animals, such as the Tammar wallaby, benefit from infrequent (20-30 years) summer or autumn fires which regenerate the thickets they depend upon for cover. Some animals, such as the mardo, favour long unburnt areas including the unburnt mosaic within spring burnt areas (Christensen and Abbott, 1989). Other animals, such as the chuditch, appear to be more favoured by areas burnt in the spring than those burnt in autumn (Morris *pers. comm.*)

Of the 31 species of mammals which were believed to have inhabited south-west forests at the time of European settlement, only three have become locally extinct: the Long Nosed Potoroo, Lesueur's Rat Kangaroo and the Rabbit Eared Bandicoot. All became locally extinct (they still occur elsewhere in Australia) before the initiation of prescribed burning in the south-west. The most likely cause of local extinction is predation by foxes. Compared with other major vegetation types in southern Western Australia, forest ecosystems have survived relatively intact.

Weed invasion

Invasion of burnt areas by exotic weed species, especially grassy annuals, occurs on the fringes of some eastern forests where they are interspersed with agricultural lands carrying crops and pasture. Invasion is more prevalent after autumn than after spring burns because in the spring the exotic grasses do not carry mature seed.. Weed invasion is most likely where forests adjoin farm paddocks and where there is some fertiliser drift into the forest from farming operations.

In the interior of the forest, exotic annual grasses are rarely found.

Operational aspects

Spring burning is much easier and safer, and usually cheaper than autumn burning. In spring, fuels are moist and weather is more stable, so fires are safer and easier to implement. There are more days in spring when prescribed fires can safely be set. Control and mop-up costs are substantially less in spring as fewer logs catch alight, and therefore the risk of fires escaping are also less in spring than in autumn. In autumn, many trees burn down, sometimes across roads, farmers' fences or power lines.

Because autumn burns tend to consume more of the available fuel than do spring burns, and in particular, they tend to consume more of the large woody debris on the forest floor, they generate more smoke.

The autumn season is highly unpredictable. If the opening rains are early and persist, the season can close before it opens. If they are late, no suitable days for safe, effective burning might occur.

The relative benefits and disadvantages of spring and autumn burning are summarised in Table 3.

Table 3: Spring vs Autumn Burning

Autumn: The beginning of the rainy season which establishes rapidly and is usually characterised by conditions experienced in March-May. Wetting of a dry soil, vegetation and fuel profile.

Spring: The end of the rainy season which tapers off into a dry summer period and is usually characterised by conditions experienced in September-November. Drying of a wet soil, vegetation and fuel profile.

Spring Burning	*Autumn Burning*
Operational considerations	
• More days available to safely execute fuel reduction burns, therefore: ➢ better able to achieve protection program.	• Fewer days available.
• Fire weather and behaviour more predictable and stable, therefore: ➢ facilitates good planning and efficient resource allocation; ➢ low risk of escapes; ➢ lower intensities therefore easier, cheaper control; ➢ low ignition rate of logs etc. so reduced pre-suppression and mop-up costs.	• Fire weather and behaviour less predictable and more unstable, therefore: ➢ burning opportunistic, poorer allocation of resources; ➢ high risk of escapes; ➢ higher fire intensities so increased costs; ➢ higher ignition rate of logs and trees, so increased pre-suppression and mop-up costs.
• Low impact on commercial and aesthetic values.	• High impact on commercial and aesthetic values.
• Higher risk of re-ignition over following summer.	• No risk of re-ignition over following summer.
Environmental Considerations	
• Less physical damage to vegetation/habitat.	• More physical damage (higher levels of scorch and defoliation).
• Incomplete removal of litter and vegetation.	• Complete removal of fuel, especially leaf litter, scrub, logs and some trees.
• Burns patchy, with pockets of unburnt vegetation especially along streams therefore greater habitat diversity, refuge areas.	• Burns complete, entire area including streams burnt therefore reduced habitual diversity, no refuge sites.
• High retention of hollow logs, dead and old trees therefore available habitat.	• High consumption of logs, dead trees and old trees often burnt down.
• Lower losses of volatile nutrients (function of fuel consumption).	• Higher losses of volatile nutrients especially from green foliage burnt.
• Disruption to flowering at peak flowering period.	• Flowering not disrupted during peak flowering period.
• Gradual depletion of soil stored seed (but not eliminated).	• Superior germination of soil stored seed.
• Lower germination and seedling survival rate.	• High seedling germination and survival rate.
• Decreased abundance of hard seeders (acacias, legumes, obligate seed species), but these are not eliminated.	• Increased abundance of hard seeders and obligate seed species.
• No effect on resprouting vegetation. These are often favoured.	• Resprouting vegetation can be reduced in density, but not eliminated.
• Low Impact on fauna (mammals, birds).	• High adverse short-term impact on fauna.
• Short-term disruption to birds nesting and foraging in low shrubs.	• Short-term disruption to birds using shrubs and trees for food shelter.
• Lower emission of smoke and of greenhouse gasses especially CO_2.	• High emission of smoke and greenhouse gasses due to higher levels of fuel consumption.

Fire and Dieback Disease

Dieback is a generic name for tree diseases which result in the dying back of the tree crown. In Western Australia the most significant tree decline disease is associated with infection of Jarrah by fungal pathogens of the genus *Phytophthora*, by far the most significant being *Phytophthora cinnamomi*. However, the disease is not only associated with trees as the fungus is pathogenic to a wide range of understorey plants and as a result causes extensive ecosystem damage.

Disease expression is a result of the interaction of three factors; the pathogen (*P. cinnamomi*), the susceptible hosts and the environment. There is no disease expression where the host species are resistant or the environment is such that the pathogen is not able to grow and propagate actively. Because *P. cinnamomi* is a water mould it requires warm moist conditions to optimise its growth and reproductive potential.

Fire is a dominant environmental factor in south-west ecosystems, hence its role in either facilitating or inhibiting disease development has been speculated on and studied to some degree. The following possible interactions of fire with disease development have been postulated:

- Opening up the forest canopy through logging and the use of low intensity fires in prescribed burning has been attributed to the alteration of the jarrah forest understorey composition from one dominated by Acacia sp. (resistant to infection by *P. cinnamomi*) to one dominated by *Banksia grandis (highly susceptible to infection)* (Underwood and Christensen 1981)

Banksia species are highly susceptible to infection by P. cinnamomi and a dense stand allows a build up of inoculum potential, a mechanism for lateral movement, and a place of survival for the fungus over the summer. Acacia species, in particular *Acacia pulchella*, are resistant to infection by *P. cinnamomi* and in dense stands *A. pulchella* has been shown to suppress activity of the fungus. *Acacia* species, however, regenerate by soil stored seed which requires a fire of higher intensity conducted under drier soil conditions (summer or autumn) than would normally be practised for fuel reduction burning.

It has been proposed that fire management could reverse this by the use of prescribed fire conducted at an appropriate time and of sufficient intensity to kill the banksias and replace them with acacias germinated by the fire. The technique has been attempted at the experimental plot stage and on an operational basis. However, it has not been adopted into general practice because the weather conditions required to achieve these burns occur infrequently and the fires of the intensity required to achieve a significant reduction of banksia over large areas are dangerous and difficult to control, hence further technical development is required (Burrows 1985). In addition such fires can cause serious scarring and wood defects in jarrah and other eucalypts (Burrows 1987). Acacia species also have variable site preferences thus after a burn the regeneration can be very patchy (McCaw 1988) and the ability of other legume species to suppress *P. cinnamomi* has not been determined.

Even if this theory were able to be applied over broad areas satisfactorily, subsequent research into how *P. cinnamomi* kills what is a moderately resistant tree in jarrah, has shown that it would not counter the most severe impact sites of the disease. It is now known that the most severe disease impact is associated with the perching of water on the surface of an indurated duricrust layer up to three metres below the surface (Shea *et al.* 1983, Kinal 1986). Here ideal conditions for fungal development result in rapid growth and the production of spores which are transmitted laterally with the water flowing over the duricrust surface. This results in very heavy root infections and subsequent rapid collapse of the trees. The type, composition and density of vegetation on these sites has no effect on the susceptibility to *P. cinnamomi.*

- The removal of deep litter layers and understorey vegetation from the forest floor by prescribed burning destroys microbial and ectomycorhizal populations potentially antagonistic to *P. cinnamomi* (Malajczuk 1983) and exposes the soil to increased radiant energy from the sun resulting in increased soil temperatures hence conditions more conducive to growth of the fungus.

The contention that regular burning favours *P. cinnamomi* by destroying the litter layer has not been proven and in any case has two difficulties with it. These are that *P. cinnamomi* can operate at a depth well below the organic layer where most microbial activity occurs and under favourable conditions can quickly produce very large numbers of spores which to counter the antagonists must be already at very high population levels or have a similar capacity to develop rapidly (Shearer and Tippett 1989).

Surface soil shaded by vegetation and litter has been shown to be cooler than open forest by approximately 2°C in winter and 10°C in summer (Christensen 1975; Shea 1975). The gradient of temperature with depth is obviously just as important to *P. cinnamomi* but information on temperature with depth is lacking except for one study at Dwellingup which showed temperatures in winter at 1.5 metres below the surface were warmer and fluctuated less than those near the surface and temperatures at 1.5 metres on an area with 60 percent canopy cover were 2-5°C cooler than in an area with 10 percent canopy (Shearer and Tippett, 1989).

Recent re-measurement of dieback spread plots in the Manjimup region, however, has shown no difference in the rate of spread of the fungus between a long unburnt plot with deep litter and the burnt plot (Podger *pers comm.*).

Since fire is a dominant environmental parameter in south-west ecosystems which can be manipulated. The possible effect of fire regimes on disease management continues to be investigated. There is no evidence that any fire regime contributes to the spread and intensification of *Phytophthora cinnamomi* in the forests of the south-west.

Fire and Landscape

The short-term visual effects of any fire in the bush are dramatic: beautiful shrubs and flowers are reduced to ash, kangaroos depart for greener pastures, tree trunks are blackened and their leaves scorched brown, and there is an eerie silence in the bare ruined choirs where once birds sang.

However, the powers of recovery of Western Australian native forests and heathlands after fire are remarkable. Within days the first new green shoots appear, and within months, there is a sheen of green across the soil surface and in the shrub and tree canopy. In tough resilient ecosystems like the jarrah forest, the visual effects of fire quickly disappear - often within a few years it takes a very experienced eye to see that the area had been burnt at all, especially after a low intensity fire.

The more intense the fire, the more dramatic the visual effect, and the longer it takes for the landscape to recover. This is particularly true in the karri forest. Because of the height of the tree canopy above the flames, and the very rapid regrowth of understorey shrubs, the visual effect of a mild intensity fire disappears very rapidly. However, a high intensity fire will kill mature karri trees, or will kill the tree crowns, so that a landscape remains of large dead trees, or trees with dead crowns and bushy epicormic growth up the stem. These can persist for decades, as monuments of the fire. This happened in the Walpole Nornalup National Park, where hundreds of dead karri trees are still standing after being killed in the severe bushfires there nearly half a century ago. Even after one high intensity fire, such as the one which burnt through Brockman National Park in 1985, the karri is seriously disfigured and significantly less attractive to tourists.

An objection to prescribed burning is the visual impact it has on the forest. Although prescribed burns are at the low end of fire intensity, they still cause a dramatic (albeit short-term) change to the appearance of the forest. This is true of both spring burns, which have the disadvantage of occurring in "the wildflower season" but from which the bush recovers very rapidly because most native plants produce their new leaves over summer; and autumn burns which have little effect on blossom, but from which the bush is much slower to recover. For example, jarrah trees scorched brown in an autumn burn can take nearly ten months to regrow their crowns, whereas a tree scorched in spring is completely green again within a few weeks.

CALM seeks to minimise the adverse visual effects of both prescribed burns and wildfires. Prescribed burns are lit under the coolest conditions which will still provide effective fuel reduction; tree canopy height is measured before a prescription is drawn up so as to reduce the risk of scorch; burns are confined to one side of a tourist road in the one season, or are set back from the road edge, so as to minimise the amount of burnt bush tourists observe as they drive through. In the karri forest, burn intensity is kept as low as possible to avoid damage to mature trees.

The key to minimising the undesirable visual effects of disturbance like wildfire is to ensure the forest is buffered against the disturbance - i.e. has the capacity to absorb it, rather than magnify it. The best way to buffer a forest landscape against the visual impact of high intensity fire is to maintain low fuels so that when a fire occurs, its severity is reduced and the rate of recovery is rapid. This is particularly true of the karri forest, whose visual beauty is held in especially high regard by West Australians and is an important resource for tourists. This prized landscape can only be preserved in the long-term by buffering it against high intensity fire by regular fuel reduction prescribed burning.

Summary

Fire is a complex ecological factor. Experience and research to date reveal that there are advantages and disadvantages associated with both spring and autumn burning for different elements of the forest ecosystem. The most appropriate regime is one which maximises the benefits and minimises the adverse effects of each. Therefore, a variety of spring and autumn burns, together with occasional periods without fire, is the regime which is considered to best meet both protection and environmental needs of the forest, and is the regime CALM is pursuing (see Chapter 7). There is no scientific evidence that the prescribed burning regime applied by CALM in the south-west has any deleterious effect on any plant, animal or ecosystem.

THE EFFECTIVENESS OF PRESCRIBED BURNING FOR BUSHFIRE MITIGATION

It is a matter of simple physics that the damage potential or killing power of a bushfire is directly proportional to the amount and the rate of heat energy released by the fire, and this in turn is a function of the amount of fuel burnt and its rate of consumption.

It is a matter of long experience and observation by those who practise it, that fuel reduction by prescribed burning in the south-west of Western Australia is essential to reduce the incidence and damage from wildfires.

The main advantages are:

- It is highly effective in decreasing fire intensity and rate of spread allowing easier suppression.
- It results in less damage to areas burned by a fire.
- It allows land managers the flexibility to implement special fire regimes for habitat management, regeneration and control of weeds and pests.
- The presence of areas of reduced fuel widens the strategic options for the firefighter, especially in situations of multiple simultaneous fires. Priorities can be assigned to the fires or to the sectors of fires where either the problem is greatest, or the opportunity to do useful work is highest.
- It is an excellent way of providing practical experience for fire management personnel in fire behaviour and control, thus increasing their confidence and safety in dealing with wildfires.
- It provides safer working conditions and refuges for firefighters.

The effect of fuel reduction on fire intensity and rate of spread

The importance of fuel reduction to fire behaviour is readily demonstrated by fire behaviour models. Byram (1959) determined that fire intensity is related to fuel weight and rate of spread in the following relationship:

$$\text{Intensity} = H \cdot W \cdot ROS$$

Where intensity is the rate of heat release at the fire line (kW per metre), H is the heat content of the fuel, W is the weight of the available fuel per unit area and ROS is the rate of forward spread of the fire. Because ROS is also directly proportional to W in eucalypt forests, intensity is proportional to W^2.

The effect of fuel quantity on fire intensity is shown in Figure 8.

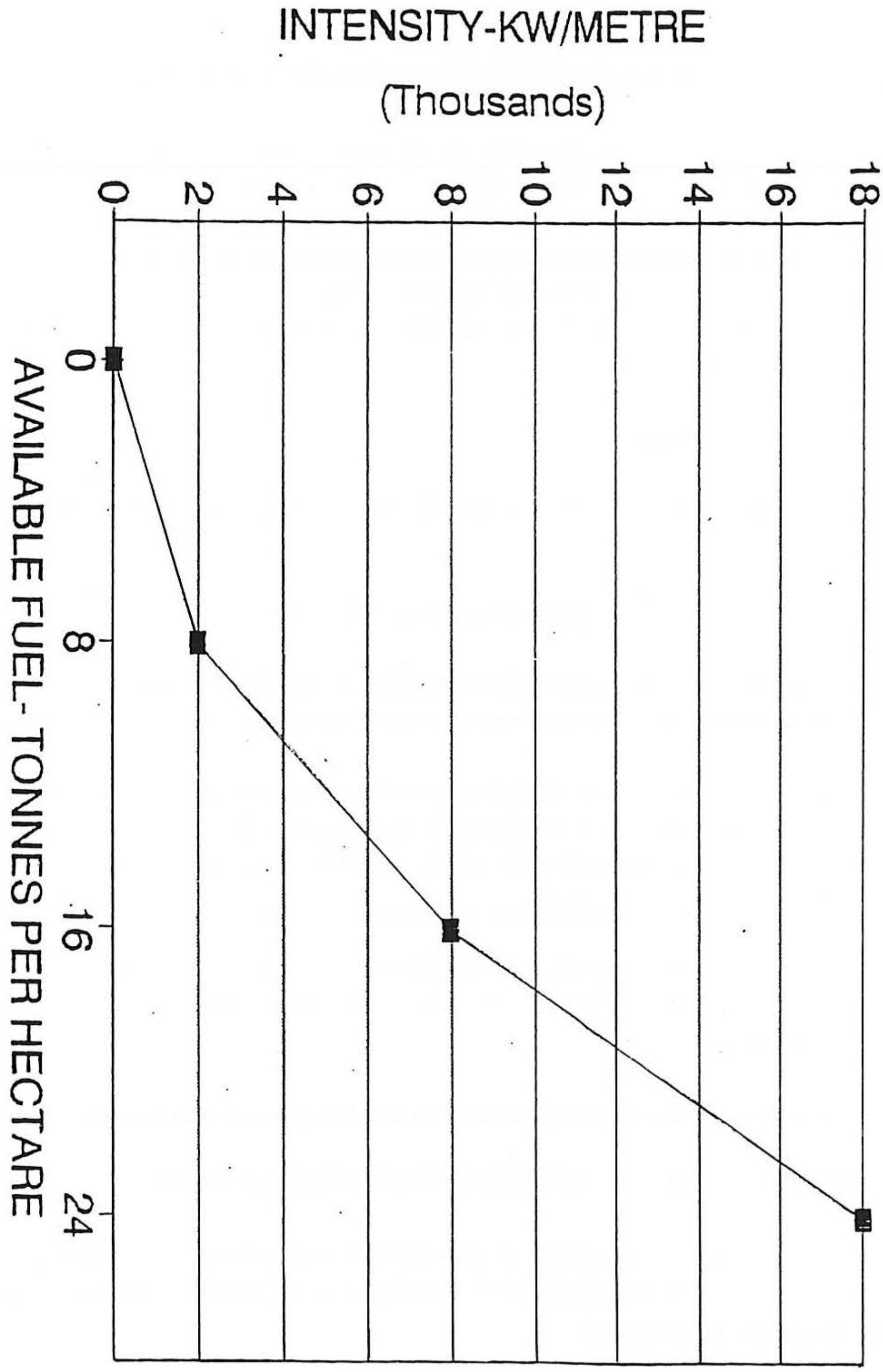


Figure 8 **Relationship between fire line intensity and quantity of forest floor fuels**

Fire intensities under most summer weather conditions will exceed 2000 kW/m when fuel exceed 8-10 tonnes, and when fires reach intensities above 2000 kW/m they are uncontrollable.

From an operational viewpoint, the reduction in fire intensity which occurs when a fire runs into an area of reduced fuel is always welcomed by the firefighter. If fire intensity drops to below 2000 kW/m a direct attack can be made on the fire with machines or hand tools. If direct attack cannot be attempted on the headfire, it can frequently be successful on the backfire and along the flanks, thus "pinching in" the head. In many fires in south western forest country, the long eastern or northern flank of a fire breaks away as a headfire when winds back around from north-westerly to south-westerly as the low pressure trough moves inland. The capacity to control north and east flanks in situations where headfires are too intense or fast-moving to attack is of vital importance in many forest fires.

In situations where none of the flanks of a fire can be attacked and back burning or burning out to roads is the strategy adopted, the presence of lighter fuels is also a significant advantage. Backfires can be very dangerous in forest country, especially under the unstable atmospheric conditions and high winds which are usually associated with bad fires; this danger is minimised if the back burn is done up against light fuels in which the inevitable hopovers can be more readily attacked.

The view expressed by critics of prescribed burning that its effects are "minimal and fleeting" and therefore not worthwhile, appears to be based on the well-known fact that fuels re-accumulate after a fire. It is true that the effect on mitigating fire intensity is greatest immediately after a fire, and then steadily declines as dry leaves, twigs and bark litter begin to fall again on the forest floor, and shrubs regenerate. Because it is a key factor in understanding fire and planning a prescribed burning program, the re-accumulation of fuels has been studied intensively by fire scientists, and the rates and structures of fuel accession are well known, especially for various forest types in Western Australia. The reason for repeating prescribed burns in the same area is precisely because it is necessary to do so to remove new accumulations of fuels.

Experienced firefighters in south-west forests acknowledge that the most effective fuel reduced areas are those where the fuel is four years old or less. For this reason, some areas (e.g. immediately around bush settlements) are burnt every four years. In the jarrah forest this ensures fuels remain below about five tonnes per hectare, which means that even under very severe weather conditions, fire intensity remains below 2000 kW/m and headfires can be tackled directly. In most of the jarrah forest, however, burns are not repeated until fuels reach eight tonnes per hectare, and this takes between five and seven years, depending on site and rainfall. In an area of forest which is subdivided into patches which are burnt about every six years, over half the forest will be carrying fuels which are four years old or less. It is these areas which present the firefighter with the best opportunity for fire control. No-one who has ever been responsible for controlling a large forest fire, would describe the advantage of having over half the area in front of the fire with four year old or younger fuels as "minimal and fleeting."

The question of the relationship between fuel and fire suppression difficulty in Western Australian forests was examined by Dr Malcolm Gill of CSIRO in 1986. Gill calculated the number of days on which fire intensity would exceed 2000 kW/m for different fuel tonnages in the forest. He found that even for the hot, dry conditions experienced in Western Australia each summer, if fuels are below eight tonnes per hectare, there are few days on which fire intensities exceed 2000 kW/m and therefore few days on which fire attack would not succeed. On the other hand, if fuels accumulate to 20 tonnes/hectare, uncontrollable fires can occur on about 130 days each year. This period extends to over 200 days/year where fuels exceed 30 tonnes/hectare.

The safety factor

Fighting wildfires in forests is one of the most dangerous tasks undertaken by any Australian worker. This is because there are inherent perils associated with falling limbs and trees, the rain of burning embers ahead of the front, intense heat, searing flames and choking, blinding smoke, all of which are overlain by a high probability of unexpected or unpredictable changes in fire behaviour caused by sudden wind, topographic or fuel changes. To these problems can be added the personal ones of extreme stress (especially in life-threatening circumstances) and fatigue, which unfortunately is also sometimes accompanied by inexperience and lack of physical fitness; and costly damage to vehicles and equipment.

