FOREST FIRE MANAGEMENT IN WESTERN AUSTRALIA

R.J. UNDERWOOD and P.E. CHRISTENSEN

Contents

I INTRODUCTION

The jarrah (Eucalyptus marginata) and karri (E. divisicolor) forests of Western Australia cover approximately 1.9 million hectares in the south-west corner of the State (Fig. 1).

The climate of the region is typically mediterranean, with hot dry summers and cool wet winters. Periods when the risk of fire is high, with successive days or weeks of hot dry conditions with strong winds from the interior of the continent, occur every summer. These conditions, together with the inflammability of the forest and the constant presence of two sources of fire - man and lightning - lead to a very high incidence of fire in the forest, and periodically result in devastating fires, such as the Dwellingup fire of 1961 (Luke and McArthur, 1978).

Unlike many of the hardwood forests of Europe and North America, Australia's sclerophyllous forest communities are highly inflammable. Of the many factors which contribute to the flammability of both tree and understorey scrub species, the two major ones are the high content of volatile oil in the leaves (King and Vines, 1969) and the rapid accumulation of inflammable litter fuels on the forest floor (McArthur, 1967) (Fig.).

Two main fields of evidence suggest that the association between our forests and fire has been a long one. Firstly, indigenous plant species show a wide array of characteristics that enable them to survive fires. Examples are the thick, protective bark of many eucalypts; the swollen carrot-like roots or lignotubers of some species; the hard, resistant seeds of legumes; and the protective fruits of Banksias, Hakeas and others (Gill, 1975). Secondly, carbon dating of charcoal from south-coastal swamps indicates that fires burnt through the forest frequently in the long-distant past (Churchill, 1968).

And yet although fire can be regarded as an integral part of the forest environment, it poses many problems. Where once vast forests and woodlands stretched untouched across the south-west, today there is a mosaic of farms, forests, towns and settlements. Timber, water supply catchments, National Parks and many other resources and community assets face the threat of damage or destruction by uncontrolled summer wildfire. Each year the Forests Department suppresses 300 to 400 fires in State Forests, and many more are controlled by rural bushfire brigades and land-holders. Foley (1947) lists 127 fires that occured in the south-west between 1914 and 1944.

Since its inception in 1919, the Forests Department has built up a highly effective fire-control force, with some 600 trained men and officers, a large pool of fire-fighting plant and vehicles, an advanced fire detection system based on spotter aircraft and an efficient radio communication network.

Experience has shown that despite these developments, intense fires burning in heavy fuels under adverse weather conditions cannot be fully controlled. Given present forest and community values, such a situation is intolerable.

Clearly, the policy for fire management adopted by the Forests Department must above all be effective in ensuring the suppression of major fires, particularly in multiple fire situations when fire-fighting resources are invariably overstretch The current management strategy involves a technique known as <u>prescribed (or controlled) burning</u>, which limits the accumulation of heavy forest fuels and thereby minimizes the risk of uncontrollable fires.

The effectiveness of this management practice was thoroughly tested as recently as 4 April 1978, when 90 simultaneous fires, driven by cyclonic winds through very dry fuels, threatened State Forests. These fires penetrated the forest for only a limited distance before they were controlled, and the area of indigenous forest that was burnt was restricted to approximately 7000 hectares of the total 51 000 hectares burnt. Because there were multiple fires it was necessary to attack them on the basis of priority so that limited fire-fighting resources could be used to the best possible advantage. Priorities were established minimizing danger to life or property, but this was only possible because the fuels over large areas of forest had previously been reduced to low levels by prescribed burning (Fig.).

Damage to life and property would certainly have been far more widespread and severe in the absence of a fuel reduction programme. This observation can be supported by the evidence of previous severe fires burning in heavy fuels, such as the Hobart fire of 1967.

The place of fire in the forest is not always fully appreciated. There are those who still regard fire as totally destructive, and alien to the environment. This view is partly a reflection of our European origins, for certainly the indigenous aboriginal population did not share it (Hallam, 1975). Others, whilst accepting that periodic wildfires are a part of the natural ecosystem, seriously question the forest manager's manipulation of fire for prescribed burning.

This paper reviews the historical background that led to the adoption of widespread prescribed burning, discusses research into the practice, its application, and the effects of mild controlled fire compared with those of intense fire on the forest environment.

II HISTORICAL REVIEW

Before Man

There can be little doubt that the eucalypt forests of the south-west of Western Australia have been subject to periodic fires since they evolved. Indeed, since lightning represents a constant threat of ignition, fires must have occurred ever since combustible plant material appeared on earth.

The genus Eucalyptus, together with certain other modern plant genera, probably evolved at least 19 or possibly even 30 million years ago (Lange, Department of Botany, University of Adelaide, personal communication). Eucalypt forests accumulate litter on the forest floor very rapidly, and this fuel is highly inflammable. Given such a long history in a fire-prone environment, it is not surprising that the eucalypts themselves, together with their associated understorey species, display an impressive array of adaptations which enable them to survive fire (Gill, 1975).