In these situations firefighters are sometimes "caught" by a fire - that is, surrounded, with no way out but through the flames. When this happens crews are trained to move to the areas where fire behaviour will be least intense and then "bed down" inside a vehicle cab or underneath a bulldozer, or dig themselves in behind a log, until the flame front has passed. The best area into which to retreat is one which has been recently prescribed burnt, and in which the fuels are light. If conditions are hot and windy, the fire will still run through these areas, but the intensity of the fire will be significantly reduced, and the probability of survival of the crew will be considerably increased.

CALM has a proud record of firefighter safety in the forest country since the advent of broadscale prescribed burning: no staff have been killed in recent years, and many have used light fuel areas to ensure their safety in dangerous situations.

Fire damage

Fire "damage" is a subjective term - whether something is damaged or not, depends on the value which is ascribed to it, and also on the capacity and speed of recovery. When a high intensity fire burns through a forest, and all species recolonise or regenerate in the burnt areas, there is no long-term change in species composition or ecosystem function. However, a second or a third fire shortly after the first may impair the capacity of some species to regenerate, and this may result in long-term ecological changes. Even in these situations, the extent and permanence of the change is difficult to assess, because the whole forest is never burnt at the one time, either in terms of area or species.

However, damage to human assets or values is far more tangible. Fires can damage:

- *timber values* by burning down or scarring or wounding trees or by consuming stockpiles of logs in the forest, or burning mills and logging equipment;

- *recreational and aesthetic values* by scorching or defoliating fine stands of trees and by destruction of trails, bridges, signs, lookouts;

- *water resource values* by causing erosion in catchments;

- *infrastructure values* by burning powerlines, culverts, bridges, railways, pipelines;

- *neighbouring economic values* by burning out of the forest into farms, plantations, housing estates, settlements.

In all of these situations, the extent of damage is proportional to fire intensity. This was demonstrated following the Dwellingup fire in 1961 by Peet and Williamson (1968) who studied the relationships between fire intensity and the physical damage to jarrah forest stands. They found that physical damage increased curvillinearly with increasing fire intensity, which they found was directly related to the fuel age and the quantity of fuel burned in the fire.

The value of property and human assets located in and around south-west forests is incalculable, but probably exceeds several $100 million. Compared with this CALM spends approximately ($3 million) on its total fire management programs across the State, every year, including the cost of prescribed burning.

Fire training

When fire officers and their crews undertake a prescribed burning program, they are forced to become very familiar with fire. This takes the form of measuring fuels, calculating fire behaviour, studying fuel moisture changes, prescribing fires for given situations, lighting and controlling fires, assessing impacts and monitoring actual versus predicted fire behaviour. The control of a large aerial burn in the karri forest, for example, requires personnel to carry out most of the managerial and technical functions they perform at a wildfire - planning, organising, supplying, directing and controlling, plus suppression, mopping up, patrol, preparing and back burning edges and building firelines.

Fire management is proverbially difficult, and no two fires are ever identical. This means that strategic decisions must continuously be made "on the run" by those involved. Moreover, because the influence of local weather conditions can be so significant, but are so hard to forecast, the prediction and the "reading" of fire behaviour at the micro-scale requires wisdom and judgement as well as science-basal knowledge. A regular prescribed burning program provides the ideal training ground for fire management staff in developing this experience and the confidence which goes with it, as well as in the straight forward technical skills of fire suppression.

Fire at the urban interface

The urban/rural interface is the most fire vulnerable part of the Australian (and world wide) environment. The mixture of bushland, houses, people, paddocks and stock is optimum for the occurrence of difficult fires which cause maximum damage.

In Western Australia there are many urban interface areas of great concern, particularly the hills area east of Perth, the new suburbs north of Perth, the "hobby farm" and rural retreat areas along the Leeuwin-Naturaliste ridge and similar areas in and around the karri forest and along the south coast.

The solution to the fire threat in these areas must involve a package of strategies, including house design and protection measures, maintenance of fire breaks and clean areas around buildings, sprinkler systems, well trained and well disciplined householders and the nearby presence of well equipped and highly readied fire suppression crews. However, central to all these things being effective is the prevention of high intensity fires with long flames and heavy spotting, driving out of the bushland which surrounds the settlements. The best crews cannot contain such fires, and if the intensity is high enough, the fires will overwhelm nearly all other precautions, leading to houses, schools, shops, homesteads etc. being consumed in the fire. This happens quite regularly in the USA (especially southern California), and has occurred in recent years in South Australia, Tasmania, Victoria and New South Wales. Repeated experience has shown that when high intensity bushfires are driving in, settlements catch alight and burn well before the arrival of the flame front. Ignition results from the rain of burning embers which precedes the fire and which, swirling on high winds, penetrates buildings and sets fire to shrubbery, trees, hedges, wood heaps etc. surrounding houses. The only way to minimise this is to reduce the intensity of the fire driving at the settlement by burning to reduce the fuels to a depth of at least one kilometre in the area, well before the worst heat of summer.

Fuel reduction is therefore a pivotal part of the overall strategy for preparing for wildfire at the urban interface. As in the forest, not every area needs to burned every year, or even every four or five years. It is essential to have a network of bush in which fuel has been reduced throughout the matrix of bush and settlement. ***This will not prevent bushfires!*** But it will ensure that those fires which do occur will tend to be less intense and therefore easier to control and less damaging and therefore less costly to the community.

There are numerous examples of this strategy working in Western Australia - see McCaw, Landscope (Summer, 1993).

Fire fighting options

The presence of areas where the fuels have been reduced through the forest provides fire fighters with additional options, especially when they are hard pressed in multiple fire situations.

The most classic demonstration of this in recent times in Western Australia occurred during the Cyclone Alby fire emergency in 1978. During the height of this emergency there were about 90 bushfires burning simultaneously in south-west forests (Van Didden, 1978). These fires were being driven by cyclonic force winds, and many threatened towns, bush settlements and farms. Fire controllers could not possibly attack all fires, as there were simply not enough forces available. So decisions were made to attack only those threatening the highest values. Many fires were burning in light fuels which had been reduced, by prescribed burning up to four years before, and attack on them was deliberately deferred. or was assigned to inexperienced, "scratch" crews. One fire in State forest which was burning in fuels less than one year old was allowed to burn unattended for nearly two days, because it was causing no damage and posed no threat.

The presence of light fuels also increases the strategic options when deciding how to tackle an individual fire. The headfire can be allowed to burn into light fuels before attack is initiated, thus saving effort and risk, or flanks can be allowed to burn out to light fuel areas rather than construct firelines along them. Back burning is always safer and easier when the fire fighters' backs are up against light fuels, than it is when the adjacent fuels are heavy, and hopovers are uncontrollable.

The Incidence of Wildfires in Western Australian Forests

The true measure of the effectiveness of prescribed burning becomes apparent when two sets of factors are considered (i) the record of serious bushfires in Western Australian forests before and after the introduction of broadscale prescribed burning for fuel reduction; and (ii) case studies of individual wildfires where the effect of fuel on fire behaviour has been measured, or where projections of fire behaviour in the absence of fuel reduction have been made.

Currently CALM attacks between and two and four hundred wildfires in the south-west of Western Australia each year. This figure has gradually increased over the last 15 years.

The causes of fires have also changed over the years, with the encroachment of residential sub-divisions into the forest, increase in populations in the south-west and a decline in some traditional sources of fire such as steam locomotives and agricultural clearing burns. A significant and worrying trend is the steep increase in the incidence of deliberately lit fires (arson) which now make up about half the fire causes.

The average size of fires suppressed has varied greatly over the years depending on the severity of the weather experienced each year. Following the introduction of broadscale prescribed burning the average size of fires declined. In recent years, average sizes have again begun to increase. The average size of wildfires in native forests in 1988/89 was 14 hectares, in 1992/93 it was 46 hectares.

Nevertheless, the combined effects of all the contributing elements of CALM's fire management policy (i.e. fire suppression, preparedness, detection, prescribed burning, staff training etc.) have resulted in an extremely good record in forest fire control since 1961. There have been no major property losses, few large fires, few injuries or deaths and many significant "saves" even under extreme fire weather conditions. Over 90 percent of the fires that CALM staff attend in the forest are kept to less than 10 hectares in size. Most of the large fires which have occurred have been in the more remote sections of the forest well away from settlements and were associated with extreme weather conditions.

The Tasmanian fire scientist, Tony Mount (1985), compared the fire management achievement in south-west Western Australia with that in similar forests in Tasmania over the period 1951/52 to 1983/84. Over that period he found that the average Tasmanian wildfire was 270 hectares in size whilst that in Western Australia was 15 hectares; in Western Australia in only one fire season (1961) did the area burnt by wildfires exceed 100 000 hectares, while during the same period in Tasmania this occurred on four occasions. Mount (1985) attributed these differences to the fact that broadscale fuel reduction burning was undertaken in Western Australia to a very much higher degree than in Tasmania.

Case Histories Supporting the Value of Prescribed Burning

Dating back to 1937, records are available of nearly every fire which has occurred in Western Australian forests. This data bank can be used to assess the value to fire suppression of fuel reduction.

The most detailed analysis carried out to date is that of Underwood, Sneeuwjagt and Styles (1985). They reviewed nine separate fires which occurred during the years 1969 to 1984 in a variety of forest types. The case studies included some of the severe fires that were fanned by the cyclone winds associated with Cyclone Alby on 4 April 1978. For each fire studied, actual fire size was compared with the potential size of the fire had the headfire not run into an area where the fuels had been reduced by prescribed burning. The study clearly showed that the presence of fuel reduced zones in the forest was the critical factor in reducing the fire size and improving the ease of control in the case studied.

Sneeuwjagt (1989) studied the number of large fires in jarrah forests east of Harvey. He found there was a remarkable reduction following the introduction of broadscale fuel reduction burning. The wildfires which occurred in the 1930s, 40s and 50s were both extensive and frequent, averaging about 300 hectares each. After 1961, when broadscale fuel reduction burning was implemented throughout the jarrah forest, the size of wildfires in the study area decreased to less than 15 hectares each.

Similar examples of the effectiveness of prescribed burning in eucalypt forests in the Eastern States are given by Billing (1981), Rawson (1983), CSIRO (1987), Rawson, Billing and Rees (1985) and Buckley (1992).

Another useful analysis of the effectiveness of minimising wildfires was undertaken by Abbott as part of a study on Leaf Miner infestations in jarrah forest east of Manjimup (Abbott, 1993). His Figure 2, reproduced below as Figure 9, dramatically shows the decline in the size and number of serious wildfires which occurred in the study area after the introduction of prescribed burning for fuel reduction by the Forests Department.

Although there are some intangibles to be considered in analyses of this type (e.g. fire fighter availability and effectiveness under the prevailing weather and fuel conditions, time between fire ignition and detection and between detection and attack etc.), the studies presented incontrovertible evidence that the presence in the forest of zones where fuels were light was a major factor in reducing fire size and fire control difficulty.

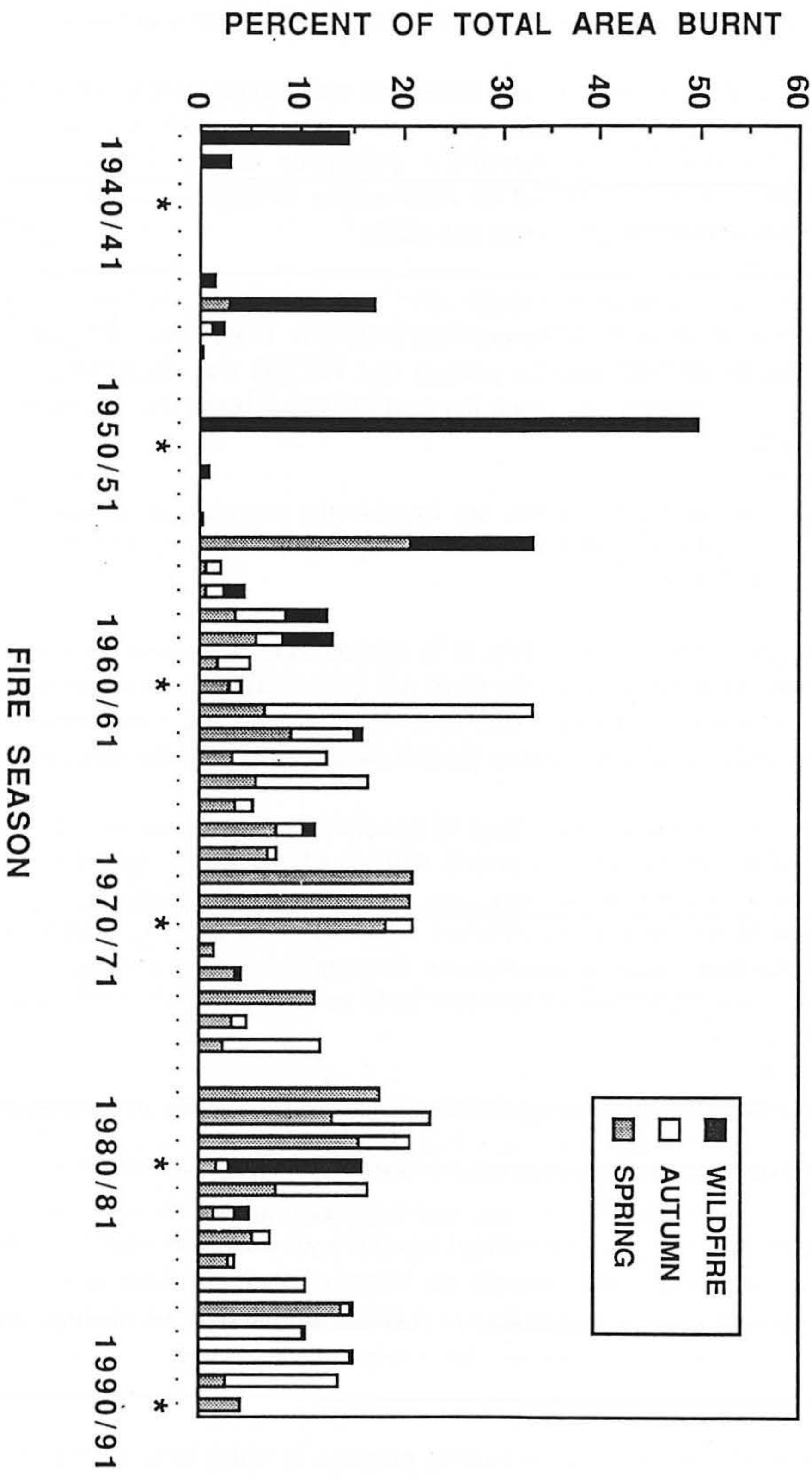


Figure 9 **Wildfire and prescribed burning history in the Perup area**
(from Abbott *et al.* 1993)

PRESCRIBED BURNING AS A SOURCE OF WILDFIRE

Despite the amount of research carried out into fire behaviour, weather forecasting and forest fuel complexes over the last two decades, not everything is known about these subjects.

And despite the best efforts of well-intentioned and well-trained staff, a small proportion of the prescribed burns carried out by CALM each year escape from their boundaries, or burn more intensely than intended. This is undesirable, principally because it results in a decline in community confidence in CALM and its management strategies, and also because in a few instances unacceptable damage and costs can result.

In fact the extent of the problem is quite small, and is declining. The percentage of wildfires attributable to escapes from CALM prescribed burning in 1989/90 was 7.5 percent, in 1990/91 was six percent, in 1991/92 was five percent and 1992/93 was three percent. These figures should be seen in the context of several hundred individual burns undertaken by CALM in the forest every year.

Moreover, the bulk of the fires which are listed in the statistics as "escapes from prescribed burning" occur during the milder weather of spring or autumn, and therefore are easily suppressed and do little damage.

The most serious problem faced by CALM in relation to escapes from prescribed burns occurs at present in the karri forest, although there will be increasing risks in some south-coast and mid-west heathlands in the future where open edge burning and wind-driven strip burning is being incorporated in some management plans (this issue is beyond the scope of this paper).

The karri forest is not a continuous block of one uniform forest type, as occurs in most of the jarrah forest. Karri stands are interspersed with stands of jarrah, open heaths and wetlands ("flats"), mixed karri-marri stands and pure marri forest, all of which have different fuels, different drying characteristics and different wind flows which in turn affect fire behaviour. Furthermore, the karri stands themselves are intersected by steep river and creek systems, in which there are strong differences between fuels on southern and northern aspects, and on ridges and in valleys.

When broad-area prescribed burning first began in the karri forest in the late 1950s and early 1960s, the problem of differential fuels and fire behaviours was tackled by the attempted subdivision of the forest into "compartments" of different forest types; roads were constructed around patches of karri, jarrah, flats etc., and individual burns were planned to be confined to the one type. However, it was soon realised that this policy was unworkable. In the first place, it was impossible to construct and maintain the length of roads required; in the second place the problem of dieback made it undesirable to increase the amount of roading; and in the third place, there was simply not enough staff and funds to make an impact on the size of the burning task.

The solution was to initiate an aerial burning program in which large blocks of forest could be prescribed burned in the same year, thereby minimising the amount of roading required and maximising the effectiveness of staff. At the same time, a major research effort into karri fuel classification and drying was undertaken; this culminated in the publication of the Western Australian Forest Fire Behaviour Tables in the early 1970s.

The technique used is one of sequential lightnings for each area: as particular fuel types dry out and the conditions arise in which the prescribed fire intensity can be achieved, an aerial ignition takes place. Generally the flats are burnt first, then the open jarrah, then the heavy jarrah, then the mixed karri-marri, then the more open karri on north-facing aspects and finally the dense karri on south-facing aspects. Six or more lightnings are often needed for the one burn, and since these are usually interrupted by passages of cold fronts and rain, it can sometimes take three months to complete a burn, with the final lightnings taking place after Christmas.

Karri burns can be difficult to manage, and although most are completed without problems, there is always a constantly high level of concern, and from time to time burns do escape. This generally happens when the karri fuels do not become available for burning until late in the year and then they move rapidly (often overnight) from being too damp to being too dry. If this situation coincides with a trough movement and strong north-westerly winds, fast-moving fires can develop within the burn area and penetrate the southern or eastern boundaries. This happened on 20 December 1974, on 31 January 1991 and on 8 December 1993.

However, karri burning is a highly complex operation, and there is an ever-present risk. More recently the difficulty has been increased by the expansion of areas within the karri forest with heavy fuels - i.e. No Planned Burn areas within the national parks and areas of young regeneration established after timber harvest. A third problem is the growing area of private bushland in which little effective hazard reduction takes place. The presence of these areas mean that staff are increasingly burning up against heavy fuels, rather than up against light ones.

Any escape from a prescribed burn is unacceptable to CALM. Every effort is made to plan burns to minimise risks and then to conduct them carefully and responsibly. If an escape occurs, an investigation is held, the causes determined and corrective measures put in place. The proportion of fires in forests which originate from CALM prescribed burning is low, and the area and impact of these fires is small. Given the complexities of prescribed burning in Western Australia it is inevitable that a small proportion of prescribed burns will escape. In assessing the impact of these incidents the community must weigh up the indisputable benefits that result from prescribed burning against the scale and impact of these fires.

CHAPTER 5

ALTERNATIVES TO PRESCRIBED BURNING AS A FUEL REDUCTION MEASURE

The "Rapid Response" Approach

The earliest approaches to organised fire control in forests were developed in Europe. In these areas a combination of high populations and dense settlement, relatively mild summer weather (compared to Australia), grazing and a huge local demand for firewood meant that forests were kept relatively free of woody debris and other organic matter; as a result, the frequency of intense forest fires was relatively low. The European method is based on rapid response by firefighters; a 19th Century version is described in "A Treatise on the Care of Timber Lands" by Nicholas Jarchow in 1893:

> *"Whenever a forest fire is discovered the church bells in all neighbouring villages begin to ring and all able bodied persons - men, women and children, turn out with axes, spades, shovels, rakes, brooms etc. under the guidance of acknowledged leaders. They combine their movements according to the direction of the wind and other circumstances and dispose their forces within intelligence and in promptitude ...... they direct their forces to one of the open paths in the woods upon which no shrubs or trees are allowed to grow and .... cut down and burn and trample and shovel earth and carry away stuff etc. and when the fire reaches that spot he finds little food, hesitates and at last is generally conquered".*

This was the approach indoctrinated into many of the European-educated foresters who came to Australia at the end of the 19th Century and early in the 20th Century. Fire was regarded as an unnatural element in the forest which should and could be prevented or expelled by well trained and well located suppression forces. Prescribed burning was not regarded as having any role to play in this approach. The influential C.E. Hutchins, an English forester who visited Australian in 1916 to advise the locals on forest management, did not accept that fire had any part to play in native forests; he referred to prescribed burning as "burning the carpets to save the house". Hutchins was an advocate of the "hilltop forester approach". This involved stationing forest rangers on hills throughout the forest from which they could quickly descend to any forest fire, and rapidly extinguish it. Hilltop forester stations were actually established in Western Australia in many places in the northern jarrah forest and at Dryandra in the 1920s. They were known in Western Australia as Overseer Stations. Most had been abandoned by World War II.

A similar approach was adopted by the US Forest Service at about this time, also under the influence of European-trained foresters who regarded all fires as disastrous. The American system was based on a massive fire suppression organisation and the policy was to keep the forests completely fire free. The symbol for this program was "Smokey Bear" with his shovel.

From the very beginning there was debate in Western Australia about whether or not broadscale prescribed burning for fuel reduction should be carried out. Most field foresters and second or third generation bushmen were aware that the Aborigines had burnt the bush regularly, and also knew from personal observation that fires in long unburnt eucalypt forest were almost impossible to control, no matter how quickly they were attacked. Nevertheless, the principal policy approach up until the 1950s was to rely on suppression forces to handle fires when they occurred. The concept involved rapid fire detection by strategically located lookout towers, communication by bush telephone and High Frequency radio, and very large gangs of firefighters stationed in district and sub-district centres throughout the forest area. The gangs initially used horses, later motorbikes, but by World War II were fully motorised. Forestry gangs in those days were frequently supplemented by large numbers of bush and sawmill workers who could be called upon to fight fires.