However, one can only speculate as to the type of fires, their frequency and the season in which they occurred.

Certainly the rapidity of fuel accumulation and the ready flammability of our forests result in conditions which will support continuous fire on a three to four year cycle during the summer months. Furthermore, weather records kept over many years for the jarrah forest region show that fires can burn through the forest on nearly half the days in every year.

It is therefore reasonable to suppose that fires could and must have burnt through our forests under a very wide range of conditions. Fire behaviour varies day by day as the weather changes, and hour by hour according to variations in fuel, topography and many other factors, so that having started, a fire might easily burn for the duration of the summer, alternately flaring and smouldering, its progress dictated by weather, fuel and forest type. The number of possible combinations of the variables that affect fire behaviour is almost infinite, their complexity making any simple classification of prehistoric forest fires almost impossible: clearly, mild or intense fires starting in spring, summer or autumn could always have occurred. At any particular moment the forests would have been a patchwork of burnt areas of different sizes and shapes, resulting from fires at different seasons of the year and at almost any frequency greater than 3 or 4 years.

The coming of the Aboriginal

With the coming of the aborigines some 25 000 to 30 000 years ago, natural fire patterns in the forest changed. The aborigines were nomadic hunters and food-gatherers, moving regularly about the countryside in small tribal or family groups and avoiding only the coldest and wettest depths of the karri forest. Because fire-kindling was a tedious and time-consuming task they carried fire with them wherever they went, in the form of fire-sticks (lighted brands or coals). Bushfires were started accidentally not only with the fire-sticks but also as a result of the constant lighting of fires for cooking, warmth and ceremonial purposes.

In addition the aborigines practised "fire-stick farming": the deliberate and systematic lighting of the bush in consecutive sections to facilitate hunting and food-gathering. This operation was carefully described by Scott Nind, resident medical officer at King George Sound, Albany, in 1827 (Hallam, 1975):

> At the dry seasons of the year, large districts are abandoned for want of water ... About Christmas they commence firing the country for game, and the families who through the winter have been dispersed over the country, reassemble .... The violence of the fire is frequently very great and extends over many miles of country; but this is generally guarded against by their burning it in consecutive portions (Hallam, 1975, pp. 30, 32).

Another observer, J.L. Stokes, who visited the south-west of Western Australia with Charles Darwin during the voyage of the

Beagle (1837-1843) gave the following description of burning by the aborigines:

> On our way we met a party of natives engaged in burning the bush, which they do in sections every year. The dexterity with which they manage so proverbially a dangerous agent as fire is indeed astonishing. Those to whom this duty is especially entrusted, and who guide or stop the running flame, are armed with large green boughs, with which if it moves in a wrong direction, they beat it out (Hallam, 1975, p.33).

There is a considerable body of literature on this subject. Hallam (1975) reconstructs a picture of fire patterns in the south-west at the time of the first European colonization. In those areas most intensively populated by the aborigines a regular, cyclic burning regime every 3 to 5 years may have been common, but in the denser forest areas such as the karri forest of the south, fires appear to have been less frequent (Underwood, 1978). This burning, along with periodic fires started naturally by lightning, ensured that no forests remained permanently free from the effects of fire.

European Man

With the coming of European man to Western Australia in 1827, changes in land use and therefore in fire patterns took place almost immediately. The dispersal of the aboriginal tribes of the south-west and the destruction of their aeons-old way of life were virtually complete within 50 years. Clearing of the forest for farmlands commenced, settlements and towns grew up and herds of animals were depastured in the bush. Above all, a large timber industry developed. There was uncontrolled felling over wide areas of forest, which resulted in a dramatic increase in the amount of inflammable debris on the forest floor. Both the timber workers themselves and the steam locomotives, which burned wood and which were used to haul logs and timber through the forest, represented new sources of fire. Away from the settlements, the lighting of fires could not be policed; nor were there any means of suppressing fires that developed under severe weather conditions (King, 1963).

From a time when regular, cyclic and fairly well regulated burning by the aborigines was the norm, at least along the coastal belts and in the drier northern forests, the scene had quickly changed. The new cycle in the forest was one of heavy uncontrolled cutting or clearing, followed by devastating fires. The era of the bushfire as an enemy of man had begun.

Forestry Begins

Forest conservation and protection were virtually non-existent in Western Australia until the Forests Act was passed in 1918 and the Forests Department was established in the following year. The first foresters to be appointed were appalled at the condition of the forest for which they assumed responsibility. The magnificent virgin forest that the first settlers had explored some 80 or 90 years before had been decimated by agricultural development, uncontrolled cutting and raging fires. With meagre finances and a small staff, the embryo Forests Department faced a massive problem. By the early 1920s, however, the first fire management policy had been devised.