Despite the number of firefighters involved and their location throughout the forest in long gone centres such as Carinyah, Leslie, Gleneagle, Banksiadale, Tallanalla, Wheatley etc. large bushfires in heavy fuels continued to occur, and the heavier the fuels, the harder they were to contain. The reason for this is well known today. Unlike in many European and North American forests the litter and woody debris on the floor of Australian forests does not decompose rapidly, but builds up over the years. As soon as these fuel weights reach a critical level, fire intensity becomes too great for any firefighter to handle no matter how many of them there are and how quickly they are on the scene. (This lesson has also been learnt in many parts of the USA, where prescribed burning for fuel reduction is now being introduced.)

A dramatic illustration of the powerlessness of firefighters in areas of heavy fuels was the fire which burnt out over a third of Kings Park in a few hours in 1989. Although park staff were trained, equipped and ready for action, and together with dozens of professional firemen from neighbouring fire stations were on the scene within minutes, and despite the fact that Kings Park is a small reserve and is well broken up by bitumen roads, wide grassed boulevards and reticulated picnic areas, the fire was not stopped until it burnt out to Winthrop Avenue with numerous spot fires occurring in the rubbish bins in the carpark of Sir Charles Gardner Hospital.

Despite this record of ineffectiveness, some critics of prescribed burning still advocate dependence on fast attack forces stationed throughout the forest. Presumably at some astronomically high density of firefighters, this policy might work, because all fires start small. However, it is hard to see how any government could afford the cost of such an arrangement; nor is it likely that it would be effective on days when there are multiple ignitions over wide areas or when forest access is blocked by fallen trees and limbs, as occurs when cyclonic winds hit the forest.

Alternative Measures of Fuel Reduction

Given the necessity to reduce fuels so as to enable wildfires to be tackled under difficult conditions, what options are available other than burning?

One strategy which has been proposed is to remove the fuel manually or with machinery. This approach has never been spelt out in detail, but presumably involves gangs of people moving into the forest and gathering up leaves, bark and twigs by hand, or with agricultural implements towed behind tractors collecting litter and harvesting flammable shrubs. The harvested material is then taken "elsewhere".

This has not been tried on a large scale in West Australian forests. In the first place artificial removal of litter and shrubs could not be regarded as a natural ecological process. Secondly, it would be so enormously demanding in terms of money and people that it would be impractical. Thirdly, the use of agricultural implements and tractors in the forest may create additional risks of spreading dieback. Finally, the natural distribution of fallen trees and other woody debris on the forest floor would need to be cleaned up and removed in advance to allow access for the machinery.

Fuel reduction can also be achieved by grazing. A dense stocking rate of hoofed animals like sheep, cattle or goats will ensure shrubs and grasses are cropped back and dry leaves and twigs are trampled. Horses are highly effective in removing the bark from lower tree trunks, and goats are even capable of eating karri forest bare.

Grazing to reduce fuels is frequently used in softwood and hardwood plantations where grass constitutes the main fuel, and occasionally by farmers concerned about fuel build-up in their remnant bush areas. However, grazing is neither a desirable nor an effective option in State forests, nature reserves and national parks. Sheep, horses, cattle and goats can cause soil compaction, spread dieback and weeds and can prevent the regeneration of some plant species. They also successfully compete with native herbivores. Nor can this approach be used when "poison plants" (*Gastrolobium* species) are present.

There have also been suggestions that prescribed burning in some situations (e.g. for the protection of small settlements surrounded by forests) would be unnecessary if the settlements were equipped with roof-mounted sprinkler systems which could be activated in the event of a fire. Sprinkler systems are desirable to protect houses. However, they require an excellent and reliable source of water and power, and people must be present at the time of the fire to turn them on, or to activate back-up power if the SEC reticulated system fails as it often does in high winds or when fires are burning. Furthermore, if bushland grows right up to the edge of houses or if trees and dense shrubs are hanging over houses, the intensity of burning embers and firebrands can be so great that they penetrate the houses, which then burn from within. For these reasons, it would be foolish for people to depend on sprinklers alone to protect settlements adjacent to bush carrying heavy fuels from which fires with 20 metre flames can emerge under hot and windy conditions. Fuel reduction in the bush surrounding a settlement, as well as vegetation management within the settlement, is considered essential.

Numerous other suggestions have been made to CALM from time to time on how to mitigate bushfires without prescribed burning. These include the use of unemployed youth to mulch forest litter and take it out to the wheatbelt for spreading on farms, the construction of stone walls throughout the forest against which forest fires will burn out, and the use of a fleet of aerial water bombing aeroplanes located in the hills and gathering water from Perth's water supply dams.

None of these suggestions can be regarded as practical or economic. Water bombing, which is widely used in Canada and the USA and occasionally in Victoria, has been thoroughly investigated but rejected in the West Australian situation. Perth's water supply dams are not available for this purpose, because of risks of pollution and because of the scarcity of the resource; the only other resource is the sea. Sea water could be used on some occasions but is rarely accessible under the sorts of windy conditions when fires occur - sea water is also highly saline, and toxic to many native plants. Neither water nor retardant dropping from aeroplanes is effective in controlling high intensity forest fires. This was demonstrated graphically in the USA at the time of the Yellowstone National Park fires in 1988. At those fires the US Forest Service and the US National Parks Service spent over a million dollars on aerial water and retardant dropping, but they concluded later that this had not affected the final shape or size of the fire to any degree.

A subset of the water bombing approach is the strategic use of helicopters and water buckets. CALM is now using this technique in some circumstances - e.g. remote sites and mild fire behaviour. This technique was used on a fire in the wilderness area of the Walpole-Nornalup National Park in 1992/93. It provides tactical assistance to ground firefighters working on a difficult edge, but cannot be relied upon by itself to suppress an intense fire.

CHAPTER 6

RESEARCH

Bushfire behaviour and its ecological effects are complex phenomena. Their study cuts across almost the whole gamut of physical and biological sciences. Forest fire management in turn involves all these aspects plus interactions with politics, economics and sociology. This complexity demands a high level of commitment to research and to the application of science to operations.

The aim of forest fire managers in Western Australia is to base their work on the best current scientific understanding of all the elements of the situation. It is also necessary to have a commitment to change, as techniques and approaches must be constantly evolving as new information comes to hand.

CALM and its predecessors have a long history of commitment to fire behaviour and fire ecology, research undertaken by the Department is regarded as second to no other land management agency in Australia.

Australian bushfire research virtually began in the jarrah forest in the 1930s. This work provided forest managers for the first time with a scientific basis for forecasting fire danger and for predicting fire behaviour within reasonable limits. Not long after this, forest managers recognised that an understanding of the effects of fire regimes on forest ecosystems was essential for determining appropriate fire management strategies and for predicting temporal and spatial effects and this led to the commencement of fire ecology research which continues today.

It is beyond the scope of this submission to review in detail the large body of forest fire research carried out by Government land management agencies, CSIRO, and researchers from the University of Western Australia, Murdoch University and Curtin University over the last 30-50 years. Some of the early fire research was not published in scientific journals but is held in CALM archives or is produced as internal documents or management guides. Published material is listed in "Bibliography of Fire Ecology In Australia" (Gill *et al.*, 1991), cited by Gill (1986) in "Research for the Fire Management of Western Australian State Forests and Conservation Reserves", Burrows and McCaw (in Dell *et al.,* 1989) and Christensen and Abbott (1989) who reviewed the literature pertaining to fire effects in south-west forests and woodlands. Taken together these documents provide a comprehensive bibliography of fire research publications.

The following is a brief summary of the most significant research which has contributed to the fire management of south-west forests; future fire research priorities are also discussed.

Forest Fire Behaviour Research

Fire affects all aspects of land management in the south-west of Western Australia. An ability to forecast forest fire danger and to predict fire behaviour is therefore essential for planning and implementing management strategies.

The Forests Department of Western Australia commenced formal fire weather forecasting and fire danger rating research in Dwellingup in 1934. The first fire danger rating system was based on the moisture content of pine hazard rods placed in weather screens (Wallace, 1965).

Following the serious forest wildfires of 1961, and the need to increase the area of forest prescribed burnt for fuel reduction, fire behaviour research was stepped up. The first priority was to develop a more reliable forest fire danger rating and fire behaviour prediction system. During the 1960s, hundreds of small, low intensity experimental fires were set in jarrah forest near Dwellingup (McArthur 1966, Peet 1965, Peet 1968). Fuel, weather and fire behaviour were closely monitored and data analysed to produce the first version of "Forest Fire Behaviour Tables for Western Australia" ("the Red Book"). These tables enabled jarrah forest fire danger and fire behaviour to be predicted from weather (wind speed, temperature, humidity and rainfall) and fuel (moisture, quantity) variables. Fuel accumulation data for both jarrah and karri forests were incorporated into the Red Book (Hatch 1965, Loneragan 1961 and Peet 1971) together with guides for fire suppression and for conducting low intensity fuel reduction prescribed burns.

Fuel reduction burning using aircraft was developed in Western Australia in 1965 (Packham and Peet 1967) to improve the safety and efficiency of the operation and to enable full advantage of weather conditions ideal for prescribed burning to be taken.

The extension of broadscale prescribed burning to the southern forests in the late 1960s and early 1970s necessitated operational research to develop burning guides for tall open forests with dense understoreys. This work was undertaken by R Sneeuwjagt who conducted some 250 experimental fires in karri and mixed southern forest fuel types. Important outcomes from this work included improved fuel moisture and fire behaviour prediction systems, the definition of fuel loadings for different understorey types and the development of structural fuel models for the southern forests (Sneeuwjagt 1973; Burrows and Sneeuwjagt 1991; Sneeuwjagt and Peet 1979, 1985). McCaw has extended these studies into even-aged karri regrowth stands in order to develop fire behaviour models for these complex fuels.

At about the same time the return to clearfelling as the principle silvicultural system for karri-marri stands prompted new research into the use of fire for regeneration burning. Studies were conducted into fuel consumption in relation to weather conditions, alternative ignition techniques and the development of prescription guidelines for slash burning.

Forest management, including fire management, is a dynamic process, expanding in scope and complexity in response to community needs and perceived ecosystem requirements. Today, prescribed fire is used to achieve a range of management objectives including fuel reduction for wildfire mitigation, protection of regrowth and plantation forests, maintenance of pyric diversity, regeneration of desired plant taxa, habitat management, protection and enhancement of rare flora and fauna and pest and disease control.

In addition to understanding fire effects, these requirements have meant that managers need fire models which are capable of predicting (within reasonable limits):

(i) fire behaviour over a wide range of potential burning conditions and
(ii) physical impacts of fire which give rise to commercial losses and to ecological responses.
(iii) smoke dispersal from fires.

Early fire behaviour research by Peet provided a model which reliably predicted the rate of spread of relatively slow spreading, low intensity jarrah forest fires. However, this model under predicted the behaviour of moderate and high intensity fires burning in dry fuels and under windy conditions. To improve predictability of jarrah forest fire behaviour over a wider range of burning conditions, a series of field experiments were conducted over summer conditions in the late 1970s and early 1980s. At the same time, studies of the immediate, acute impacts of fire on vegetation and soil were also commenced. This research formed the basis of a PhD project which is nearing completion (Burrows *pers. comm.*). As well as contributing to fire behaviour and impact, this thesis contains the data on which jarrah forest fire models are based so that the models can be verified independently. Outcomes of this research include:

(i) improved, functional relationships between fire behaviour, fuel and weather variables,
(ii) description and quantification of fuel structure and dynamics,
(iii) applied models which couple fire behaviour variables, factors affecting heat transfer and acute, physical impacts of fire on vegetation and soil which are important in interpreting ecological responses and in implementing prescribed fires to achieve a desired ecological outcome.

While the work of Peet, Sneeuwjagt, McCaw and Burrows enabled the behaviour of low and moderate intensity jarrah and karri forest fires to be predicted within acceptable limits, the behaviour of large, high intensity forest fires remained poorly understood. There is also an inadequate understanding of the relationship between fuel quantity and fire rate of spread for all fuel types and weather conditions.

Partly in response to these issues the CSIRO initiated Project Aquarius in 1983. This was a major study to investigate the effectiveness of aerial application of water and retardants on bushfire suppression. The first phase of Project Aquarius involved validation of existing fire behaviour models, particularly under conditions conducive to high fire intensities. The Western Australian Forests Department collaborated with CSIRO on this phase of the project. A series of large scale (about 100 hectares) experimental line ignition and mass spot ignition fires were studied under dry summer conditions in jarrah forest near Nannup, Western Australia. The experimental fires were monitored using an airborne line scanner. Distortion of the imagery and alternative research priorities has held up data collation and analysis. However, a technique has recently been developed which allows the imagery to be corrected.

A proposal, for which funding will be sought, is currently being prepared by scientists from CALM and CSIRO's Bushfire Research Unit to jointly progress this unique and important research.

Karri Regrowth Fire Behaviour Research

Additional research in the southern forests has focused on fire management in young regrowth stands and in particular on the initial rotation of prescribed burning following regeneration. Aspects studied have included fuel moisture regimes in young stands, fuel characteristics and accumulation, behaviour of low intensity fires and the effects of fires on a range of intensities on tree growth and condition.

A number of operational scale burns have been conducted successfully in unthinned regrowth stands 15 years and older (McCaw 1986). The considerable variation in stand growth and development between sites has made it necessary to define minimum acceptable levels for top height, basal area and stocking rather than relying on age alone when developing prescriptions for fuel reduction burning.

Guidelines for using fire to reduce thinning slash in young regrowth stands have recently been developed and tested operationally, and the impacts have been on retained trees and on the nutrient pool have been quantified. This work is currently being analysed and will be published shortly.

Softwood Plantations Fire Behaviour Research

CALM manages about 55 000 hectares of softwood plantations (mainly *Pinus radiata* and *P. pinaster*) dispersed throughout the south-west. These plantations are highly valuable but, unlike native forests, can only tolerate very low fire intensities, particularly *Pinus radiata.*

Flammable fuels accumulate through needle cast and as a result of silvicultural operations such as thinning and pruning. Research has concentrated on quantifying and describing the fuel hazard in plantations, on defining fuel and weather conditions for executing very low intensity needlebed fuel reduction burns, on developing prescriptions for slash disposal burns and on determining the effects of fire on tree health and wood properties (Peet *et al.*, 1971, McCormick 1973, McCormick 1976 and Burrows 1980, 1982, 1984). As a result of this research, guides have been produced to enable the planning and implementation of low intensity fuel reduction burns. There is a narrow window of opportunity for successfully executing prescribed burns (the window is somewhat wider for *P. pinaster*) so the amount of this type of burning done varies each year, but is generally less than a thousand hectares for *P. radiata* and about 500 hectares for *P. pinaster*.

Crown fires are a feature of intense wildfires in softwood plantation, especially in well stocked stands. Conditions leading to the initiation of crown fires and subsequent behaviour are being studied Recently, CALM assisted a postgraduate student to conduct experimental fires to investigate crown fire development in conifer plantations.

Forest Fire Effects Research

CALM is committed to the concept of ecologically sustainable management (ESM). This concept can be interpreted variously, but in its broadest sense means ensuring that management practices do not impede or damage life supporting processes such as nutrient cycling, or lead to preventable loss of species or communities, or to a decline in the productivity or of the structure of an ecosystem.

Fire effects ("fire ecology") research to date indicates no loss of productivity or of species or of communities as a result of prescribed burning (Christensen and Abbott, 1989). However, most of the published literature on this topic deals with one-off fire events and present relatively short-term findings. While there are a number of contemporaneous studies (where space has been substituted for time) reported in the literature there are few published experimental data on the long-term effects of repeated fires or of the effects of various fire regime in the one ecotype; an exception is Abbott *et al.* (1984) who reported on the outcome of burning one area 17 times during a 40 year period.

The table below summarises the published literature on fire effects studies in south-west forests. Data in the Table are from overviews provided by Gill (1986) and Bell *et al.* (1989), a bibliography by Gill *et al.* (Edition 3 1991) and a literature review by Christensen and Abbott (1989).

Table 4: Numbers of published fire effects studies by research topics for jarrah and karri forests of south western Australia

Topic	*Jarrah forest (c. 1.5 million ha)*	*Karri forest (c. 250 thous. ha)*
Soils	6	4
Nutrient cycling	12	4
Micro-organisms	6	0
Vascular plants	29	7
Invertebrates	11	1
Reptiles and amphibians	0	0
Birds	5	5
Mammals	6	4
TOTAL	75	25

The bulk of the fire behaviour and effects research has been carried out in the jarrah forest, particularly the northern jarrah forest. The jarrah forest is more extensive than karri, is closer to Perth and to the base of research agencies and is more fire prone than the more mesic karri forest.

Current Fire Research by CALM

Fire research is conducted within the Science and Information Division of CALM. In addition a range of operational research trials are conducted by fire specialists in the Fire Protection Branch and in regions and districts.

The following is a summary of active fire research is currently in progress.

1. *Fire behaviour research*

- Write-up of a comprehensive study of fire behaviour and impact in jarrah forest is nearing completion. Data gathered during Project Aquarius are soon to be analysed, as described above.

- Studies are continuing into fuel accumulation rates and fire behaviour in southern heaths and shrubland communities

- Prediction of smoke production and dispersion from forest fires.

- Fire behaviour in and the impacts of fire on commercial hardwood plantations of *E. globulus*.

- Study of crown fires in pine plantations.

2. *Fire operations research*

- Study of wind profiles in different forest types.

- Study into the effectiveness of various extinguishants (retardants, foams).

- Development of fuel moisture meters.

- Use of helicopters for aerial burning, aerial retardant drops and firefighter delivery.

3. *Fire effects research*

- Long-term effects of various fire regimes on vegetation are being studied in a jarrah/marri/karri ecotone in Lindsay State forest near Manjimup. This study was established by Christensen in 1970 and is unique in forest areas of Australia. While there has been little published from this experiment, Christensen and Abbott (1989) have briefly summarised some results obtained over 17 years. They report that there was an increase in the number of species with time after fire, the greatest increase being recorded in plots burnt on a six year cycle and the least increase in plots burnt on a three year cycle. They reported a decrease in species numbers in the long unburnt control, which is consistent with other studies (e.g. Bell and Koch 1980).

- Replicates of the Lindsay forest study were established in low rainfall (750 mm annum^{-1}) jarrah forest east of Manjimup (Perup Nature Reserve) and in McCorkill State forest (1000 mm annum^{-1}) west of Nannup in 1985. These studies are designed to investigate the long-term impacts of various fire regimes (fire frequency and season) including the normal fuel reduction burning regime. From this aspect, it is too early to report any significant findings. However, a flowering calendar has been prepared for 255 species and post-fire regeneration strategies and age to first flowering have been described for 187 species. At the McCorkill study site, 73 percent of species are resprouters and the remainder are obligate seeders. All understorey species reached flowering age within 36 months of fire. In this forest type, the interval between fuel reduction burns is normally six to seven years. Currently, research is underway to examine the soil seed bank in each of the treatment plots and data on germination and seedling survival following spring and autumn burns are being analysed.

- Maintenance of a data base of flowering phenology and post-fire regeneration strategies of karri, tingle and jarrah forest understorey species.

- The impact of prescribed burning in autumn on invertebrates and mammals is being studied in jarrah forests near Collie.

- Fire ecology in the Tingle forests is being studied at Walpole.

- A major multi-disciplinary project is underway to investigate the impact of various silvicultural systems and prescribed burning on the jarrah forest ecosystem. This recently initiated study has a two pronged approach. Firstly, an experiment will be conducted in Kingston forest near Manjimup where the effects of timber harvesting on flora, invertebrates, mammals and birds will be examined. Secondly, contemporaneous (substituting space for time) studies on these taxa over a wide range of jarrah forest types will commence next year to supplement the Kingston experiment.

Future Priority Research

While there has been and continues to be a significant commitment by CALM to forest fire research, the importance of fire in the management of south-west forests and the complexity of ecological and social issues which surround fire management mean that there will always be requirements for more research.

Research needs in fire effects and fire operations in Australia were discussed by Attiwill (1985) and Underwood (1985). Specifically for Western Australia, the following topics have a high priority for future research:

- Expansion of the existing long-term fire regime effects studies to include habitat types and taxa not currently being studied. The long-term studies described above are largely focused on the vascular flora of the jarrah forest. Similar research is needed on other ecosystem elements, especially in karri forest.

- The impact of a variety of fire regimes on selected "fire sensitive" flora and fauna, and the development of special fire regimes to promote the conservation of these species.

- The effects of fuel structure and quantity on forest fire behaviour.

- Extreme fire behaviour in karri and jarrah forests.

- Evaluation of techniques other than fire, for establishing karri regeneration.

- Development of simple cost effective monitoring systems for studying the long-term effects of fire regimes in different forest types.

Research is also needed in Western Australia into the social and economic aspects of fire management and fire control. Managers need more information on public attitudes to fire and to fire protection; they need the tools to enable them to test alternative policies on the desktop before they are tested in the field, especially to be able to evaluate the costs and benefits of different approaches; and there is a need for major studies into promoting effective fire management at the urban/rural interface. Research into socio-economic aspects is inadequate.

CHAPTER 7

CURRENT ISSUES AND PROPOSALS FOR IMPROVED SECURITY FROM BUSHFIRES

Current Concerns

Reviewing the history of fire management in Western Australian forests and associated heathlands from the beginnings of organised forestry in about 1920 to the present, it is clear that a critical point has been reached.

Scientific and technical knowledge about fire behaviour, fire effects and the organisation of fire prevention and fire suppression operations, although still far from complete, has advanced to the stage where it is possible to design and implement a system which will very largely prevent the occurrence of large, intense and life-threatening bushfires in Western Australian forests. This is achievable by a combination of periodic prescribed burning to maintain fuels at or below well-defined critical thresholds, the maintenance of a well-equipped and strategically-located fire fighting force, the provision of effective detection, communications and geographic support systems, good access to the forest, the continuation of ecological research which allows constant refinement of prescriptions so as to minimise undesirable impacts of fire, and a community liaison program which ensures public support and integration of CALM's fire management with that on other land tenures.