The Protection Era

The main aim of Western Australia's first official fire control policy was protection. It required an advanced burn immediately prior to logging, through areas planned for cutting, followed by another fire after the logging operations to dispose of the tops of felled trees and other logging debris. Narrow firebreaks 100 metres apart were constructed around the compartments of logged forest and along bush railway lines. These strips were then subjected to a controlled burn on a rotation of about 3 to 4 years. Exclusion of fire from the remainder of the forest was envisaged where this had been carried out. Since the Department had only limited resources at the time there were other areas where fire burnt considerable distances before being controlled.

Strict adherence to this regime was initially successful in reducing the number and size of destructive forest fires. At the same time, great progress was made towards the development of a structured fire control organization. The forest was mapped and access roads were constructed. A fire detection system based on a network of lookout towers was organized, telephone and radio communication systems were developed, and specially trained and equipped gangs of fire-fighters were centred at district headquarters strategically located throughout the forest. A milestone of particular importance was the establishment of the first fire research and fire weather forecasting unit at Dwellingup during the period 1934-36.

However, by the 1940s severe problems related to this policy of full protection began to emerge. In the long-unburnt sections of the forest, heavy litter fuels were building up. It became hazardous to burn the fire-break strips adjoining them and, even worse, fires that started in the protected compartments became almost impossible to suppress. The fire-break burning programme lagged seriously, particularly during the war years 1939-45, when manpower shortages were acute.

A crisis was reached in the summers of 1949 and 1950. By this time much of the forest had been protected from fire for nearly 30 years and carried huge tonnages of leaf litter and scrub. Under prolonged drought and heatwave conditions, uncontrolled fires developed all over the south-west and many of them reached an unprecendented size and ferocity: one fire starting on farmlands near Donnybrook eventually ran into the sea at Denmark on the south coast, more than 200 kilometers away. There was severe damage to the forest and to community assets.

A number of facts became obvious after these fires. The programme of burning narrow fire-breaks could no longer be maintained because it was too costly in terms of both money and manpower. It was, furthermore, the direct cause of numerous serious fires. Despite all the improvements in technology and equipment, fires in the long-protected zones had become almost impossible to control, even under relatively mild weather conditions. The morale of fire-fighters had deteriorated. Research served to emphasize the now-obvious fact that in the absence of fire, jarrah forest litter and scrub fuels continue to accumulate for at least 30 to 40 years, a sitnation quite different from that in forests in many other parts of the world where natural accession and decomposition of litter tend to balance each other.

It had become quite clear that effective control over forest fires had been lost. New problems had developed, and new solutions were therefore required to deal with them.

Fighting Fire with Fire

In 1953 the Forests Department took the innovative and at that time revolutionary decision to change from a policy of protection to one of broad-scale prescribed burning. A new policy for the management of fire in the forest was drawn up. Whilst this policy still provided for advance burning before logging and for a post-logging burn to dispose of the residual tops, it also prescribed controlled burning throughout the forest in order to dispose of the heavy fuels in the long-protected compartments. Only young, regenerating forest areas were afforded a period of protection. The initial controlled burn was to be followed by mild burning in spring or autumn over the entire forest area on rotations varying from about 4 to 7 years (Peet, 1967).

To understand the theory behind prescribed burning it is necessary to have some knowledge of basic fire behaviour. The intensity or ferocity of a forest fire depends in the main upon air temperature and dryness, wind strength, fuel moisture, fuel quantity, and topography (Peet, 1965). For example, fire intensity will be maximum under hot, dry conditions, in high winds, in heavy fuels and up steep slopes. Of these factors only one - fuel quantity - can be readily controlled by man. There are several ways in which inflammable litter can be removed from the forest floor: in some parts of the world it is collected for domestic fuel and in others it is grazed off by domestic animals, but by far the simplest and most practical means under Western Australian conditions is to burn it. In a prescribed burning operation, fires are deliberately lit in the forest under carefully chosen conditions with the specific intention of burning away accumulated litter. The aim is not to prevent forest fires, which prescribed burning cannot do, but to make it easier to control those that do start, and to minimize their destructiveness.

The value of this new policy was soon put to the test during the summer of 1960-61. A series of dry lightning storms coincided with extreme fire weather, and multiple severe bush fires were the result. The towns of Dwellingup and Karridale were burnt out, huge fires devastated karri forests south of Pemberton and near Shannon River, and thousands of hectares of farmland and forest were blackened. Only in those areas where recent prescribed burning had taken place could the fires be brought under control.

A Royal Commission inquired into the bushfires of 1961 and the findings confirmed the value of the prescribed burning policy that had been adopted. One of the recommendations was that the "Forests Department make every endeavour to improve and extend the practice of control burning to ensure that the forests receive the maximum protection practicable consistent with silvicultural requirements" (Rodger, 1961).

Since 1962 almost all the jarrah forest and most of the karri forest have been brought under a regime of rotational prescribed burning. The incidence of forest fires during this period has not varied greatly from year to year, but the size of the fires and their destructiveness has greatly decreased and the ease of their suppression has increased.