CALM (and its predecessors) have been able to provide an effective fire management program on land it is responsible for, and contributes significantly to fire control on adjacent lands in conjunction with the volunteer brigades at a very low cost ($3 million per annum) to the State and to the community. This is because CALM staff are already present on site on CALM-managed lands, and while not engaged in fire-related work are employed on other programs (many of which generate revenue) such as forest regeneration, plantation development, tourism and recreation management and wildlife conservation programs. It is estimated that it would cost in excess of $30 million per annum to provide the same level of fire protection using a separate single purpose agency. Fire management and suppression is an intensely seasonal activity, yet at certain times a critical number of personnel must be available to fight fires. The advantage of an integrated agency is the same people who are trained in forestry, park management and wildlife protection are also trained in fire prevention and suppression. Thus a critical mass of trained firefighters are available to attack fires.

There have been a number of positive technical developments which have improved CALM's capacity to control bushfires such as:

- introduction of Incident Control Systems for the effective management of large bushfire emergencies;
- Wildfire Threat Analysis;

- improvements in spotter aircraft for fire detection;
- better weather forecasts;
- the use of helicopters for both prescribed burning and fire suppression;
- the development of computer-aided support systems;
- the increased availability of logging contractors for fire control work.

There have been no catastrophic wildfires and the area burnt by wildfire has not increased dramatically. But notwithstanding the positive achievements, the Department is concerned that if there is continuation of current trends the State will be confronted with a serious deterioration in the capacity to deal with the endemic bushfire hazard.

This concern is based on the following facts:

- CALM's current prescribed burning program covers less than eight percent of the forest area each year, where it was once about 15 percent); and something in the order of 60 percent of the jarrah forest now carries fuels which are six years old or older, compared to fifteen years ago when most of the jarrah forest carried fuels which were five years old or younger. There has also been a decline in the maintenance level of firebreaks, minor tracks, water points and lookout towers.

  As a result, CALM firefighters are more frequently having to face up to difficult and often dangerous situations in which erratic and intense fires are unable to be controlled due to the heavy fuels and the overgrown access tracks.

  This is a consequence of a combination of factors, including the decline in funding which has occurred over the past several years.

- CALM's full-time workforce in south-west forest districts has been significantly reduced in recent years and there has been a halt of recruitment. The remaining staff are ageing. To some extent this difficulty is being overcome by the training of logging personnel as firefighters and it is partly being ameliorated by the transfer of CALM personnel from areas of lower workload to areas of higher workload; but the need to provide sufficient numbers of staff to carry out prescribed burns remains. Currently the number of fit staff has fallen below the desirable threshold.

- New environmental protection and wildlife conservation requirements, imposed either through management plans for specific areas in the forest, or by external agencies such a the Environmental Protection Authority, have reduced the area in the forest on which regular fuel reduction burning can be carried out, and have reduced the number of days during the fire season on which burns can be lit. The latter constraint, specifically the requirement to avoid smoke from prescribed burns blowing into Perth or Bunbury, has had a major impact on the level of prescribed burning throughout the south-west, most especially in the critical Hills area east of Perth.

  The increased complexity associated with most of the fire management plans for conservation reserves has greatly increased unit costs for burning operations and reduced the funds available for routine burn operations in other parts of the forest.

- There are many special interest groups in the community who are opposed to CALM's prescribed burning program. They have the capacity to influence the political decision-making which controls budgets and the provisions in management plans, and have made it increasingly difficult for CALM to implement a prescribed burning program in some areas. The constant barrage of criticism which is often featured in the media has also contributed to a significant decline in morale. Not surprisingly it is difficult to sustain enthusiasm in CALM staff to undertake prescribed burning which is difficult and dangerous when every opportunity is taken by some sections of the community to denigrate the practise and the people who undertake it.

- The increase in the urban/bush interface. There are a number of locations in the south-west where housing or hobby farm developments have occurred which has added significantly to bushfire hazard because the developments often feature the extension of "the bush" virtually up to houses.

  There is often considerable resistance by residents of these developments to prescribed burning in adjacent forest and the complexity and hence cost of undertaking prescribed burns adjacent to them is very high.

- The general reduction in availability of heavy earthmoving equipment which can be used for firefighting in rural areas as the era of land clearing and roadmaking comes to an end.

- A reduction in the capacity of many Bush Fire Brigades to assist CALM, as their membership declines and equipment ages.

Proposed Action

A number of measures (some are already being implemented) are proposed to address the growing bushfire security problem.

1. Resources

A variety of measures, which are aimed at more efficient use of departmental resources, are set out below. However, while the Department is confident of significant efficiency gains these will not be sufficient to achieve and sustain the level of security from bushfires in the south-west of the State which is required.

The Department is conscious of the need to reduce the draw on taxpayers funds. The Department believes, however, that the additional funding directed to bushfire prevention will result in significant long-term savings to the community. The existing expenditure of $3 million per annum is small relative to that occurring in other States which have not been as successful in controlling bushfires.

The Department will be making its submission for increased resources for fire management in the context of its submission to the Premier's Review Committee on Public Sector Management. This will ensure that the funding required is utilised effectively.

It is estimated that expenditure of between $1 to $2 million per annum in addition to current expenditure over the next five years will be required to upgrade bushfire security in the South-West.

2. *Prescribed Burning*

It is proposed to increase the annual area of forest and associated vegetation treated with prescribed fire by 30 percent to an annual program of between 180 000 to 200 000 hectares per year. This will ensure that within five years the area of vegetation carrying fuels less than the prescribed critical levels will be between 70 percent and 80 percent.

In addition to the provision of more funding the following strategies will be employed to enable prescribed burning targets to be achieved.

(i) Continue to increase the sharing of existing CALM crews between Regions to take advantage of suitable burning conditions in each Region. For example, Central Forest Region crews could be used more in the Swan Region early in the season, and in the Southern Forest Region late in the season after the bulk of Central Forest Region burns have been completed.

(ii) Supplement CALM crews with seasonal employees that are mobile and fit. These crews may need to move from the northern forest to the southern areas as the season progresses.

(iii) Develop workplace agreements to enable CALM crews and staff to work weekends and after hours at reduced penalty rates or take days off in lieu. The use of suitable burning days on weekends will significantly increase the number of burning opportunities, as current arrangements have restricted burning days to Monday to Thursday only.

(iv) Payment of brigades for prescribed burning operations not directly beneficial to the brigade's community. This option is currently available but has not been pursued because of concerns that this may lead to payment demands by brigades for burning of areas that directly benefit the community.

(v) Use of CALM contracted employees for prescribed burning. This option is currently available to the extent that the contracted employees are required to be available for training in fire control for three days per year. However there has been serious difficulty encountered due to unavailability of these contractors on days that suit CALM's burning operations. This option is not considered to lead to significant improvements.

(vi) Use of helicopter for ignition. Operational trials conducted by CALM have demonstrated the increased productivity that is possible through the use of helicopter for ignition of small to medium-sized (up to 3000 ha) burns. The main benefit of the helicopter use is that it will enable a higher number of small jobs to be ignited in a day, which would otherwise not be possible by ground lighting crews. The accuracy, flexibility and productivity of helicopter ignition makes it possible to safely burn difficult, small and awkward-shaped burn blocks, often carrying a range of fuel types. The helicopter has been found to be particularly useful in the ignition of karri regrowth stands and *P. pinaster* plantations.

If the helicopter is to become the basis for ignition of these areas, extra funding will need to be provided to cover the hire of two or more helicopters during the few days when burning conditions are suitable.

3. *Road access and maintenance*

An immediate program of strategic road access, construction and maintenance to ensure rapid and safe access to fires will be initiated with priority given to the Southern Forest Region. It is estimated that a one-off expenditure between $500 000 to $1 000 000 will be required for upgrading.

4. *"No Burn Areas"*

A review of existing areas which have been designated in the management plans as "no planned burn areas" and "extended frequency burn areas" with a view to amending the management plans to ensure that the locations and size of these areas do not exacerbate the threat from wildfire.

5. *Fire Management at the Urban Interface*

The most serious fire management problem in Western Australia, as it is throughout the world, is preventing wildfires in the new residential subdivisions and semi-rural areas which are growing rapidly throughout the south-west. It is proposed in collaboration with other Government agencies to develop a new approach to deal with the bushfire threat at the urban/forest interface based on:

- integrated planning across tenures and various administrative agencies;
- effective programs of fuel reduction;
- improved house and building design;
- a greater level of responsibility by residents for their own security;
- good fire detection and communications;
- well equipped brigades; and
- effective public education on the risks and the steps needed to minimise them.

6. *Smoke Pollution Guidelines*

The current visibility standards that the Department is requested to meet before implementing its prescribed burning program are imposing significant constraints and cost increases. The Department believes that the smoke haze which occurs infrequently as a consequence of prescribed burns has minimal impact on the community. Consequently, the Department will be submitting a request to the Minister for the Environment and the Environmental Protection Authority to reduce current restrictions on prescribed burning brought about by rigid application of visibility standards.

7. *Community Involvement in Fire Management*

Improved mechanisms are needed to more deeply involve local communities in fire management planning, especially in the analysis of wildfire threats and the options for mitigation of these threats on CALM-managed lands.

A difficulty for CALM at present is that the decision-making processes which lead to a given course of action tend to be taken "in-house" - the local community does not participate and often fails to appreciate the options which have been considered or the trade-offs made.

There are a number of different ways local communities can effectively participate in CALM fire management. CALM is committed to exploring these and trying to find the best method to match different local situations.

It is obvious that the public in general must become better informed on the factors that influence fire management, and on the planning and implementation processes that must be followed to reach fire management objectives. This will require CALM to identify the information needs for each of the relevant sectors of the public. Better ways will need to be found to pass on this information. One particular area is the need for community understanding in the application of the Wildfire Threat Analysis in fire management decision making.

The Department believes that commercial television advertisements could be utilised to inform the community of the need for community support of bushfire prevention procedures.

8. *The Bush Fires Act*

The Bush Fires Act imposes several constraints on CALM's fire planning and operations.

Two aspects of the Bush Fires Act which should be reviewed are:

(i) The prohibition of burning during the "Prohibited Time" without special negotiation between CALM, Bush Fires Board and the local government authority. It is suggested that the notion of a Prohibited Time is now an anachronism; a Restricted Period could replace it.

(ii) CALM is required to get a permit to carry out a prescribed burn in national parks or nature reserves, but not on State forest.

This is consistent. It is suggested that the same rules for national parks and nature reserves apply as applies to State forest.

9. *The Environmental Protection Act*

In some instances, neighbours or community groups have "referred" proposed CALM burns to the Environmental Protection Authority (EPA) under Section 38 of the

Environmental Protection Act. To date, the EPA has not decided to assess a CALM proposal (although it has assessed and modified a burn proposal by a Bush Fire Brigade in the hills near Perth), but once the process is activated there is a delay of several days and this can result in a burn being deferred or cancelled. This could be avoided by use of Section 6 of the Environmental Protection Act which allows the Minister for the Environment to exempt CALM's prescribed burning from the provisions of the Environmental Protection Act.

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APPENDICES

APPENDIX 1	CALM's Fire Management Policy
APPENDIX 2	The Wildfire Threat Analysis
APPENDIX 3	Smoke Management in South-West Forests

APPENDIX ONE

CALM Policy Statement No. 19

Fire Management Policy

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

POLICY STATEMENT NO. 19

FIRE MANAGEMENT POLICY

MAY 1987

1. INTRODUCTION

This policy is based upon the following premises:

1.1 Fire has occurred naturally from time to time in practically all lands managed by CALM. Fire has therefore played some part in determining present vegetation structures and composition.

1.2 Under natural conditions, practically all ecosystems are made up of a mosaic of vegetation associations and structural stages according to their fire histories. The scale of the mosaic varies in different ecosystems.

1.3 Fires from natural causes (eg. lightning) will inevitably occur. Fires resulting from human activities, either deliberate or accidental will also occur, but may be minimised by effective public education and awareness, and by legislation.

1.4 In Western Australia, weather conditions occur every year under which fires can be so intense as to be impossible to contain with currently available technologies and resources. Such fires can threaten human lives, and resources valued by the community, and their control involves considerable public expenditure and risks to fire-fighters.

1.5 The speed and intensity at which fire burns is related to the quantity of accumulated dry litter or other fine plant material. In some ecosystems, or in some high risk/high value situations, accumulated fuel loads can be reduced by prescribed burning. This reduces the likelihood of intense fires even under extreme conditions, and improves the capacity for fire-fighters to safely control a fire.

Within each major fuel type there is a recognised weight of dry fuel above which fire-fighting forces are not likely to be able to contain wildfires burning under normal hot summer conditions.

1.6 Much of departmental land, particularly in the south west, has a common boundary with well developed private assets such as towns and farms, the protection of which reduces the flexibility for fire management.

1.7 Information about the long term effects of different fire regimes, including fire exclusion on many ecosystems is limited, and any management policy must be under constant review and accompanied by research and monitoring programmes.

1.8 The Department has a moral and legal obligation to comply with those provisions of the Bush Fires Act, and CALM Act relating to fire prevention and control of wildfires on or near CALM lands.

2. OBJECTIVES

The fire management goal of the Department of Conservation and Land Management is:

2.1 To protect community and environmental values on lands managed by the Department from damage or destruction from wildfire.

2.2 To use fire as a management tool to achieve land management objectives, in accordance with designated land use priorities.

3. POLICY

3.1 Fire Suppression

1. The Department will meet its legal obligations under the Bush Fires Act and Conservation and Land Management Act by responding to fires occurring on or near CALM land to a degree that is appropriate to the values at risk.

2. The Department will assess its response to a fire in the light of potential damage to the following values in order of priority.

(i) Human life;
(ii) Community assets, property or special values (including environmental values);
(iii) Cost of suppression in relation to values threatened.

3. Where values dictate the Department will:

(i) provide a detection system which will give timely warning of the presence of a fire threatening community or environmental values;

(ii) provide a well trained and equipped suppression organisation capable of containing several simultaneous unplanned fires under extreme weather conditions in conjunction with other fire fighting organisations.

3.2 Use of Fire

The Department will:

1. Use planned fire only where this use is in accordance with an approved management plan, or, where such a plan does not exist, to protect and maintain the designated priority land use.

2. Prepare written prescriptions in advance, for approval by senior designated officers, before any planned fires are undertaken.

3. For areas where primary land use is wildlife conservation, use fire in such a way as to promote the greatest possible diversity and variety of habitats within prevailing physical or financial constraints.

   In small conservation reserves and where information on the impact of fire is limited, fire will be used conservatively. In such areas the use of fire will be restricted to:

   (i) protection of neighbouring community assets; and

   (ii) as far as is achievable and within safe limits, ensuring that different seral stages following fire are represented.

4. Use prescribed fire or other methods to reduce fuels on appropriate areas of CALM lands, where it can be demonstrated that this is the most effective means of wildfire control, and where undesirable ecological effects do not result.

   The frequency of fuel reduction measures will be governed by the rate of build-up of fuels; the degree of risk to human lives, the value of the assets to be protected; the known sensitivity to fire, or dependence on fire, of the kinds of plants and animals present; and the resources available to carry out the work.

3.3 Liaison

The Department will:

1. Ensure effective liaison with neighbours, Bush Fires Brigades, Shires, Bush Fires Board and other fire control organisations.

2. Support the concept of Shire District Fire Plans and promote mutual aid interagency agreements for fire control on lands of mixed tenure with common fire problems.

3.4 Public Awareness

The Department will provide for public education in relation to the prevention of fire, and the role and use of fire in ecosystem management, and hazard and risk reduction.

3.5 Research

The Department will undertake research into fire prevention and control, fire ecology and fire behaviour on CALM lands to improve the scientific basis for, and effectiveness of Fire Management Programmes.

4. STRATEGIES

4.1 Fire Suppression

Suppression of unplanned fires on or threatening departmental land will be given priority over normal activities, except for those involved with safeguarding human life.

A detection system based on aircraft, lookout towers or ground patrol, will be used in designated areas where early warning of a fire occurrence is essential to enable rapid control measures.

In other areas, the Department will rely on neighbours, staff presence, the public, or commercial aircraft for reports of fire outbreaks.

When a fire is detected an appreciation will be made to estimate its likely spread and potential to cause damage to life, property or environmental value.

Unplanned fires will be contained to the smallest possible area by the most appropriate means available taking into consideration the values at risk and the impact of the suppression activity on the environment.

4.2 Use of Fire

Prescribed fires will be used to achieve a range of management objectives, including fuel reduction, habitat management, forest regeneration and the management of scenic values.

According to management objectives, appropriate prescriptions will be developed, and staff will be trained in their application.

Monitoring of the effects of fires will be undertaken wherever effective systems have been developed and resources are available.

4.3 Liaison

The Department will participate in the preparation and implementation of Shire District Fire Plans and interagency agreements.

Departmental staff will attend Bush Fire Advisory Committees and Brigade meetings where appropriate, to foster and encourage good working relationships with other fire fighting organisations.

Where practical, departmental staff will assist with fire control activities on a neighbour to neighbour basis with local Bush Fire Brigades and other fire control organisations.

4.4 Public Awareness

Education of the public on the prevention of wildfire and on the use and role of planned fires will be promoted through the provision of literature, films and talks. Special attention will be directed towards school groups.

4.5 Research

The Department will undertake research and will encourage research by other agencies and institutions into the fields of:

1. Fire behaviour in major vegetation types;
2. Fire ecology;
3. Fire equipment development;
4. The application of information technology to fire management;
5. Fire detection, prevention and suppression systems;
6. Remote sensing for fire mapping and detection purposes;

7. Alternative methods of fuel reduction;
8. Social aspects of fire prevention and arson.

4.6 Operations-Research Interface

The Department will ensure that there is a rapid transmission of research results into policy and operations. Research and specialist staff will help to develop and update operational prescriptions and monitoring systems.

The Department will sponsor relationships between its staff and other agencies or organisations concerned about fire by the publication of research findings, holding workshops and seminars, and public participation in management plans.

Syd Shea
EXECUTIVE DIRECTOR

26 May 1987

Distribution: Lists A,B,C,D,E, & F

APPENDIX TWO

WILDFIRE THREAT ANALYSIS

A DECISION SUPPORT SYSTEM FOR IMPROVED FIRE MANAGEMENT

Wildfire Threat Analysis - A decision support system for improved fire management

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Abstract: The task faced by fire managers is becoming increasingly complex, involving large amounts of spatial information, uncertainty, and increasing demands. Managers must be able to withstand criticism, justify decisions, and educate others. Increasingly the experience of individuals must be supplemented by the knowledge of others. In order that fire management decisions are rational and have community support, both the basis and the process of decision making must be clearly understood and be able to be readily explained. The Wildfire Threat Analysis is a decision support system that addresses these requirements for fire protection planning. Wildfire threat is defined as a function of the values at risk, the probability that ignition will occur, the suppression response, and the potential fire behaviour. The development and practical application of the Wildfire Threat Analysis in Western Australia is discussed.

Key Words : Decision support system, Geographic information systems, fire planning, wildfire threat.

Introduction

Salazar and Nilsson (1989) succinctly summarised the problem faced by fire managers when they stated: "Fire management requires the integration of large amounts of information about environmental and societal factors, which are spatially and temporally dynamic". In making the fire management decisions, the manager must consider the fire itself; physical influences including topography, geology, weather; time and distance; social factors such as land tenure, property rights, and the often conflicting desires of involved parties; legal and moral obligations; finance and resources available; and the environmental impacts of both the fire and management actions. His decisions must frequently be made with incomplete information, they must be good, and they must work. The manager must be able to educate others, withstand the pressure from sectional interest groups, explain the strategy to gain the community support essential to allow management to continue, and be able to defend decisions made, if necessary in the law courts.

Fire management is not only complex in information, but can arouse a range of passionate argument (particularly where fires are planned to be deliberately lit) from people who see different values threatened, and who regard fire from vastly different perspectives based on their personal experience, background and beliefs. Despite its long beneficial use, call "FIRE!!!" and few think of warm meals, toasted marshmallows, or warmth on a winter's night. An instinctive first reaction is to regard fire as an enemy, a destroyer of valued possessions, something to be fought and bitterly opposed. The importance of the strong emotions which can be aroused must be recognised and addressed by the fire manager as part of the complex process of formulating and implementing a fire management strategy.

To deal with this complexity the fire manager needs assistance. The Wildfire Threat Analysis (WTA) is a map based decision support system (DSS) developed to assist the manager with strategic fire protection planning. It was first introduced for use in the forested areas of south western Australia as a manual system with simple correction factors and approximations for a limited range of conditions, that introduced users to the underlying concepts and the limitations of the data (Muller, 1990; Beck and Muller, 1991), and subsequently expanded to take advantage of CALM's (Department of Conservation and Land Management) geographic information system (GIS). The principles apply universally, and it has subsequently been introduced for use on all land managed by CALM throughout Western Australia (Muller, 1993).

In Western Australia (as elsewhere) such decision making has frequently relied on individuals with knowledge accrued over many years. Increased demands on public lands, greater intensity and complexity of management, and an escalation in the amount of information required have made it increasingly difficult (if not impossible) for any one person to maintain the required knowledge and expertise in all areas. The experience of the individual manager must now be supplemented with the knowledge of others, and aided by formal decision support systems.

Gill (1986) noted that experience and ideas are the guides to future actions and identified the major paradigms of fire management successfully utilised by experienced fire managers in Western Australia. A major tenet has been the importance of fire as a management tool, particularly for fuel reduction burning in the forests of south-western Australia (see Underwood and Christensen (1981), McCaw and Burrows (1989)), the effectiveness of which has been amply demonstrated on numerous occasions (eg. Underwood *et al.*, 1985)

In the mid-1980's reduced resources, combined with increased difficulty and cost of burning as a consequence of greater fragmentation of burns following more intensive forest management, meant all scheduled burns could no longer be achieved. The response of managers varied. In some cases preference was given to the 'easy' burns: those burns that could be achieved with minimum cost, effort and management conflict. Whilst this gave low unit costs, the burns were not necessarily those most important from a strategic protection standpoint.

Concurrent with the task becoming more difficult and resources diminishing came increased public interest in, and in some cases criticism of, the practice of fuel reduction burning. Faced with both the difficulties and criticism, there was a temptation to focus on the less criticised aspects of fire protection without proper analysis of their effectiveness. This demonstrated a need to formalise the decision making process to ensure that all alternative strategies are evaluated, and can be explained.