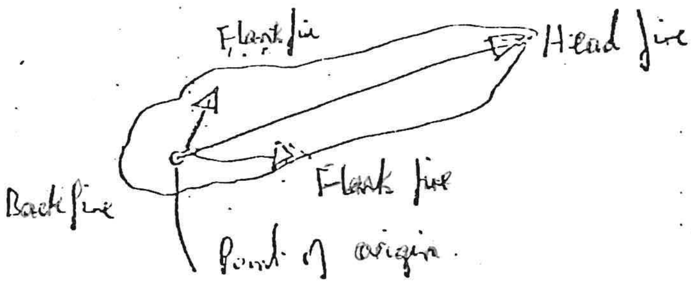
In the 15 years from 1962 to 1976, only one serious major forest fire has occurred: this was in 1969 in the lower Shannon, an area which at that time had not been subjected to rotational prescribed burning. It is significant that during the fire emergency that arose in April 1978 as a result of cyclonic winds across the south-west of Western Australia, there was very limited damage to forest areas; many fires were brought under control because they burnt into areas where fuels had recently been reduced by prescribed burning.

III FIRE BEHAVIOUR AND FIRE CONTROL

Fire in the Forest

The way in which a forest fire behaves (that is, its rate of spread, intensity, height of flames and ability to throw spot-fires ahead of the main fire front) depends upon a multiplicity of factors. For combustion to occur certain conditions must be satisfied; these include the presence of a source of ignition, the presence of oxygen, and dry fuel. Fire development after ignition is determined by air temperature and relative humidity, wind strength, forest type, topography, and the arrangement, quantity, and moisture content of the fuel.

On a flat surface with uniform fuels and no wind, fires tend to develop evenly in all directions, producing a circular-shaped burn. In such a fire, the intensity (the rate of heat release) is roughly equal at all points around the circumference. Normally, however, fires spread with the wind, resulting in an elliptical shape. Such fires have three recognizable parts: the headfire, the flankfires and the tail, or backfire.



Fire intensity is related to rate of spread, and therefore fires are hottest at the headfire and coldest at the backfire.

The ability to predict the rate of spread and intensity of fires for given weather, forest and fuel conditions is necessary for the successful use and control of fire in the forest and the understanding of its effects.

Detailed research into fire behaviour and the factors that influence it has been carried out by Western Australian foresters over the last twenty years. Fire behaviour in the major forest and fuel types is now predictable, and details are given in the "Forest Fire Behaviour Tables for Western Australia" (Forests Department of Western Australia, 1976). These allow very accurate calculations to be made of rates of spread and intensities for a wide range of parameters affecting fire behaviour, and are used by foresters for planning prescribed burning or fire suppression suppression operations.

Apart from the daily weather variables influencing fire behaviour, such as wind, temperature and humidity, a number of other important factors must be considered in any discussion of fire in Western Australian forests. Foremost among these is the duration and progressive development of the fire season itself. For example, because of the long summer drought, fires in the jarrah forest can sustain themselves for nearly six months of every year from spring through to autumn. Furthermore, the flammability of the forest increases rapidly as the season progresses, peak fuel dryness occurring immediately prior to the opening rains of winter.

Jarrah and karri trees shed about one quarter of their leaves each year. In addition there is a constant shedding of small twigs, bark, woody seed capsules and occasional branches. This leaf and trash litter (fuel) accumulates on the forest floor at rates of between 3 and 4 tonnes on each hectare every year. This fuel level is further augmented by litter from the common understorey trees such as species of Casuarina and Banksia, and by an inflammable ground layer of shrubs, bracken, and blackboys (Peet, 1971; Sneeuwjagt, 1971). The rate of natural decomposition of discarded plant material on the forest floor is well below that at which it is produced, so that in the absence of any other means of removal, it simply continues to accumulate. weights of over 120 tonnes per hectare have been measured in long-unburnt regrowth karri stands near Walpole on the south coast.

Two further important factors affecting fire behaviour must be mentioned. Even in healthy, well grown eucalypt forests nearly every tree carries some dead wood on its upper branches. These dry limbs and twigs, together with dead leaves lodged in a multitude of cracks, crevices and holes in the tree crown, seem to act as a magnet for passing sparks carried on the updraught from a fire on the forest floor. Often up to 50 metres from the ground, these crownfires are totally inaccessable to the fire-fighter and will throw sparks and burning embers, causing spot fires far ahead of the main fire front. To this can be added the massive spotting potential of jarrah bark, particularly in stands which have not burnt for long periods. The dry, outer bark ignites readily and is easily stripped from the tree and carried aloft by hot, strong winds. It can be carried to enormous heights and will float downwind to start new fires thousands of metres from the scene of the original fire (McArthur, 1967).

Finally, fires in the native eucalypt forest tend to be self-perpetuating. Scorched leaves or blackboy needles fall onto smouldering logs and these, fanned by hot winds, can burst into life again days, weeks or even months after the original fire. With all his equipment and expertise the Western Australian fire-fighter still finds forest fires difficult to extinguish. Days of painstaking mopping-up must be carried out to distances of up to 100 metres from the edge of a burn to eliminate sources of future fires. The mopping-up operation involves dousing or burying all burning material that may cause a fire escape over the firebreak.