To address the above issues, a system was developed to support strategic preparedness planning for lands managed by the Department of Conservation and Land Management (CALM), which formalises the processes undertaken by experienced fire managers in considering the threat from and responses to wildfires. This system, known as the Wildfire Threat Analysis (WTA):

* provides a framework to analyse the best available information on all factors contributing to the wildfire threat, and allow evaluation of alternative responses;

* provides a standard and repeatable process such that consideration of the same data by different persons and/or at different times will identify similar situations;
* permits objective comparisons between different areas with different problems and allow priorities to be readily determined;
* supports the clear and explicit explanation of the rationale behind fire management decisions; and
* provides a rational basis for discussion and conflict resolution in the preparation of management plans (which in Western Australia involve public participation).

The aim of this paper is to outline the WTA system and its application, and why it was developed differently from some other decision support systems in use for fire management.

The Wildfire Threat Analysis System

The factors that contribute to the wildfire threat are considered to fall into four categories:

* The community and commercial and environmental VALUES that are to be protected. In the absence of such values, there is no threat, and no further action is required.
* The RISK OF IGNITION. ie the probability that a fire will start. If there is no risk of ignition, there would be no threat, but in practice this is unlikely, although the risk may be low in some areas.
* The SUPPRESSION RESPONSE possible, which is affected by a range of factors such as the location of forces in relation to the fire, terrain, and access. In most situations, the quicker suppression action, the smaller the fire, and the lower the potential threat to values.
* The likely FIRE BEHAVIOUR, which influences both the extent and severity of damage and the success of any suppression action, and is dependant on fuels, topography and weather conditions.

The WTA utilises a series of maps to illustrate all the contributory factors. The wildfire threat is represented by the combination of four map overlays that summarise the values in each of the categories. In turn, each of these four maps can be supported by maps of the factors that contribute to a category value (Fig. 1). Hatching is used to illustrate the values in each category, the density of the hatching representing the severity at that point. Each overlay is hatched at a different angle (Figs. 2 - 5), so when overlaid the combined hatching shows the patterns of the wildfire threat (Fig 6.

FIGURE 1 NEAR HERE

(WTA Mapping Hierarchy)

Map 1 - Values At Risk

Most disagreements on fire management practices can be traced to either differences in perceived impact on values, or differences in the values ascribed to the same thing in the first place. These differences may be easily resolved where there are clear market values, but the pricing of non-market or intangible values has long been a difficulty in natural resource planning. Many techniques have been applied, such as cost-benefit analysis, multipliers, willingness to pay/trade offs, paired statistics (eg. Greig 1984; Johnston *et al.* 1967), and, in some cases, intangibles have simply been excluded from analysis (eg. Althaus and Dills, 1982). No method of tackling this issue has met with universal acceptance.

In the WTA both market (tangible) and non-market (intangible) values are grouped into broad classes, with no attempt made to assign discrete dollar amounts to the values. A single rating is assigned to each value class, and the members of a class are those perceived to be approximately equal. A guide to value classifications (Table 1) has been prepared to assist persons preparing the map to be consistent in classifying local values. It is not feasible to list all values and this guide is neither exhaustive nor final. It is reviewed as the need for further explanation or refinement is identified through use.

Where special circumstances are identified (eg. following consultation with neighbours or stakeholders) and a value is allocated to other than its obvious group, or the allocation is open to interpretation, the reasons for the decision are recorded.

All values are depicted as features on the base map and colour coded according to category (Table 1.)

TABLE 1 NEAR HERE

(Values Classification)

The area in which a running wildfire would pose a significant threat to the values concerned is shown around each value. The extent of this zone is varied according to the relative severity of the wind from different directions. The influence zone is extended furthest (3km) in the direction of prevailing winds associated with the most severe fire weather. Experience has demonstrated that for fires burning under adverse weather conditions in Western Australia's forests, at least 3km width of low fuel area (eg. < 8 tonnes/ha in dry sclerophyll forest) with moderate fire behaviour (Intensity < 2000 kW/m) is required to catch spot fires and provide time for suppression action. Whilst spotting is less of a problem with fires in other fuel types (woodlands, grasslands and shrublands) fires spread faster and therefore further during the time taken for suppression, and so the potential threat from fires in a similar influence zone is considered.

The standard (default) influence zone extends:

- 3km North-West to East of the value (commonly winds in this sector being most dangerous); and

- 1km in other directions.

These zones are shown hatched on an overlay, the density corresponding to the category of the value generating the zone. Where zones overlap, only the highest value zone is shown.

An example of a "Values" map is shown in Figure 2.

The classification and mapping of values provides a clear basis for ranking management options. It does not eliminate disagreements, but helps identify specific issues. There will always be those who disagree with aspects of any classification, and such explicit identification provides a framework to argue for change until, ideally, the classification reflects a balance of the values of the community as a whole. Comparative techniques are applied to assign values to categories. The use of more formalised Analytic Hierarchy Process techniques may improve the reliability of the overall classification where greater uncertainty exists about the correct classification.

FIGURES 2 - 6 NEAR HERE

(Individual and Combined Maps)

Fig 2 Value Threat Zones: Zones are generated around each value, extending furthest in the direction of the most severe fire weather. Fires within these zones are considered to pose a significant potential threat to the value.

Fig 3 Risk of Ignition: Ignition risk is mapped according to probability of ignitions occurring.

Fig 4 Suppression Response: Time zones are mapped according to the best available information, and may be simple or very detailed where an analysis of extensive road networks has been undertaken.

Fig 4 Headfire Behaviour: The potential headfire behaviour is mapped into 'suppressability' classes.

Fig 5 Combined Overlays: The patterns of hatching from the combination of the four overlays indicates varying wildfire threat. The relative importance and most effective ameliorating action can be ascertained from examining the individual overlays.

Map 2 - Risk Of Ignition

Ignition risk is the probability that a fire will start, not that it will necessarily spread or cause damage (factors that are addressed separately).

Fire history provides an indication of past ignition risk, but is not entirely satisfactory as a measure of either current or future risk. Firstly, it is a record of only those ignitions which were reported as fires. Not all ignitions result in fires requiring suppression action, and not all fires are reported (particularly in less populated areas or where accidental fires are put out without assistance); and in recently settled areas the potential scale and intensity of lightning ignition may not be apparent until after the first major fires have occurred. Secondly, circumstances change. Different activity patterns over time result in changed risk. An example is the marked decline in wildfires that has occurred in areas as the management of developed farmland has replaced the land clearing phase.

Historical data is useful to identify lightning prone areas where sufficient records are available, and is necessary to determine correlations between activities and fires. It is anticipated that future analysis of fire cause data and social patterns will enable improved prediction of risk.

In the WTA, risk zones are shown hatched on an overlay (Fig. 3) according to the peak frequency of occurrence of ignition sources during the fire danger period (Table 2).

TABLE 2 NEAR HERE

(Ignition Risk Classes)

Map 3 - Suppression Response

FIGURE 7 HERE

(Suppression Response map hierarchy)

Suppression response reflects the time taken to detect a fire, for firefighters to reach the fire, and for effective fireline to be constructed around the fire. The time required to complete fireline construction depends on the fire itself as well as on the method of construction and nature of the terrain and vegetation. To compare only the factors that are inherent in the site itself, fireline construction is expressed as a rate, thus making it independent of fire size.

'Suppression Response' is expressed in five classes (Table 3). It is assumed that any fire can be suppressed provided adequate resources are available on site at the time of ignition. The "Immediate" category reflects the initiating phase of fire development, where suppression has a high probability of success. Other class divisions are more arbitrary, but the use of such standardised classes permits comparison between areas.

TABLE 3 NEAR HERE

(Suppression Response classes)

Detection Time, Travel Time, and Fireline Construction Rate maps can also be prepared as separate overlays that, when combined, show the variation in times which are then grouped into the suppression response classes.

The time taken for detection depends on the detection facilities available (firetowers, aircraft, neighbours) and on the level of preparedness. This frequently depends on the prevailing conditions, the intensity of paid surveillance and the concern and vigilance of neighbours usually increasing with increasing fire danger. For example, in Western Australia aerial detection is used over most forest areas, and the flight schedules for the fire spotters is varied according to the fire danger index. Weather also affects visibility and the rate of smoke development. To provide a basis for comparison, the 95 percentile weather conditions during the fire season (the period during which there is a risk of damaging wildland fires and fire restrictions apply - usually from November to April) are chosen ie on 5% of days the fire weather conditions will be more severe. Time zones are mapped assuming the detection system is operating, and represent the likely time between ignition and detection under the selected weather conditions.

The time required for suppression forces to reach a fire depends on the location and mode of transport. The map is standardised by using the time from the crews' normal stand-by locations (usually the work centre), using their standard mode of transport. In Western Australia this is a gang truck and heavy duty tanker, but could include aerial transport elsewhere. Allowance is made for off road travel.

In many cases fire suppression will necessitate the use of heavy machinery. Separate travel time maps can be prepared for a more detailed analysis, but for a broad comparison the relative times to get such equipment to different sites are assumed to be similar to the relativities for crew travel times.

Fireline construction rate is expressed as the time taken to construct a standard length (1000m) of fireline by the method and machinery/equipment appropriate to and commonly available in the area. This time can be readily combined with the detection and travel times to classify areas, but it must be clearly understood that this is only a relative measure of the physical or site difficulties associated with a suppression response to a particular area and not the time taken to suppress a fire, which will depend on the fire behaviour, the forces available, and the fire size when they arrive.

Map 4 - Headfire Behaviour

Factors influencing fire behaviour vary spatially. The relative importance of each factor at any point can be readily seen if theme overlays are prepared as follows:

FIGURE 9 NEAR HERE

(Headfire Behaviour Map Hierarchy)

Headfire behaviour determines the suppression action crews can take in fighting a fire. The Headfire Behaviour is mapped in classes that have practical application (Table 4) based on both published (McArthur, 1972; Loane and Gould ,1986; Wilson, 1988) and unpublished (N. Burrows, pers. comm; L. McCaw, pers. comm.) data and experience in Western Australia over many years. Despite the direct relationship between headfire rate of spread (HFROS) and the fireline intensity (I) of the headfire (Byram, 1959) both are considered as either may be a limiting factor in particular circumstances.

TABLE 4 NEAR HERE

(Headfire Behaviour Classes)

Intensity of the headfire is expressed by:

$I = Hwr$ (Byram 1959)

where I = fireline intensity (kW/m)

H = heat of combustion (kJ/kg)

w = weight of fuel consumed (kg)

r = fire rate of spread (m/sec)

The heat of combustion depends on the fuel and its moisture content, and for natural fuels is generally quoted in the range 15000-19000 kJ/kg.

A value of 16920 kJ/kg was used which facilitates manual calculations as this equation reduces to:

I = 0.47 * HFROS * W

where I = Headfire intensity (kW/m)

HFROS = Headfire rate of spread (m/hr)

W = Weight of fuel consumed (tonnes/ha)

Headfire Rate Of Spread (HFROS) can be calculated from a range of existing fire behaviour tables, circular slide rules, or equations. When first introduced in Western Australia, the WTA system applied only to forest areas and used an expression derived from the Forest Fire Behaviour Tables for WA (Sneeuwjagt and Peet 1985) to estimate the HFROS from the Fire Danger Index (FDI) for a limited range of conditions:

HFROS = FDI * FQ * FT * WR * S

where:

FDI = WA Northern Jarrah forest fire danger index

FQ = fuel quantity correction factor

FT = fuel (forest) type

WR = correction factor for wind ratio (the ratio between the tower wind in the open, and the wind at 1-2 m above ground in the forest)

S = slope correction factor

The correction factors were based on classes with a range of values to simplify calculations for the manual preparation of the WTA. To reduce inaccuracies, it is preferable that calculations use prime data where possible; that grouping into classes is minimised during calculations and is instead deferred until required to provide visual displays. This requires a large number of complex calculations. To make this feasible the above method of calculation was replaced by a simple program for a personal computer (Muller 1990), and subsequently by a geographic information system (GIS) based version for use where digital geographic data is available.

Additional spread models have been included in the computer program which enables much broader application of the WTA. These use equations (Appendix 1) developed by Beck (1989) for the Forest Fire Behaviour Tables for WA, by Noble *et al.* (1980) for the McArthur Grassland Meter Mk III, for Mallee Heath Shrublands (L. McCaw, pers. comm.) and

Hummock Grasslands/Spinifex (Burrows *et al.*, 1990). All equations have stated application bounds and where these are exceeded, the limiting values are assigned and warning flags displayed. This has little practical significance as these limiting values generally already fall into the "Direct Attack Not Possible" category (Table 4).

TABLE 5 NEAR HERE

(Guide to Wind Ratios)

The forest fire spread equations are based on empirical data which measured wind speed within the forest, and are expressed to use wind at 1-2 metres. Where the original equations for other fuels used the 10m tower wind, they have been modified to also use wind at 1-2 metres by the inclusion of a wind ratio factor to correct for the lower wind speed nearer the ground. Non-forest equations are then used to model HFROS where non-litter fuels are considered to dominate fire behaviour, even in forest/woodland situations. For example McArthur's model was derived for open grassland, but the modified equation is also used for situations with a grassy understorey beneath a forest canopy, with the wind speed adjusted by an appropriate ratio (Table 5) according to the height and density of the canopy. In the standard grassland situation the wind ratio value for open grasslands cancels the modification, and the equation is identical to that of Noble *et al.* (*op. cit.*).

The fuel type identifies the spread model to be used. Forty five fuel types have each been assigned to one of ten models to calculate the headfire rate of spread using the equations outlined. (Two additional models in the "Fire" program can be applied to *P radiata* and *P pinaster* slash which are not separately identified on the existing digital database.) Additional types can also be assigned as required, and for fuel types where there is no appropriate model, an 'expert opinion' value can be used.

Fuel quantity is obtained either from direct field measurements, or can be derived from fuel age using fuel accumulation rates for each vegetation type.

For fire spread calculations the actual slope data is used, but for display maps are normally produced in five degree classes.

A WTA may be undertaken for any given weather conditions. To enable comparison of the threat between areas with differing frequency and severity of adverse fire weather in Western Australia the 95 percentile conditions during the Restricted and Prohibited Periods (nominally the fire danger period) are used as standard This arbitrary figure was chosen as the starting point for fire protection planning. In areas with exceptional values this level of risk may be unacceptable and a higher percentile chosen.

Discussion

The WTA was conceived to support practical land management. It is recognised that decisions must frequently be made on the basis of incomplete knowledge, but this should never be an excuse for not using that information which is available. The WTA is designed to bring together 'best available' information which may range from highly accurate mapped data, to the "thumb-nail dipped in tar" variety. Models used include interim equations and equations with very restricted application bounds. As new/improved models become available they are introduced, and there is room for 'expert opinion' input where no models apply satisfactorily.

The variability in the reliability of models and data can pose a problem if the threat maps are used without knowledge of the inputs. Where maps are manually produced and used by the same personnel locally, the limitations are known and the results treated with appropriate caution. This is not necessarily the case with computer generated maps that can inspire a false sense of confidence. To address this, in the GIS version the reliability of all data used is tracked and a key map is displayed showing the reliability for the different parts of the area. A second key map identifies any areas where calculations have exceeded the application bounds of a model and limiting values have been used. These calculations are also flagged in the "Fire" program (Muller, 1990,1993).

WTA is intended primarily as a planning tool, not to provide real-time fire modelling for fire suppression support. The potential HFROS and Byram's Intensity are calculated for all parts of the area under consideration, but there is no attempt to model the spread of individual fires as do other DSSs such as the National Bushfire Model (NBM, Beer, 1990,1991), PREPLAN (Kessell and Good, 1980, 1985), FIREMAP (Vasconcelos and Guertin, 1992), and the Wildfire Incident Management System (WIMS, Beck, 1989a). However, much of the data required to support suppression decisions is the same as that used by the WTA, and the hard copy WTA data maps showing values, slope, fuels, and fire behaviour provide invaluable information during fire suppression, particularly where more sophisticated computer based systems and facilities are not available.

Wherever possible, direct input values are mapped and modelling in minimised as each layer of modelling inevitably introduces error. Some modelling is done where data is not available. For example canopy density (required to determine applicable wind ratio) is modelled where cutting is known to have occurred since last interpretation from remote sensing. Environmental gradients such as used in PREPLAN (Kessell and Good, *op. cit.*) are avoided, and vegetation is mapped directly from remote sensing.

Many support systems rely on a GIS. Whilst GIS is most useful to address the complexities involved, such systems cannot be used where data is not available in a suitable digital format. Acquisition of such data is time consuming (and often expensive), and in the interim the manager must confront the same problems and make management decisions. The WTA provides a framework to support planning decisions which is not dependant on GIS. It can utilise GIS, manual map data, or a mixture of both. However, the manual preparation and regular update of maps can be slow and tedious, and this limits the potential for more detailed examination of alternative scenarios. This is facilitated by the GIS version of the WTA. As this was developed for strategic planning purposes, a plotter is used for output (ie not screen graphics) and it is not real time. However, alternative maps to enable comparison of "what if" scenarios can be readily plotted where digital input data for the different scenarios is available.

WTA is a decision support system, not a decision making system - it does not replace the manager with an automated process, but provides a logical framework to consider all available information on contributory factors, to enable sensitivity analyses on these factors, and thus aid better management decisions. A series of map overlays provide the information required to make the best decisions, and exposes where uncertainties in the data may be. The manager is provided with all essential information on which to assess alternatives when reaching a decision.

An index similar to the hazard rating systems developed by McRae (1991) and Morris and Barber (undated) was initially sought as it is simple to use when subsequently determining priorities such as for allocating scarce resources, but was not pursued because the perceived disadvantages and limitations were considered to outweigh this benefit. The most effective response to counter the threat cannot be determined from an index as it provides no information on its component parts. Knowledge of the relative contribution of each factor is needed to determine the best response. The unthinking application of a transparent index can result in poor decisions. For example, to carry out prescribed fuel reduction burning or increase equipment levels is not the best action if the major component of the threat is the high probability of ignition and the ignition source can be removed.

Further, an index value implies a level of accuracy that cannot be sustained by the precision of either the models or data currently available. Whilst some relativities between the factors which contribute to the wildfire threat can be stated with confidence, there is not sufficient information for an objective and accurate rating to be made in all cases. It is preferable that these uncertainties are exposed to decision makers, rather than hidden in an index.

Whilst an index cannot be used to determine the appropriate action, indices are useful and valid to rank priorities once the appropriate action has been determined from an analysis of all factors. Such an index based on the WTA parameters is used to determine burn priorities in the many areas of Western Australia where burning is considered to be the most appropriate response to the identified threat.

Field managers must not only make the best decisions using all the information available, but they must be able to justify them. Although prompted in part by the reduction in resources for fuel reduction burning, the WTA is much more than merely a justification for burning; it provides a logical basis for all necessary fire protection actions, including prescribed burning for fuel reduction where this is the most effective way of minimising a wildfire threat. Its usefulness became rapidly apparent immediately after its initial introduction as illustrated by the following two examples.

Case Study 1

Considerable concern regarding the future fire management of a proposed new National Park was being expressed by both neighbours and conservation groups. At a workshop arranged to exchange information participants were provided with the WTA maps for the area, invited to amend any factual data presented that they believed was incorrect, formed into small syndicates and asked to propose acceptable fire protection solutions. The proposals were remarkably uniform and in line with the land management agency's intent. Whilst a few individuals refused to acknowledge any but their own prejudices, the overwhelming majority, when presented with information from a much broader perspective, reached similar conclusions. A cynic has stated that good planning is achieved when all opposing parties are equally unhappy. In normal circumstances this unhappiness is directed at the planner. The use of the WTA reduced the resentment against the management agency by focusing on the issues, rather than the manager.

Case Study 2

A manager's request for additional (expensive) aerial surveillance over a recognised very high threat area was questioned. The high values, hazards (potential fire behaviour) and moderate risks were obvious, but the WTA showed that the area already had excellent detection through neighbours and a more distant spotter circuit. The marginal gain from the additional expenditure on improved detection was not warranted. Much greater impact could be achieved through additional risk and hazard reduction.

Using the logical framework of the WTA facilitates resolving disagreement on proposed action by helping to quickly eliminate areas of agreement and focussing on the specific concerns. The potential for discussion to degenerate into acrimonious general argument is reduced when specifics are discussed. As well as its use for reducing conflict and explaining decisions, the WTA is used in Western Australia for strategic and local planning, to allocate priorities for scarce resources, and provide measures of performance (Muller, 1993a).

WTA is a dynamic process of continual improvement. Improvement commences with the requirement to formalise opinion. The written word makes people honest. More care is taken when people are required to commit themselves to paper, and be held accountable for their statements. Improvement continues as the WTA maps are discussed/criticised/defended. The WTA invites such discussion. The greater the number of people involved in its use the better the models, definitions, and final information base; in particular the more accurately will the values groupings reflect those of society as a whole. The structured approach of the WTA provides an excellent basis for interested persons or groups to contribute to the information on which the decisions are based.

Continued use will ensure that fire management decisions are based on the best available information.

Appendix 1 - Equations used for modelling HFROS in the WTA

Slope

The equation of Noble *et al. (op. cit.)* for McArthur's slope corrections for HFROS has been applied to all equations, although the validity has not been verified experimentally for all fuels.

$$SLCF = \exp(0.069 * Slope(^0))$$

Wind Ratio

All equations are expressed to use wind at 1-2 metres above the ground. ie the wind at the fireground.

$$WINDfg = TW/WR$$

where

WINDfg= wind speed at 1 - 2 m.

TW = wind speed at a 10m tower in the open

WR = ratio between tower wind and wind at 1 - 2m.

Forest Fire Behaviour

The equation and application bounds quoted by Beck (*1989*) used to calculate HFROS in dry sclerophyll forests in Western Australia (predominantly Jarrah forest types) is:

$$HFROS = (Yj + Aj * \exp(WINDfg * Nj)) * FQCF * SLCF$$

where:

$Yj = 27.29 - 2.38 * SMC + 0.045 * SMC^2$

$Aj = 47.56 * SMC * \exp(-0.58 * SMC) + 6.67$

$Nj = -0.0013 * SMC^{1.60} + 0.43$

SMC = Surface moisture content of the litter fuels.

FQCF = fuel quantity correction factor

(Application bounds 3 > SMC > 26%)

0 > WINDfg > 11.2 km/hr)

and for wet sclerophyll forests (predominantly Karri forest types) by:

$$HFROS = (Yk + Ak * \exp(WINDfg * Nk)) * FQCF * SLCF \quad m/hr$$

where

$$Yk = 3.39 - 155.41 * SMC^{-3.34}$$

$$Ak = 103.95 * SMC^{-1.04}$$

$$Nk = -0.0084 * SMC + 0.59$$

(Application bounds 3 > SMC > 25%)

0 > WINDfg > 7.2 km/hr)

Beck's (*op. cit.*) equations for fuel quantity correction factors for application within specified SMC% and available fuel quantity (AFQ) ranges, are used:

$$FQCF_{(K)} = 0.95 / (1 + 957.74 \exp(-0.52 * AFQ)) + 0.16$$

(Application Bounds 5.0 < AFQ < 17.0

3.0 < SMC < 26.0)

$$FQCF_{(K)} = (5.08 + 6.26 * AFQ) / 111.5$$

(Application Bounds 17.1 < AFQ < 64.0

3.0 < SMC < 9.9

$$FQCF_{(K)} = (17.35 + 1.70 * AFQ) / 46.25$$

(Application Bounds 17.1 < AFQ < 64.0

10.0 < SMC < 18.9

$$FQCF_{(K)} = (10.88 + 0.46 * AFQ) / 18.70$$

(Application Bounds) 17.1 < AFQ < 64.0

19.0 < SMC <26.0

$$FQCF_{(NJ)} = 1.02 / (1 + 7266.83 * \exp(-1.36 * AFQ)) + 0.10$$

(Application Bounds 2.5 < AFQ < 8.0

3.0 < SMC < 26.0

$$FQCF_{(NJ)} = (6.03 + 5.81 * AFQ) / 53.44$$

(Application Bounds 8.1 < AFQ < 25.0

3.0 < SMC < 9.0

$$FQCF_{(NJ)} = (11.19 + 2.92 * AFQ) / 35.02$$

(Application Bounds 8.1 < FQ < 25.0

9.1 < SMC < 18.0

$$FQCF_{(NJ)} = (0.055 + 0.0023 * AFQ) / 0.074$$

(Application Bounds 8.1 < AFQ < 25.0

18.1 < SMC < 26.0

$FQCF_{(PR)}$ = AFQ * (-0.0065 * SMC + 0.21) + (1.31 - 0.47 / (1 + 33.99 * exp(-0.36 * SMC)))

(Application bounds $4.0 < AFQ < 25.0$
$3.0 < SMC < 35.0$

$FQCF_{(PP)}$ = AFQ * (-0.0061 * SMC + 0.24) + (1.28 - 0.49 / (1 + 38.96 * exp(-0.25 * SMC)))

(Application bounds $4.0 < AFQ < 25.0$
$3.0 < SMC < 40.0$

Whilst Beck (*op. cit.*) has also derived equations for AFQ, these are not used. The corrections for available fuel vary mainly during the transitional drying period from winter to summer and have their main application for prescribed burning. There is little variation during the summer conditions which are the prime focus of the WTA, so the available fuel for summer conditions can be predetermined and used as the input.

Surface moisture contents for forest litter fuels other than Jarrah are derived via Beck's equations:

$SMC_{(SJ)}$ = 1.12 * SMCnj
(southern jarrah fuel type)

$SMC_{(K3\&6)}$ = 1.20 * $SMC_{(NJ)}$ + 0.90
(karri type 1 and 2)

$SMC_{(K1\&2)}$ = 1.61 * SMCnj + 1.70

$SMC_{(K4\&5)}$ = 1.53 * SMCnj - 0.10

(Application bounds $4 < SMC_{(NJ)} < 50$
$5 < SMC_{(SJ)} < 56$
$6 < SMC_{(K3\&6)} < 60$
$7 < SMC_{(K4\&5)} < 74$
$9 < SMC_{(K1\&2)} < 80$)

and

$SMC_{(PP)}$ = 0.74 * SMCnj + 1.51
(*P.pinaster* needlebed)

$SMC_{(PR)}$ = 0.86 * SMCnj + 1.02
(*P. radiata* needlebed)

$SMC_{(PS)}$ = 0.66 * SMCnj + 1.40
(*P. pinaster* slash aerated needles)

$SMC_{(RS)}$ = 0.77 * SMCnj + 2.29
(*P. radiata* slash aerated needles)

(Application bounds $5 < SMC(NJ) < 80$

$5 < SMC_{(PP)} < 63$

$4 < SMC_{(PS)} < 56$

$5 < SMC_{(PR)} < 70$

$5 < SMC_{(RS)} < 64$)

Grassland Fire Behaviour

All the equations in the WTA have been expressed to use wind at 1-2 metres. For grass fuels the equation developed by Noble et al (*op. cit.*) which used the 10 metre tower wind has been modified as follows:

HFROS = 0.13 * F * SLCF* 1000 m/hr

where

F = 2.0 * exp(-23.6 + 5.01 * ln(curing) +0.0281 * temp - 0.226 * $(RH)^{-2}$ + 0.633 * $(1.33 * WINDfg)^{-2}$)

RH = relative humidity %

temp = temperature (^0C)

(Application bounds F $\leq$ 100,
WINDfg $\leq$ 45 km/hr,
curing > 70%)

The wind ratio factor (1.33) used is the 'rule of thumb' value quoted by Cheney *et al.* (1989).

Hummock Grassland (Spinifex) Fire Behaviour

The equation used (after Burrows *et al.*, 1990) is:

ROS = 3.9 * $(WINDfg)^2$ - 82.08 * MC% + 5826.36 * cover + 43.5 * temp - 4935.29) * SLCF

(Application bounds WINDfg <= 40 km/hr
12 => MC% <= 31 (moisture content of entire clump)
cover : application bounds not set: experimental bounds 40-50%)

This equation has not been validated for hummock grasslands other than the experimental area.

Shrublands Fire Behaviour

An unpublished preliminary equation developed by L. McCaw (pers. comm.) for Mallee Heath shrublands is used as a interim model. This will be replaced if required when McCaw completes analysis of all experimental data, and a final equation is published. The current equation applied is:

ROS = (90.637 * WINDfg * 2.5 + 1.5) * SLCF

(Application bounds WINDfg <= 20 km/hr
SMC% <= 8)

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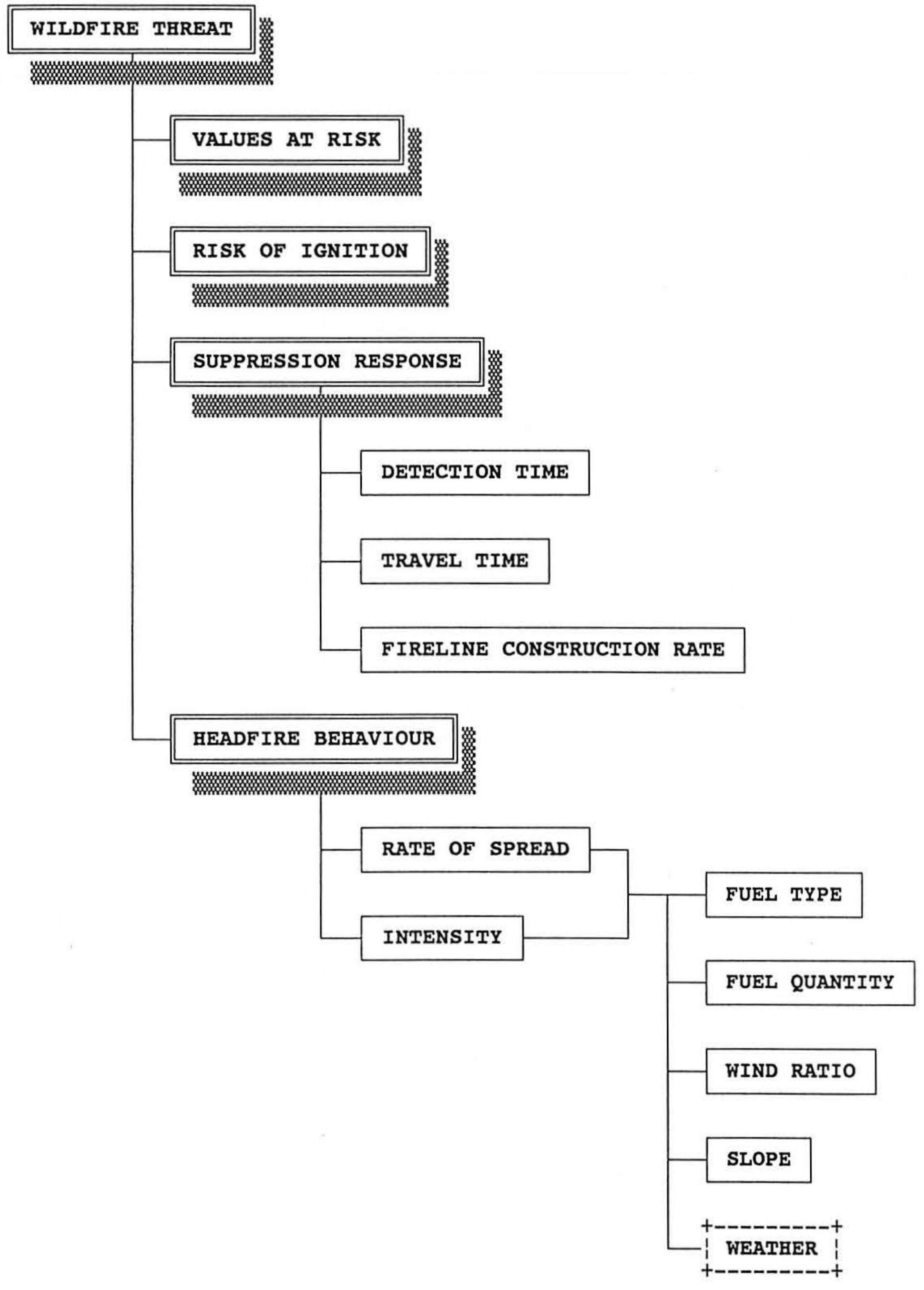
FIG 1

WILDFIRE THREAT ANALYSIS MAPPING HIERARCHY



VALUE THREAT ZONES

- Within 3km NW-E/1km in other directions of Group 1 values
- Within 3km NW-E/1km in other directions of Group 2 values
- Within 3km NW-E/1km in other directions of Group 3 values
- Within 3km NW-E/1km in other directions of Group 4 values
- Within 3km NW-E/1km in other directions of Group 5 values
- Within 3km NW-E/1km in other directions of Group 6 values
- Other areas

RISK OF IGNITION

- HIGH (potential ignitions on >4 days/month)
- MODERATE (1-4 sources/month)
- LOW (<1 source/month)

SUPPRESSION RESPONSE

- POOR (> 6 hours) Response + Production time
- SLOW (4.1-6 hours) Response + Production time
- MODERATE (2.1-4 hours) Response + Production time
- RAPID (0.6-2 hours) Response + Production time
- IMMEDIATE (< 0.5 hours) Response time only**

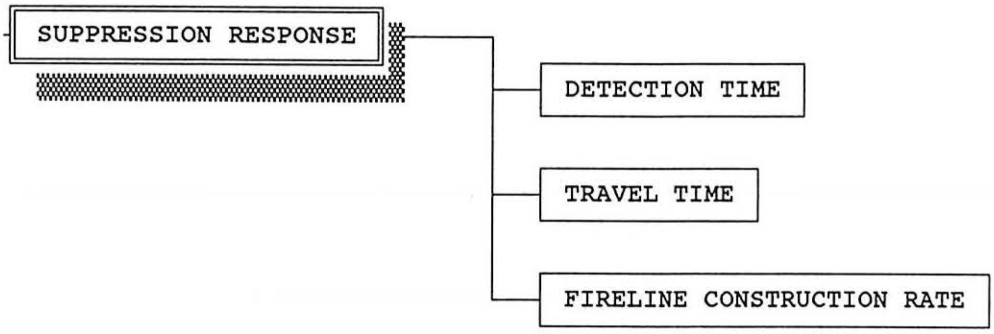
** In the first 0.5 hours the fire is considered still in the developing stage, suppression difficulty is at a minimum, and length of fireline required is not considered significant in the overall time.

HEADFIRE BEHAVIOUR

- Direct attack not possible. intensity > 3000kW/m and/or ROS > 800m/hr
- Ground attack not possible. intensity 2-3000kW/m and/or ROS 4-800m/hr
- Machine attack possible. intensity < 2000kW/m and/or ROS < 400m/hr
- Hand attack possible. intensity < 800kW/m and/or ROS < 140m/hr
- Readily suppressed. Intensity < 800kW/m and/or ROS < 60m/hr

Temp: 24.5C RH: 36% SMC: 8%
Wind Speed: 24.0km/h FDI(NJ): 80.0m/h

Username: VOOOP
Date/Time: 9/28/1993 10:43 AM
Plotfile: &TAMPLOT:CHRIS_ALL_A3.PLT


SUPPRESSION RESPONSE
DETECTION TIME
TRAVEL TIME
FIRELINE CONSTRUCTION RATE

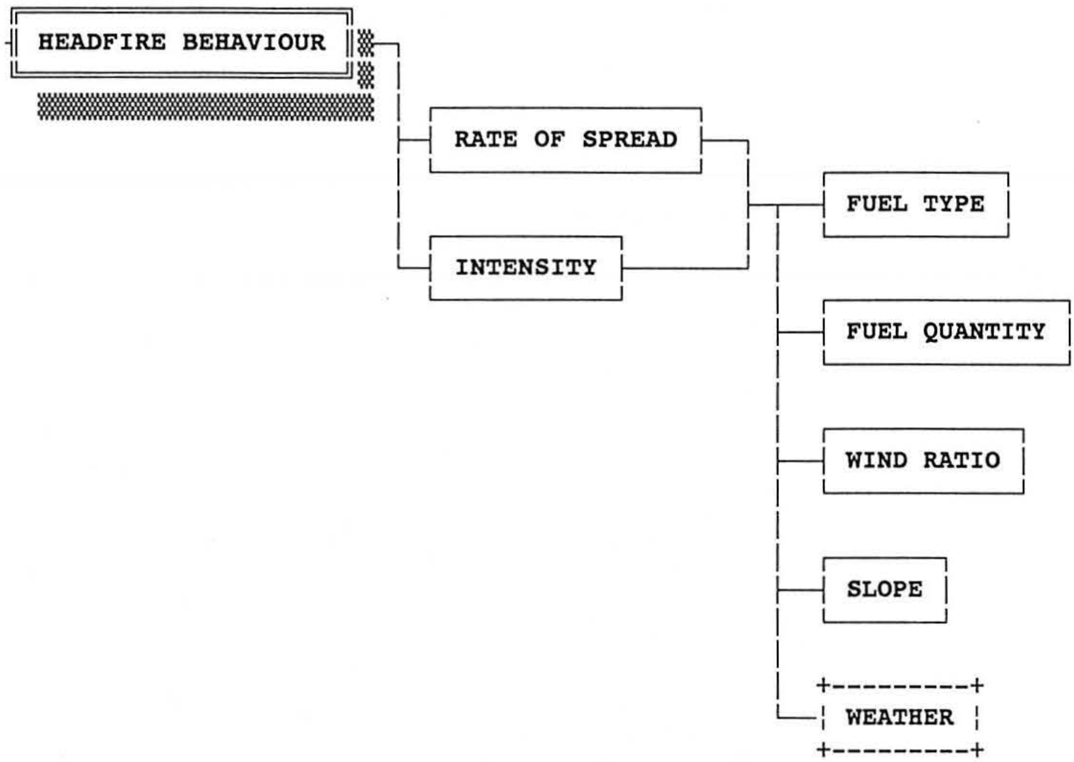

HEADFIRE BEHAVIOUR
RATE OF SPREAD
INTENSITY
FUEL TYPE
FUEL QUANTITY
WIND RATIO
SLOPE
WEATHER

TABLE 1

CLASSIFICATION OF VALUES FOR WILDFIRE THREAT ANALYSIS IN SOUTH WEST FOREST AREAS OF WESTERN AUSTRALIA

GROUP I VALUES: (RED)

* Human Life - Areas where there is a significant threat to lives in the event of wildfire;

  Eg: Bush townships, settlements, summer camps etc., where access and surrounds and/or the numbers and ages of the population makes evacuation or safe refuge impracticable. Does not include sites where adequate refuge exists (eg beachside camp-sites) or relatively low numbers of people and good access provide for reasonable egress/evacuation.

GROUP II VALUES: (ORANGE)

* High property values; possible risk to life in event of fire, but generally low.

  Eg., developed 'Special Rural Sub-divisions' (moderate density housing - block size 2-10 ha) with good access/egress.

* Sole known sustainable populations of fire vulnerable threatened species (as defined below).

GROUP III VALUES: (YELLOW)

* Local sustainable populations of fire vulnerable threatened spp.
* Major softwood plantations (> 100 ha) 8-20 year old.
  (ie maximum investment, minimum salvage, and high re-establishment costs following fire).

GROUP IV VALUES: (GREEN)

* Scientific reference areas not to be burnt.
* Known sustainable populations of designated uncommon fire vulnerable spp.
* Major Plantations

Softwood	> 100 ha, < 8 or > 20 years old.
	< 100 ha, 8-20 year old
Hardwood	> 250 ha, < 5 year old.

* Hardwood regeneration/saplings/poles in areas designated for timber production - consolidated areas > 250 ha .
* Scattered houses near CALM land.

GROUP V VALUES: (LIGHT BROWN)

* Developed farmland. (Exceptional crop/stud values at risk may be rated higher).
* Other plantation areas (Hardwood & Softwood).
* Scattered patches of regeneration/sapling or pole regrowth.
* Harnessed catchments with erodible soils.
* Fire vulnerable anthropological/historical sites.
* Outstanding landscapes (on which fire would have a long term impact).
* High erosion susceptible areas.
* Restricted populations of common fire vulnerable spp.

GROUP VI VALUES: (LIGHT BLUE)

* Common fire vulnerable species.

GROUP VII VALUES: (UNCOLOURED)

* 'Base' values such as multiple use forest or park areas. These are not separately highlighted on the map.

(Table ctd. next page)

TABLE 1 (Ctd.)

Definitions:

Sole Population:

Includes discreet groups (populations) in a restricted area that are susceptible to damage by a single wildfire event.

Local Populations:

One of several known populations.

Sustainable:

The population can reproduce and sustain itself in the wild.

Fire Vulnerable:

Vulnerability may depend on the stage of the species and recent fire history. For example it is unlikely that a single fire event will be catastrophic to most plants, but it would render an obligate seeder vulnerable for a period till a sufficient seed store is re-established.

Classifications often change with time and must be regularly reviewed.

Threatened

Any animal taxon or plant declared under the Wildlife Conservation Act as 'likely to become extinct or rare'.

Threatened species rate very highly as they are irreplaceable if lost. Care must be taken not to assign the classification 'fire vulnerable' lightly. In the absence of complete knowledge of an individual species Wildlife Research staff are required to provide an expert written opinion based on best knowledge (Eg closely related species), or conduct necessary research to justify specific protection against wildfire.

TABLE 2

IGNITION RISK CLASSES

HIGH: (potential ignitions on >4 days/month)

Examples:

Regular path of summer storms and lightning strikes recorded.

Areas within spotting distance (up to 3km) of active land clearing involving burning, or other planned burning (eg regeneration burning, stubble burning)

High visitor use areas involving camping, barbecues, or marron fires.

Recent history of ignitions from other sources. (Eg, deliberate lightings) and activity pattern believed unchanged.

MODERATE: (1-4 sources/month).

Examples

History indicates little/no past ignition, moderate visitor use, reasonable access for visitors.

LOW: (<1 source/month).

No history of fires. Little/no human activity at or near site, poor access for visitors.

Summer storms rare. No recorded lightning strikes.

TABLE 3

SUPPRESSION RESPONSE CLASSES

POOR:	Response* + Production# time	> 6 hours
SLOW:	Response + Production time	4.1-6 hrs
MODERATE:	Response + Production time	2.1-4 hrs
RAPID:	Response + Production time	0.6-2 hrs
IMMEDIATE:	Response time only **	< 0.5 hrs

* Response Time = Detection Time + Travel Time

Production Time = Time to construct 1000m fireline

** In the first 0.5 hours the fire is considered still in the developing stage, suppression difficulty is at a minimum, and length of fireline required not considered significant in the overall time.

TABLE 4

HEADFIRE BEHAVIOUR CLASSES

Indirect attack unlikely to succeed
Intensity > 3000 kW/m in forest
Intensity > 8000 kW/m shrubland and grassland

Direct attack not possible/unlikely to succeed.
Intensity > 2000 kW/m and/or ROS > 400 m/hr in forest
Intensity > 2000* kW/m and/or ROS > 1000 m/hr in shrubland
Intensity > 5000 kW/m and/or ROS > 6500 m/hr in grassland

Machine and tanker attack possible
Intensity < 2000 kW/m and/or ROS < 400 m/hr in forest
Intensity < 2000* kW/m and/or ROS < 1000 m/hr in shrubland
Intensity < 5000 kW/m and/or ROS < 6500 m/hr in grassland

Hand tool attack possible
Intensity < 800 kW/m and/or ROS < 140 m/hr) in forest and shrubland
Intensity < 800 kW/m and/or ROS < 300 m/hr in grassland

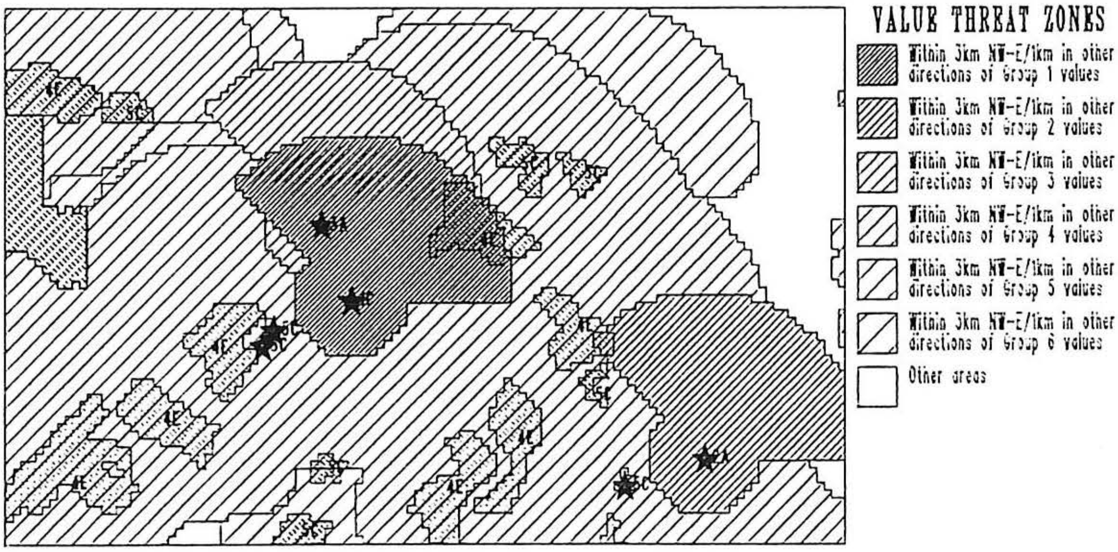
Readily suppressed.
Intensity < 800 kW/m and/or ROS < 60 m/hr in all fuels

* This assumes fire requires fireline construction to provide access to tankers, and the same limits as for forest apply. Where access permits direct attack with water, this should be 5000 kW/m applies.