The Climate

The climate of southern Western Australia is typically mediterranean, characterized by cool wet winters and hot dry summers. The combination of a large land mass and descending air produces a zone of high pressure, which lies across the southern half of the continent during the summer. This high-pressure zone is normally resolved into a series of intense high or anticyclones, which move regularly from west to east on a cycle of about 7 to 10 days. The passage of each of these highs is usually accompanied by the formation of a low-pressure trough along the west coast, followed by a weak cold front as a precursor to a new high-pressure cell. Cycles of high temperatures, strong north-easterly to north-westerly winds and occasional lightning storms followed by a cool change and then a rapid return to warm weather occur and re-occur repeatedly in the south-west of Western Australia each summer (Luke and McArthur, 1978).

Generally the worst fire weather occurs when for some reason the easterly movement of the systems is blocked. Usually this happens when an anticyclone becomes stationary in the Great Australian Bight simultaneously with the formation of a cyclone off the north-west coast. In this situation, heatwave conditions occur, accompanied by strong, dry winds from the interior of the continent. Vegetation becomes tinder-dry and the merest spark will start a wildfire. These are known as blow-up days, and have been associated with all the worst forest fires in Western Australian history, especially when accompanied by dry thunderstorms and lightning. Fires on blow-up days can develop into fire storms where energy release is well beyond that normally experienced in fire behaviour. Under these conditions, fires simply cannot be controlled at the headfire.

Periods of intense fire weather occur normally about twice every ten days during the peak summer months in the jarrah and karri forests. Blow-up conditions occur usually once or twice every summer.

Fire occurrence

Detailed statistics about wildfires in or threatening State Forests have been kept by the Forests Department since the early

1940s. These show that between approximately 200 and 600 forest fires are suppressed each year by Departmental personnel. The average size of individual fires tends to vary from year to year, but has generally decreased, together with the total area of forest burnt by wildfire each summer, since the advent of broadscale prescribed burning (Fig.). The introduction of this burning, however, has not affected the number of fires occurring each year as much as it has affected their severity.

Values Endangered by Wildfire

Uncontrolled wildfires are a threat to many community assets in the south-west forest zone.

Human lives and property are of primary concern and clearly, any fire management policy must provide for their protection. Some 80 000 people live on farms or in country towns in and adjoining State Forests in the south-west, whilst the metropolitan and outer suburban areas north and east of Perth abut the northern jarrah forest. The 800 000 hectares of farmlands that directly adjoin State Forest, as well as a further 2.5 million hectares of private property in the south-west, would be threatened if uncontrollable wildfires developed within State Forests.

Other assets for which fire represents a potential threat include the major south-west water supply catchments (80% of which are in State Forest), the timber industry, wilderness and scientific reserves and the many popular tourist and recreation areas in the forest. The increasing demand for these assets emphasises the need for their effective protection from damage or destruction by uncontrolled fire.

Fire Protection Operations

Fire protection in Western Australian forests is based upon prevention and upon the techniques of presuppression and suppression.

Fire prevention involves two areas of activity. The first is concentrated on reducing the risks of fires starting, and involves public education, liaison with Bush Fire Brigades and the enforcement of the Bush Fires Act. The second involves reducing the fire hazard in the forest, and is accomplished by a programme of prescribed burning. This is discussed in detail later in this section.

Fire presuppression involves all those fire control operations that must take place to prepare for the occurrence of wildfire. These include training and equipping fire-fighters, establishing an effective fire detection system and communications network, maintaining access through the forest, and ensuring constant water supplies for fire fighting. Although new techniques are constantly being developed, the basic method of fire presuppression has remained unchanged since almost the beginning of forestry in Western Australia.

Fire suppression involves putting out fires once they have been detected. There are two keys to successful fire suppression. The first is the reduction to a minimum of the time between detection and attack, which is mainly dependent on the effectiveness of the detection and communications systems and on the degree to which the organization is prepared for action. The second factor influencing the success of fire suppression is the organization's ability to mount and supply a suppression force capable of extinguishing the perimeters of a fire at a greater rate than that at which the fire is expanding.

Since 1961 the suppression organization and resources of the Forests Department of Western Australia have proved adequate in most forest fire situations, although overloading can still occur, particularly when multiple fires develop under blow-up conditions. In these cases, suppression priorities must be set, and fires in light fuels not threatening life or property are allowed to burn until the more severe fires have been suppressed.

Prescribed Burning

A broad-area prescribed burning programme aimed at continuously reducing fuel accumulations on the forest floor is the cornerstone of fire control in Western Australian forests. Without this programme, a massive expansion of the suppression organization would be necessary to ensure continued protection of both the forest and the community. Even so, success would not be guaranteed. For example, the state of California in the United States has a massive suppression force by Australian standards, and yet widespread damaging fires still occur with regularity.

In prescribed burning the costs of the operation must be balanced against the potential losses if the operation were not carried out. In other words, the cost of the burning must be less than the value of the assets being protected. However, since many of these cannot be evaluated in monetary terms, they must be assessed subjectively; this will be discussed later.