TABLE 5

GUIDE TO WIND RATIOS

Open Grassland		1.33 : 1
Flats, low coastal heath		2 : 1
Mallee Heath Shrublands	2.5 : 1	
Jarrah, Wandoo,	30% canopy, ridge	3 : 1
Jarrah, Wandoo	30% canopy, lower slopes	4 : 1
	60% canopy, ridge	4 : 1
	60% canopy, lower slopes	5 1
Thinned Pine Plantations	4 : 1	
Southern Jarrah		5.5 : 1
Karri 3 & 6, unthinned pine plantations Eucalypt plantations		6 : 1
Karri 4 & 5		7 : 1
Karri 1 & 2, Karri regrowth		9 : 1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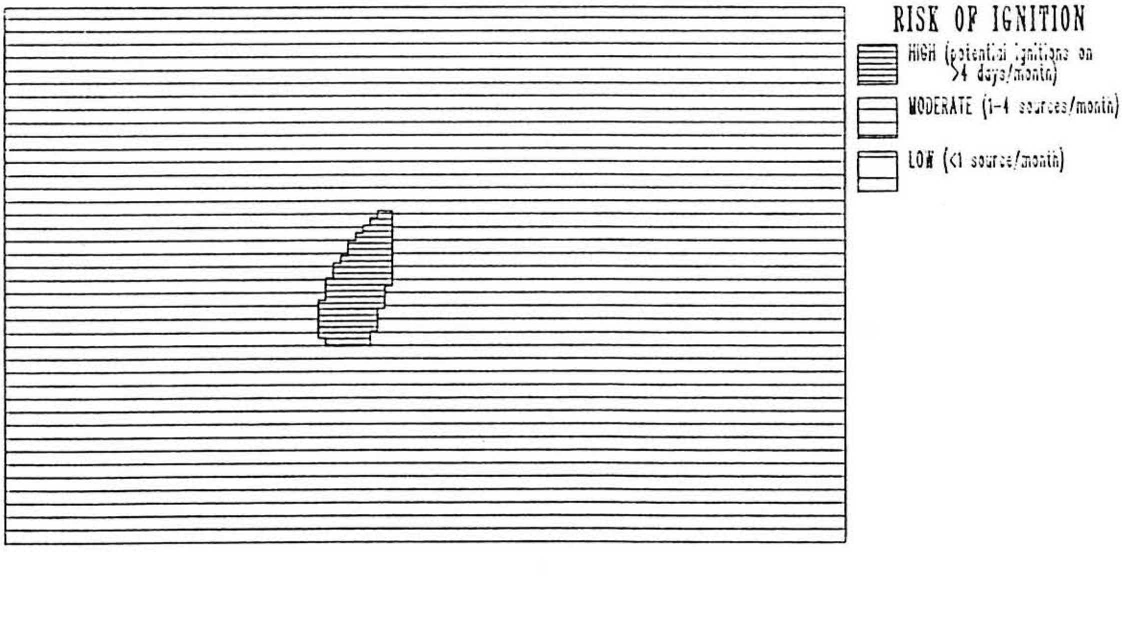
Other areas


RISK OF IGNITION
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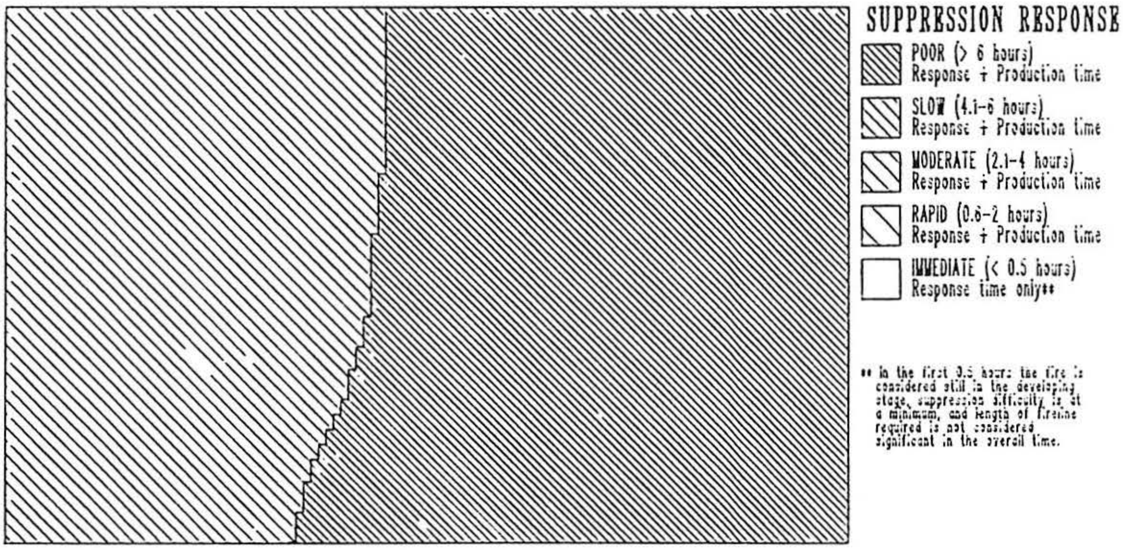
MODERATE (1-4 sources/month)
LOW (<1 source/month)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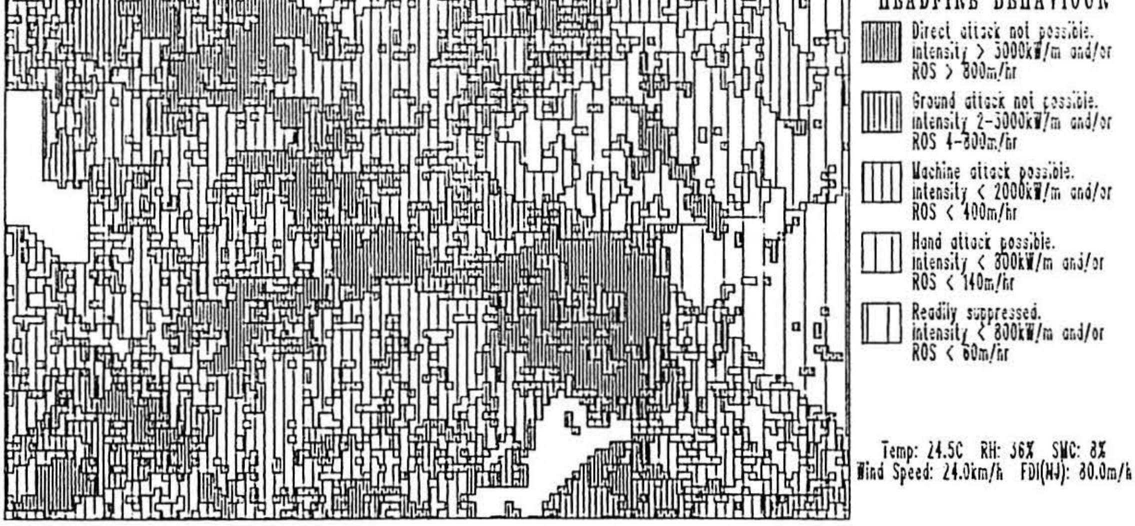
HEADFIRE BEHAVIOUR
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Machine attack possible. intensity < 2000kW/m and/or ROS < 400m/hr
Hand attack possible. intensity < 800kW/m and/or ROS < 140m/hr
Readily suppressed. intensity < 800kW/m and/or ROS < 60m/hr
Temp: 24.5C RH: 36% SMC: 8%
Wind Speed: 24.0km/h FDI(MJ): 80.0m/h

APPENDIX THREE

SMOKE MANAGEMENT IN SOUTH-WEST FORESTS OF WESTERN AUSTRALIA

SMOKE MANAGEMENT

IN SOUTH-WEST FORESTS OF WESTERN AUSTRALIA

R Sneeuwjagt, Manager Fire Protection Branch
Department of Conservation and Land Management, Western Australia

INTRODUCTION:

The Department of Conservation and Land Management of Western Australia (CALM) carries out an extensive prescribed burning program in the south-west forests, in order to reduce flammable fuels and mitigate the undesirable social, economic, environmental and human problems caused by destructive wildfires.

In part, CALM's burning program stems from the direction to do so, made by a Royal Commission which enquired into the widespread bushfires in summer 1961, which destroyed Dwellingup and several other settlements.

In part, CALM is also responding to the Bush Fires Act which requires landowners to take responsible action to minimise fire hazard. Whilst CALM is not a landowner in this sense, it has a duty of care as a neighbour to carry out appropriate works which reduce the probability of fire spreading onto neighbouring properties.

Prescribed burning is carried out by CALM district staff often with the assistance of volunteer bush fire brigades. The work is done in accordance with a Fire Management Plan for the district which sets out the areas to be burnt and the frequency and season of the burns. Fuel reduction burns are concentrated in the areas where the highest values need to be protected from potential wildfires. Other planned burns are lit for a variety of purposes, including wildlife habitat management and forest regeneration.

The fuel-reduced areas which result from prescribed burning have enabled fire fighters to suppress many potentially serious wildfires, to the extent that there have been very few major fires in the past thirty two years in the jarrah forest.

Unlike other Australian states, during this time no fire fighter has been burnt to death in a forest fire in Western Australia, nor has there been any loss of civilian life within the forest zone.

Land managers have a responsibility to ensure that prescribed burning is strategic, timely, appropriately and correctly applied. This responsibility applies to the impacts of smoke from prescribed burning on the community. Smoke from these burns can be more than a nuisance as it can reduce visibility along highways, close airports and upset metropolitan residents because of perceived health risks associated with smoke concentration.

SMOKE AND WEATHER CONDITIONS:

Fuel reduction burns in the south-west forests are normally carried out in the spring, early summer and autumn months early in the cycle of anticyclones which move from west to east across the southern half of the continent.

Burns in the northern jarrah forest can be carried out on the westerlies which occur as the anticyclone begins its easterly movement across the bottom part of the State. The south-easterly winds are most often used for the southern parts of the forest zone as these coincide with moderate weather conditions and suitable fuel moisture levels on the forest floor.

The winds in the southern quarter provide the safest conditions under which to light prescribed fire as these conditions are generally characterised by mild temperatures, relatively moist fuels, predictable and moderate wind speeds and relatively stable atmospheric conditions. Unfortunately those conditions that are normally suitable for a safe effective fuel-reduction burn in the forest are most often the same that lead to poor smoke dispersal and high smoke accumulation.

South-easterly winds transport smoke from burns in the northern jarrah forests directly into Perth. Further south, smoke can be carried by the south-easterlies over the Indian Ocean from where some of the smoke can be advected back over the coast and Perth by the late afternoon south-westerly sea breeze.

During days of very stable atmospheric conditions this has resulted in a smoke haze in Perth when the visibility index exceeds international standards for several hours overnight. This haze normally disappears in the morning with the dissipation of the nocturnal inversion and the onset of the prevailing easterlies.

High intensity wildfires normally occur on north-east, north or north-west winds. Whilst such fires generate much larger volumes of smoke, the smoke is normally carried south away from population centres. Any "pollution problem" associated with bush fire smoke in Perth is therefore more related to prescribed burning than to wildfires.

MANAGING THE SMOKE:

The Department of Conservation and Land Management has managed smoke in the northern jarrah forest, within one hundred kilometres of Perth, for nearly twenty years. Based on smoke distribution studies conducted by the CSIRO in conjunction with the Forests Department of Western Australia in the early 1970's (Vines et al, 1971), a computer model was developed to make accurate predictions about the fate of smoke plumes from planned burns. The model has been used to determine the maximum size of an area that can be burned at a predetermined distance from Perth so that the air quality in the metropolitan area is not significantly affected. Burn areas within the northern jarrah forest zone are restricted to a size given by the following simplified equation.

Burn area (ha) = Distance from Perth Airport (km) x 20.

For example, the largest burn area for a location 80 km south of Perth Airport is 1600 ha.

This formulae is applied where winds are likely to lead smoke directly into Perth. Larger burns can be conducted only when winds are predominantly from the south-west. Stringent application of these guidelines over the past twenty years has resulted in very rare instances when smoke from northern forest burns has blown directly onto Perth, usually as a result of an incorrect wind forecast.

In 1990 the Environmental Protection Authority (EPA) made CALM aware that smoke haze from southern forest burn operations was exceeding visibility standards on seven or eight occasions, mostly night time, each summer. These instances were detected on three nepholometer recorders located in and around Perth. The origin of these smoke sources were confirmed by LANDSAT images. Figure 1 shows the Visibility Index recorded by the Environmental Protection Authority during November 1990, during which time the accepted visibility standards were exceed on four occasions.

As a result, CALM has undertaken studies into determining the relationship between weather and burn operation factors and the incidence of smoke haze from these southern forest burns (Smith 1991 and 1992).

The studies identified the following factors that may contribute to the incidence and extent of smoke haze in the Perth metropolitan area.

(i) **Atmospheric Stability:**

Atmospheric stability as measured by the rate of temperature change with height. The presence and depth of low-level temperature inversion measured at 7.00 am each day at the Perth airport provided a good guide on the probability of smoke haze occurring in the metropolitan area. The stronger the inversion temperature change, the more likelihood that smoke will accumulate and exceed limits.

(ii) **Total Area Burnt Within a Day:**

The area of prescribed burning that can be conducted without resulting in smoke haze appears to be dependent on the atmospheric instability. Under weak inversion (<3°C change) the total area can exceed 15,000 ha. This area is reduced to about 12,000 ha under moderate inversion (<3-6°C change); and 6,000 ha for strong inversion (7-10°C change). Inversion temperature changes in excess of 10°C were rare and often associated with a west coast trough that prevented any dispersion of smoke haze on the west coast.

(iii) **Burn Concentration:**

The concentration of burn jobs appears to be related to the concentration of smoke. Separation of burns by more than 80km reduces the likelihood of high smoke haze levels recorded in Perth.

(iv) **Wind Direction:**

The transport of smoke from southern burns into Perth occurs predominantly under southerly winds. The incidence of the afternoon seabreeze appears to be strongly related to the occurrence and timing of arrival of smoke haze in Perth.

Winds with a northerly component appeared to reduce the likelihood of smoke haze in Perth.

(v) **Scheduling of Burns:**

Smoke from burns that are ignited later in the day are likely to affect the Perth area after dark. These late burns may also miss the effect of the seabreeze.

A set of smoke management guidelines have been developed over the past three years which take into account atmospheric conditions, wind direction, forecast of seabreeze, location of burn in relation to metropolitan area, the size of burns, location in relation to other large burns, total area likely to be burnt on the day, burn priority and recent history (eg: already partly alight), availability of resources including aircraft for ignition, and incidences of other burn operations undertaken by other agencies.

To assist fire managers to co-ordinate the complex burning program in accordance with these smoke management guidelines, a decision model has been recently developed and applied in 1992/93 and will be further tested in the 1993/94 burning season. This model shown in Appendix 2.

The application of the smoke management guidelines during 1992 resulted in a low incidence of smoke haze in Perth although there was one serious haze occurrence that plagued Perth for three days from 21st to 23rd October 1992, this appeared to be a result of an unusually intense inversion over the Swan Coastal Plain which trapped smoke from wildfires and private burning operations to the north of Perth. CALM's burning operations were cancelled during this period to avoid contributing to the problem.

FUTURE DEVELOPMENTS IN SMOKE MANAGEMENT:

Smoke management has been significantly improved in Western Australia, but it is far from perfect. Unpredicted weather events can still surprise the weather forecasters and fire managers, and re-ignition of unburnt fuels on subsequent days can cause smoke to accumulate over population centres.

There is still much to learn about smoke transport and dispersion. CALM and the Bureau of Meteorology are to conduct a joint study that will hopefully provide a means of accurately predicting the trajectories of smoke parcels on the days of proposed burns. The Bureau's current operational numerical model (RASP) runs a trajectory plotting routine, but the model's grid resolution (150 km) was too coarse to capture the detail required. It is proposed that the use of a mesoscale numerical model with a grid resolution around ten kilometres would be developed by the Bureau to predict the transport of smoke emitted from sources throughout the south-west.

In addition, the Bureau is investigating the synoptic situations during which smoke haze problems have occurred. It is hoped this will help improve the identification of dispersion factors and the development of a Dispersion Index similar to that used in Southeastern United States (Lavdas, 1986).

CONCLUSION:

Whilst the applications of smoke management guidelines and appropriate burning prescriptions will help to minimise the occurrence of smoke haze over Perth, there is no guarantee that it can be eliminated altogether.

The complete cessation of prescribed burning may have short-term impact on the incidence of smoke haze, but will inevitably create another social problem; the cost and tragic impact of destructive wildfires on communities, properties and forest ecosystems in the south-west. It is simply not acceptable to put rural communities and our natural assets at risk to wildfire damage and destruction in an attempt to eliminate occasional bush fire smoke from the city.

ACKNOWLEDGEMENT:

The analysis of burn operations of weather data and smoke haze measurements was conducted by Russell Smith, Fire Protection branch, Bunbury.

The prescribed burning and smoke management decision system was developed by David Ward, Science and Information Division of the Department of Conservation and Land Management, Como, Western Australia.

REFERENCE:

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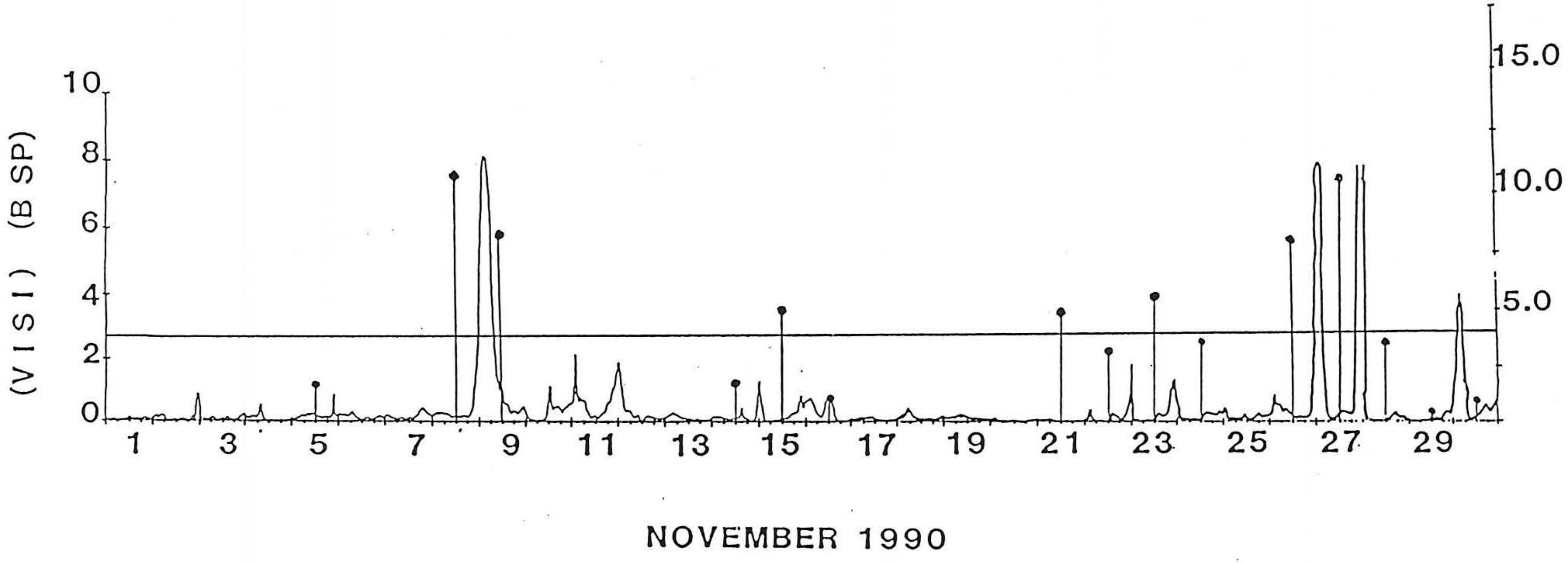
FIGURE 1:

VISABILITY COEFFICIENTS AT HOPE VALLEY AIR QUALITY MONITORING STATION AND TOTAL FOREST AREA BURNT IN NOVEMBER 1990

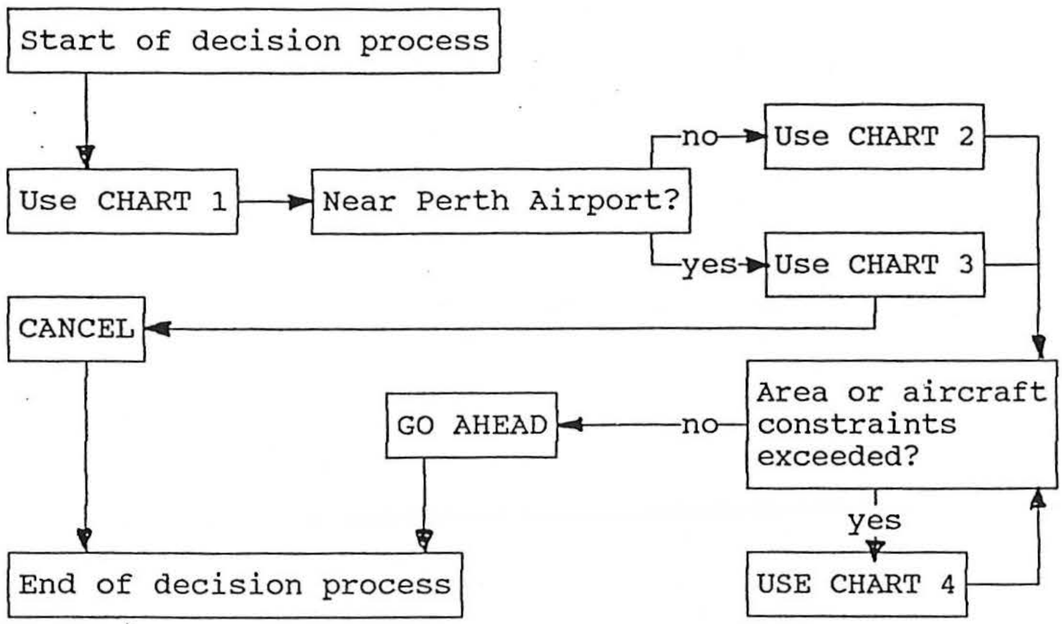


Appendix 2.