For any forest area, the prescribed burning programme commences with the preparation of a master burning plan, which gives the most suitable burn frequency (or rotation) and season of burning for each forest area, and prescribes fire treatment for any special management priority areas and dieback quarantine zones.

The period between burns varies with the rate of accumulation of litter fuels; generally, the aim is to restrict the amount of flash fuels in jarrah forest areas to below 8 tonnes per hectare. The location of the forest also influences the length of time between burns, which ranges from about 4 years in stands surrounding high-value or high-risk areas, such as townships, to 7 or 8 years in the eastern jarrah and wandoo forests and the cooler southern karri forests.

The intensity of burns also varies, but most are mild rather than hot. Normally, the conditions for burning are selected to ensure that the rate of spread of headfires remains below 60 metres per hour. Low intensities are preferred for two reasons: firstly, they cause minimum damage to the trees in the forest and secondly, they permit maximum control over the fire. Hot fires, particularly those in late summer and autumn, can be very difficult to control and, furthermore, can cause undesirable scars on the tree trunks, the section from which timber is sawn. They will certainly cause severe damage in killing small saplings, the trees of the future. The Bush Fires Act restricts burning to spring and autumn in most State Forest areas, and summer burning is carried out only where special fire treatments are required, for example regeneration burning in karri forest.

However, within any large prescribed burn there is a wide range of fire behaviour, resulting from variations in the forest, the fuel and the microclimate within the burn area. For example, in a study of 25 aerial burns carried out during 1976, it was found that the rate of spread of fire ranged from 15 to 65 metres per hour and that it is possible for up to 32% of a burn area to remain unburnt. Typically, a burn produces a mosaic of burnt and unburnt areas, and of sections burnt at mild, moderate and high intensities, and these patterns change with successive burns over the same area.

IV EFFECTS OF FIRE

Although fire may have a dramatic effect on the values that man places on the forest, it is rarely catastrophic. Its permanent exclusion can only be at the cost of major changes within the forest ecosystem.

The stark, blackened and leafless trunks seen after an intense fire are an awesome sight. To many observers the forest appears to have been destroyed. Nothing, it seems, could ever restore it to its former grandeur. Yet within weeks vigorous new shoots sprout from the trunks and limbs of many trees, seedlings emerge from the blackened soil, birdsong is heard again and kangaroos and wallabies reappear. Few of those same observers can detect an area burnt only two or three years previously, although careful observation will usually reveal crow damage, dead saplings and scarred boles.

To those who have spent a lifetime in the bush, this miraculous recovery of Western Australian forests is common knowledge. But only in recent years have scientists begun to study the various processes whereby it occurs.

Fire and Plants in Western Australian Forests

The native trees and plants in the forest possess an array of remarkable adaptations that enable them to regenerate and sustain themselves successfully after fires of almost any frequency and intensity (Gill, 1975).

Some species have thick bark, which insulates and protects the growing tissue, the cambium, beneath it. Species such as jarrah (*Eucalyptus marginata*), marri (*Eucalyptus calophylla*), the Christmas tree (*Nuytsia floribunda*) and paperbarks (*Melaleuca* species) are good examples. In these species there are also dormant buds beneath the bark, and these spring to life after a fire, producing new epicormic crowns.

Many small, woody scrub species and trees at their seedling stage have a large underground woody storage organ, the caudex, which produces vigorous shoots when the above-ground organs of the plant are killed by fire. The lignotuber of jarrah is a good example.

Many tree and scrub species are more easily killed by fire, but nevertheless show special adaptations to ensure the survival of the species. For example, the large woody fruits of Banksias and Hakeas and the capsules of eucalypts protect seed from radiant heat during fires, and furthermore, the heat of a fire stimulates them to open, allowing the release of seed onto burnt ground where the ash provides a perfect seedbed (Christensen, 1971).

This accounts for the forester's use of fire in regeneration programmes for species such as karri.

Other plants, particularly the native legumes such as the Acacias, many species of which are well known "fire-weeds", have hard, heat-resistant seed and depend largely upon fire for their regeneration. Laboratory trials have shown that only a small proportion of these seeds germinate without heat treatment. Field trials in wet sclerophyll karri forests show that fires that burn away all the leaf litter to expose the bare mineral soil result in high levels of legume germination (Christensen and Kimber, 1975). However, in the drier jarrah forests, legume seeds are often buried by ants (Portlock, 1977) and an intense fire is therefore needed to generate sufficient heat to penetrate the soil and stimulate germination (Buehrig, 1977).

Many native shrub species produce prodigious quantities of seed. Seedfalls of up to ten million seeds per hectare in a single year have been recorded under some Acacia thickets. These seeds have great longevity, and despite heavy depredation for various reasons, vast numbers remain stored in the soil ready to germinate after a fire. Quantities of over one thousand seeds per square metre of topsoil are not uncommon beneath the wet sclerophyll karri forests (Christensen and Kimber, 1975).