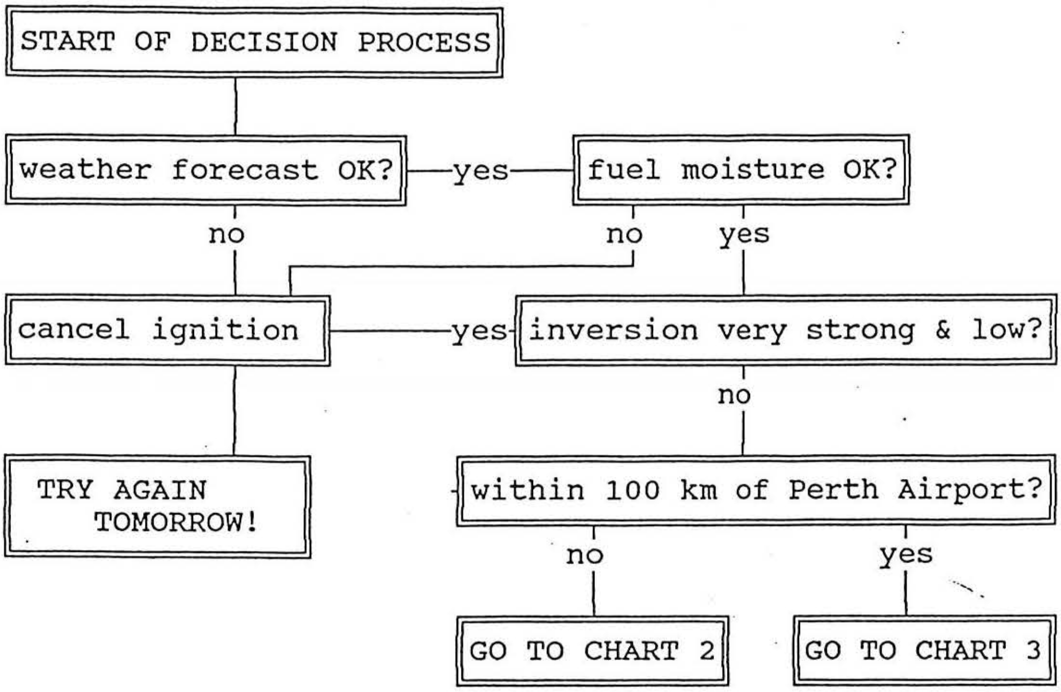
PRESCRIBED BURNING & SMOKE MANAGEMENT DECISION SYSTEM

FOR SOUTH-WEST FORESTS OF W.A.

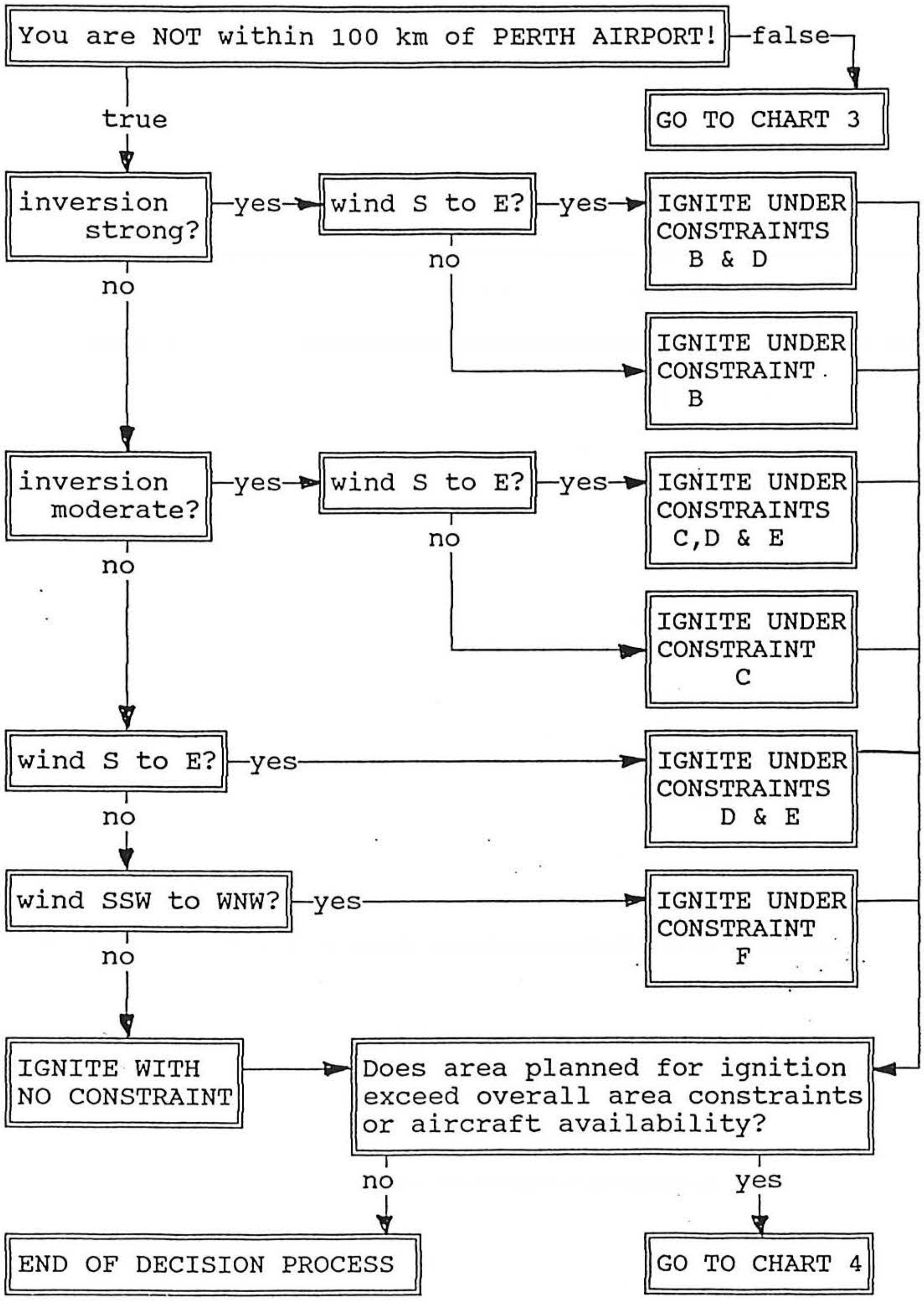
POSSIBLE PATHWAYS OF SYSTEM



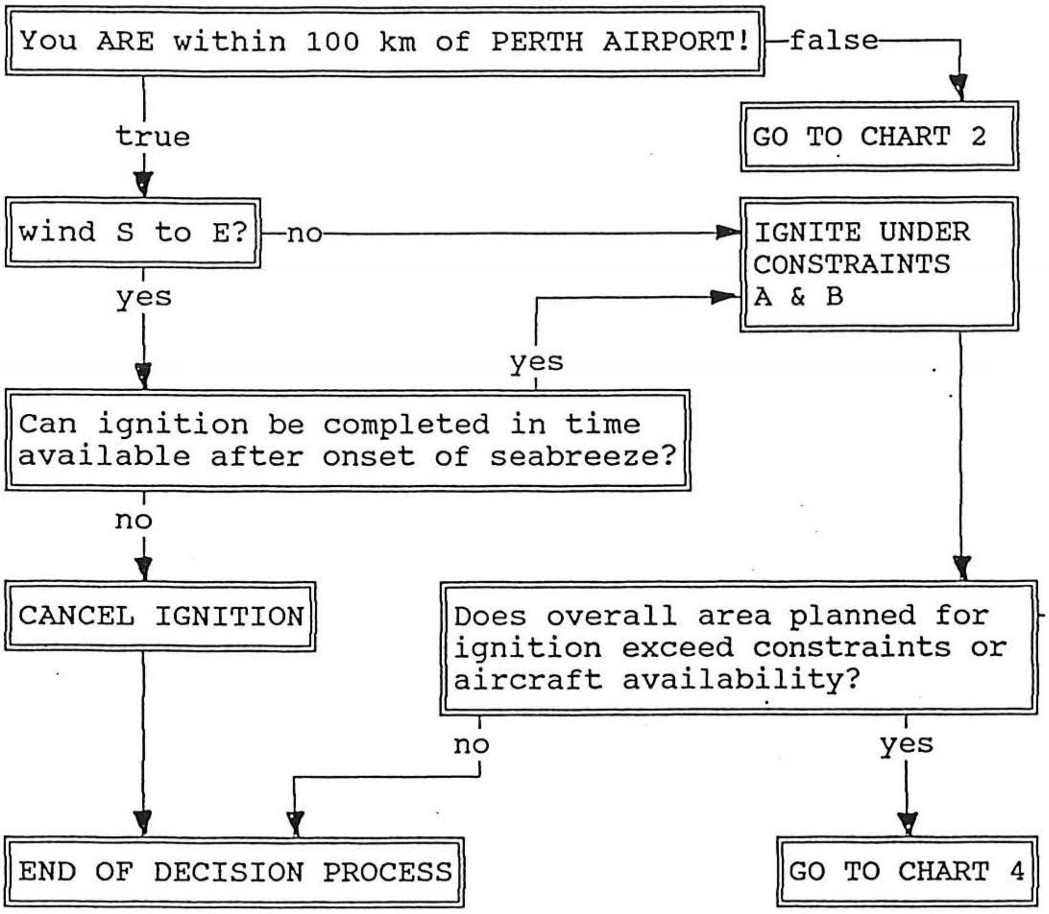
PRESCRIBED BURNING & SMOKE MANAGEMENT - DECISION CHART 1



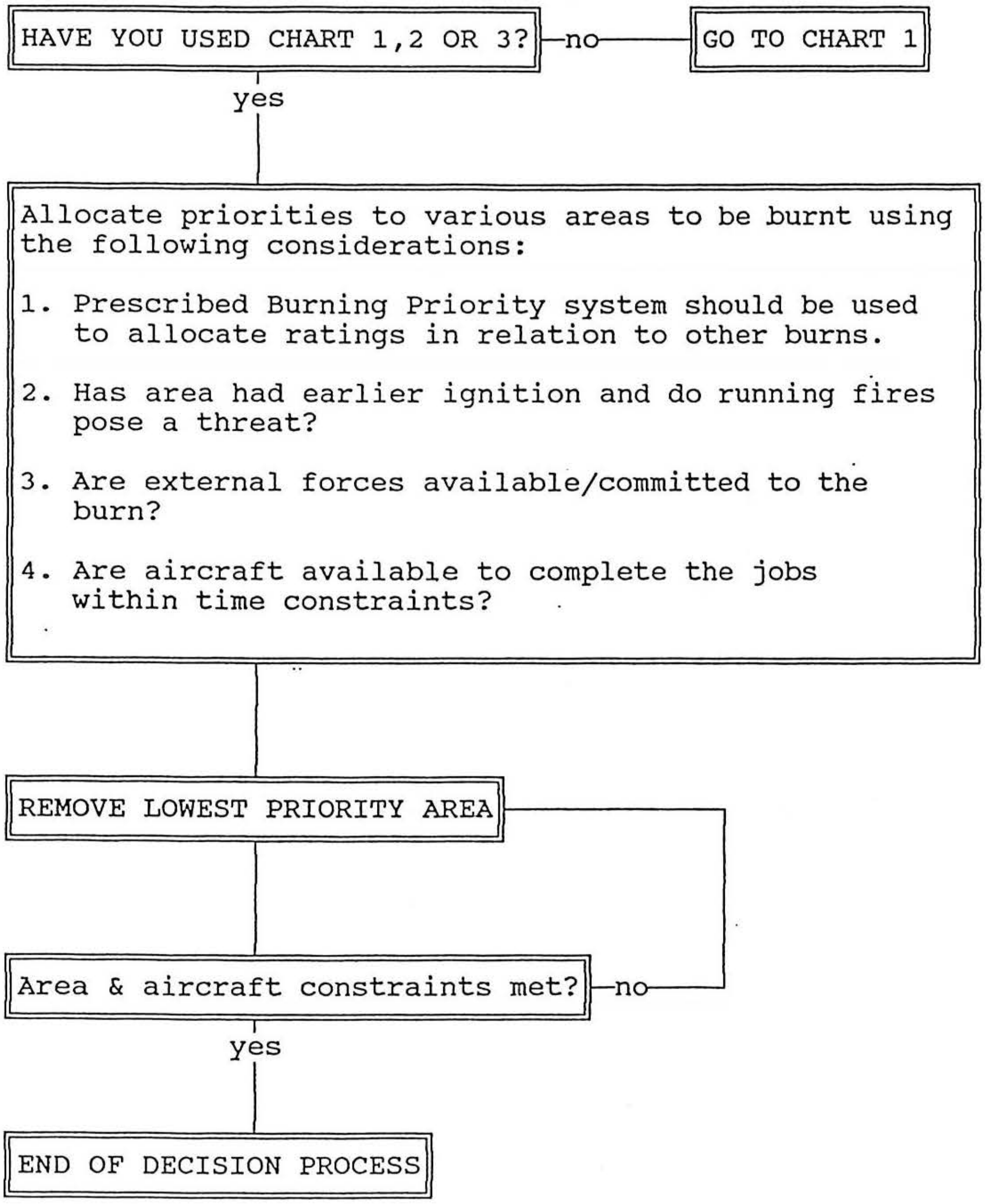
PRESCRIBED BURNING & SMOKE MANAGEMENT - DECISION CHART 2



PRESCRIBED BURNING & SMOKE MANAGEMENT - DECISION CHART 3



PRESCRIBED BURNING & SMOKE MANAGEMENT - DECISION CHART 4



CONDITIONS OF BURNING
A...Individual burn areas limited by ratio rule*.
B...Total area burnt not to exceed 6 000 ha.
C...Total area burnt not to exceed 12 000 ha.
D...Burns greater than 4 000 ha to be at least 40 km from any other burn on first & following day.
E...Total area burnt within any 80 km radius not to exceed 10 000 ha.
F...Total area burnt within any 80 km radius not to exceed 15 000 ha.

* Area = 20 x Distance to Perth Airport [km]

MENT OF CONSERVATION AND LAND MANAGEMENT

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Phone (09) 334 0333
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Please address all correspondence to Executive Director, P.O. Box 104, COMO W.A. 6152

EDIIA

ENV934788

Our Ref:
Enquiries:
Phone:

HON MINISTER FOR THE ENVIRONMENT

MINISTER TO NOTE

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT
- 8 NOV 1993
COMO, W.A.

SMOKE IN PERTH

There is a small amount of smoke arising from CALM prescribed burning in the city this morning. Quantities peaked at 6.00 am and are expected to have declined significantly after 9.00 am.

The smoke is a result of two prescribed burns undertaken in the Mundaring and Jarrahdale areas several days ago. These burns were carried out under south-westerly winds so as to take the smoke away from the city. Unfortunately the smoke drifted back in overnight when it became caught up with the low pressure trough which is currently moving backwards and forwards along the coast. These sorts of conditions are almost impossible to forecast. There has also been a small amount of re-burning in the areas yesterday and the day before.

The situation is not serious from a health or smog point of view but is likely to generate some critical comment from the environmentalists and the media. My response in these situations is to say that we are doing our best to ensure smoke does not come into the city; we cannot always forecast the weather conditions several days in advance; and it is essential that we carry out prescribed burning in the forests near Perth so as to minimise likely bushfire problems later in the summer.

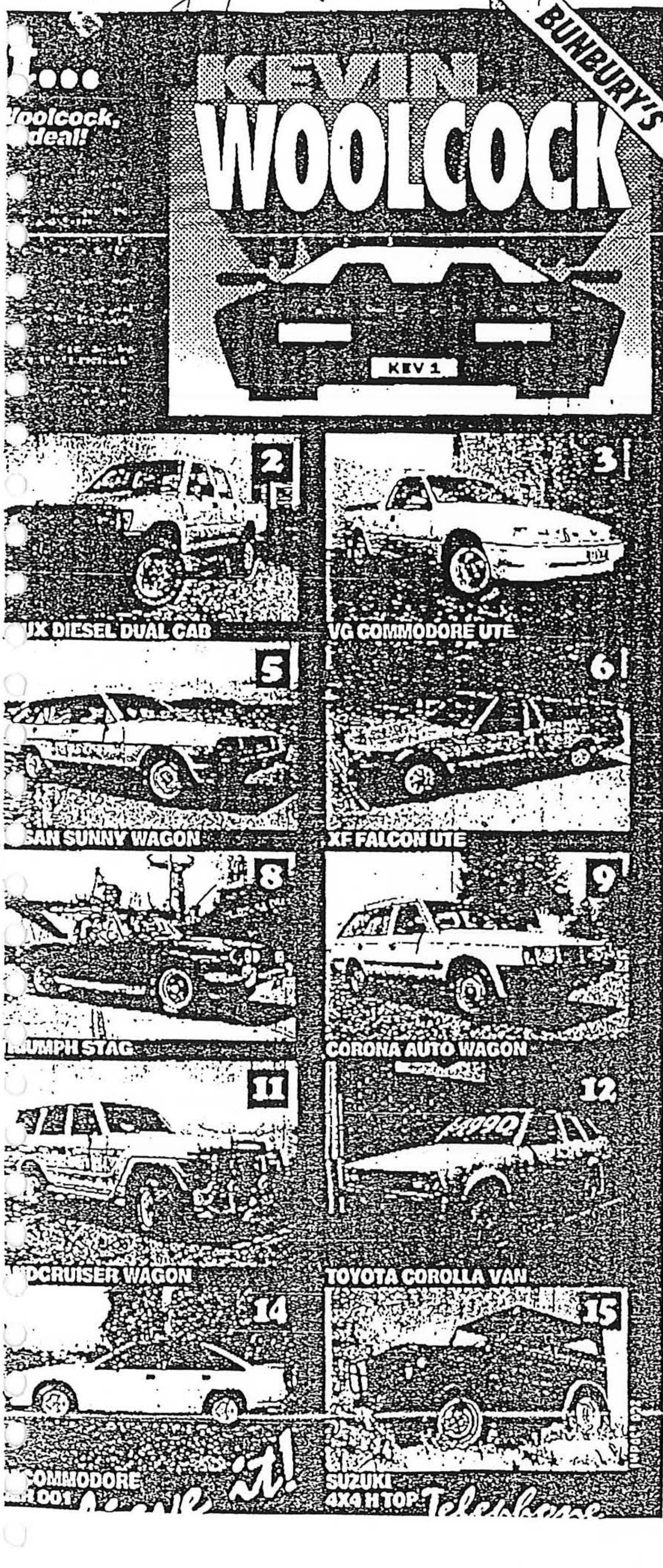
Syd Shea
EXECUTIVE DIRECTOR

21 October, 1993

1. General Manager - to note
2. Records - File 11.11.93
3. Mr. [illegible]
✓ copy on Prof. file pl.

FOLIO DESCRIPTION
Folio No. 001
File No. 034731F0108
Expec. Comp.

9/4/93



EPA will look into burn-off pollution

By SCOTT MACLEAN

THICK smoke which clouded over Bunbury last week has prompted an investigation by the Environmental Protection Authority.

The smoke, which came from the Department of Conservation and Land Management and private burn-offs, filtered through the city last Wednesday and Thursday.

EPA Bunbury regional manager Henk Van der Wiele said the smoke would have affected the health of some Bunbury people.

"We are certainly taking this matter up with CALM because of the severity of the event," he said.

"The level of smoke would have affected people who are sensitive to materials within the emissions. Visibility was also affected, " he said.

But, Mr Van der Wiele said, there would be no long-term effects from the smoke.

CALM senior fire officer Terry Maher said it was unusual for the smoke from the burn-offs, taking place in Busselton, Pemberton and Nannup, to drift as far as Bunbury.

"We always try to avoid putting smoke over large communities, but now and then the unforeseen happens," he said.

"The reason for the burns is for fire protection and forest management.

"The other option to burn-offs — well, just look at the footage of Southern California burning," he said.

Mr Maher said the smoke which fell in Bunbury was the result of a change in air temperature

He said it was unlikely to happen again.

Trading hours to go 'public'

THE State Government will hold a public forum in Bunbury during its review of retail trading hour laws.

Fair Trading Minister Peter Foss said he would be calling for written submissions from all people affected by the Retail Trading hours Act.

Mr Foss said he would also call community forums on regional areas so there was widespread community input into the review.

It is a statutory requirement that the Act is reviewed every five years and the Minister reports to Parliament on:

- The operations of the Act.
- The operations of the Retail Shops Advisory Committee.

noted
Smoke Manager file.

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HON MINISTER FOR THE ENVIRONMENT

SMOKE HAZE ALONG WEST COAST ON 5 NOVEMBER 1993

The hazy conditions that prevail along the west coast this morning are the result of smoke from large bushfires near Geraldton which has been trapped under an intense atmospheric inversion. One of these wildfires burnt out 420 ha of agricultural crop valued at $50,000.

The inversion is the result of a cool south-westerly change underneath an upper warm air mass.

The air circulation along the coast has become trapped by a trough which lies immediately off the west coast.

CALM cancelled 6 aerial burns yesterday, the 4th November, in anticipation of today's conditions which were forecast by the Bureau of Meteorology.

Three prescribed burns near Nannup and Kirup lit earlier in the week were burnt out yesterday to secure their boundaries.

Several other burns in the south-west which have had initial lightings will be burnt out and made safe today.

The Bureau of Meteorology expects hazy conditions to clear late today, although there is a chance that the haze will recur on Saturday morning.

Syd Shea
EXECUTIVE DIRECTOR

5 November 1993

FAXED 5/11

Smoke file