No two fires are ever the same. They vary in size, intensity and pattern of development, and furthermore, as we have seen, different sections of the same fire can differ greatly in behaviour as a result of wind, day-to-night fluctuations in temperatures and humidity, or changes in fuels or slopes. This results in a mozaic of burnt and unburnt patches and of areas burnt at a wide range of different intensities.

Fire intensity is probably the most significant factor to consider when discussing the effects of fire on the native flora. On certain sites in the jarrah forest, for example, high-intensity fires kill more plants and germinate thickets of legumes than do low-intensity burns which encourage rootstock species and tend to diminish legume thickets (Peet, 1971; Christensen and Kimber, 1975). When all other factors are more or less equal, fire intensity is determined by fire frequency. When there are long intervals between fires, heavy fuels accumulate and high-intensity fires can occur, whereas frequent fires will maintain low fuel levels that can support only low-intensity, slow-moving fires. Weather conditions and season are also important, of course. High-intensity fires are more likely on hot, windy days in summer and autumn than under the cooler conditions of spring or early summer.

The effects of fire on many wildflower and shrub species occurring in the main forest areas of Western Australia have been studied, and all species investigated were found to flower and produce seed within two or three years of regeneration after burning. This is normally too short a period to allow the accumulation of enough dry fuel to carry another fire, except where exotic grasses and other introduced annuals have invaded the forest, a situation which often occurs along road verges in agricultural areas or where forests adjoin farm paddocks.

In the forest itself, however, even the most careful studies have failed to document the disappearance of any species of native plant as a result of repeated frequent fires. Species composition on burnt sites depends largely on the species present before the fire. However, fire sometimes brings about the reappearance of some species that have not been recorded on the site for many years. An immediate increase in both species numbers and species diversity is therefore common after a fire in an area that has been protected for a long time (Peet and Van Didden, 1973).

A fire such as this also triggers a well defined plant succession. Small colonizing ephemerals appear and disappear within the first year or two and are quickly followed by the common wildflower species, which are eventually crowded out by "fire-weed" thickets after four or five years. As the years pass these too begin to decrease in numbers and fewer, larger plants of a smaller number of species are found on the area. Very long-unburnt stands in the karri forest, for example, eventually become quite open, with grass or dense bracken and only an occasional specimen of the taller, longer-lived Acacias or Hakeas as remnants of the original scrub layers.

Studies of the various and complex relationships between fire and the native flora in the forest are still continuing, since there remain a multitude of details at both individual and community levels that need to be clarified. Nevertheless, results to date indicate that the native plants possess remarkable resilience and adaptation to a wide range of fire regimes.

Fire and Animals in Western Australia

Between the plants and animals of the forest there is one fundamental difference: animals are mobile whereas plants are not. Like the flora, the native fauna has incredible tenacity and is able to survive the fiercest holocausts. Animals survived in the burnt areas after the historic 1967 Tasmanian bushfires, in which about 250 000 hectares burnt at extremely high intensities (up to 80 000 hectares per hour at the peak). Hundreds of birds, caught up by the strong winds, were killed by heat and suffocation

and were carried

out to sea, and many possums, kangaroos and other animals were overtaken by the flames and incinerated. Similar observations were made after a wildfire in Nadgee nature reserve in New South Wales (Recher and Christensen, in press).

The remarkable feature of these fires, however, was not the deaths but the survivals. Great numbers of possums, bandicoots, poteroos and small mammals survived even in those areas that had been most intensely burnt, and birds of all species were to be found in less severely burnt areas soon after the fire had passed.

Data from experiments investigating the effects of cooler fires on the animals of the forest are increasingly available. It has been shown that some 80-90% of the microfauna inhabiting the upper soil and litter layers are destroyed even by mild fire, but that this is followed by a rapid increase in both numbers and species during vegetative recovery in the immediate post-burn period (Leonard, 1972; Bornemissza, 1969). The effect of cool and moderate fires on the vertebrate fauna, however, is in sharp contrast. Birds have little trouble in avoiding the direct effects of such fires; indeed, the species of the upper canopy are almost completely unaffected. In the shrub and understorey layers, fire initiates a well established succession starting with species such as the robins, which prefer an open understorey, and later, as the vegetation develops further, the original inhabitants return to re-occupy the site.

Small mammals seem able to avoid the direct effects of a forest fire. Studies using capture-recapture techniques have shown that animals will stay within their normal home range or territory. Immediately after the fire there is normally a dramatic fall in population numbers, but this is due to predation on the burnt open ground, where little cover remains to provide refuge and escape, rather than directly to the effects of the fire (Christensen and Kimber, 1975). In any case, population numbers increase rapidly through breeding and through recolonisation of the burnt areas by animals in neighbouring unburnt areas (Christensen, 1977).

Radio-tracking of tammar wallabies (Macropus eugenii) and rat kangaroos or woylies (Bettongia penicillata) in jarrah forest near Manjimup has revealed that both species are remarkably calm in the face of a bushfire. Of almost thirty animals tracked during fires, not one left its home range during the fire, and there was no evidence of panic. The animals moved in front of the fire, apparently searching for somewhere to escape the flames. Many found refuge in tiny unburnt patches of vegetation, but most were able to double back through the flames and reach the safety of the burnt ground beyond.

In contrast with the plants, the mammals of the forest show no special adaptation to fire, except perhaps the quality of calm fearlessness. General characteristics such as their mobility, which allows them to seek refuge, their rapid breeding, and various behavioural traits enable the native mammals to cope with fire in much the same way as they enable them to cope with other natural sources of danger such as drought and disease. There is one species native to the forest, the mardo or marsupial mouse (Antechinus flavipes), that appears to be ill-adapted to frequent fire; dense populations have only ever been recorded in long-unburnt areas. The reasons are as yet unexplained. By contrast, the introduced house mouse (Mus musculus), hardly an animal one would associate with fire, is normally the first species to colonize burnt forests in most parts of Australia. Other species soon replace it, for as with plants, there is usually a well defined succession of animal species after fire, different populations of fauna associating with different stages in the succession of the vegetation. For example, the tammar wallaby of the southern forests is found only in thickets that occur at one specific stage in the post-fire succession. Similarly, kangaroos and wallabies are far more common in recently burnt forest areas than in long-unburnt zones.

Fire and the Nutrient Cycle

Apart from the direct effects of fire on the plants and animals, other more subtle relationships exist. Most Western Australian forest soils are very infertile (Leeper, 1970), and their capacity to retain nutrients is very poor. In the absence of fire, nutrients become locked up in woody tissues and litter, and are therefore unavailable for plant growth. Under these conditions, the community degenerates (Specht *et al.*, 1958): its productivity declines, and the diversity of plant and animal species is reduced.

In the major eucalypt forests of Western Australia, where the rate of accumulation of litter exceeds its rate of decomposition, fire plays a vital role in the system by releasing the unavailable nutrients bound up in the dead tissues and thereby ensuring nutrient turnover. However, considerable amounts of some nutrients, particularly nitrogen, are lost in smoke from bushfires (Vines *et al.*, 1971), and others can be leached from the ash and carried away from the site in rainfall run-off. Whilst most of the leached nutrients are replaced through natural weathering processes or by recycling through the plants and trees of the forest, the replacement of the essential nitrogen is a more complex process. It is achieved by the action of special bacteria in the root nodules of some native plants (including *Macrozamia* and the native legumes such as *Acacia*), which fix atmospheric nitrogen and convert it to forms that can be used by plants. A fire that may cause a loss of nitrogen in smoke thus may also ensure its replacement since it can stimulate the germination of nitrogen-fixing plant species (Hatch, 1977; Shea and Kitt, 1976).

In the northern jarrah forest, where hot fires are required for good germination of legume seed, it is possible that repeated mild prescribed burning may be interfering with the nitrogen cycle of the forest. Obviously, any imbalance in the nitrogen cycle could have long-term implications, so careful research is necessary to provide the necessary basic data on which to make management decisions.

The importance of nitrogen in the ecosystem is perhaps most evident amongst the higher animals, the mammals with complex food cycles. Research has shown that nitrogen can be a limiting factor controlling the numbers of species of kangaroo living in dry arid environments. During seasons when the nitrogen content of their forage is low they select and eat those species with higher nitrogen contents (Brown and Main, 1967). They are also able to recycle the urea (a nitrogen compound) in their urine for re-use in the body rather than wasting it by excretion (Kinnear and Main, 1976). Furthermore, it has been shown that the woylie and tammar wallaby depend on periodic fires to maintain adequate levels of their food species in their habitats (Christensen, 1977).

Fire and Forest Disease

There are indications of a link between fire and forest disease. Jarrah dieback is an introduced disease of the jarrah forests of Western Australia, caused by a soil-borne fungus, *Phytophthora cinnamomi*, which attacks the fine feeding roots of jarrah and many other native plants. For most of these species, attack by *Phytophthora* leads to the death of the plant. Almost 10% of the Western Australian jarrah forest is infected with the dieback disease.

Research has shown that the ecology of the disease is highly complex.

In recent years interesting relationships between disease spread and fire regimes have begun to emerge, and whilst this work is still in its infancy, it has nonetheless revealed the following two points.

Firstly, opening up of the forest by logging, together with repeated cool fires, stimulates development of the highly susceptible *Banksia grandis* at the expense of certain highly resistant native legumes. The banksias provide a good food source for the fungus and thus favour its spread.

Secondly, less frequent, hot fires germinate dense legume thickets which affect the physical nature of the upper soil by changing the soil temperature and the moisture availability, making conditions less suitable for fungal development. The legumes also improve the overall nutrient status of the stand by fixing atmospheric nitrogen (Shea and Kitt, 1976).

The interrelationships between fire, legumes, nitrogen, animals and forest diseases are as yet far from fully understood. However, it seems likely that the results of research currently being carried out in this field will lead to considerable changes in fire policies in the future.

V THE FUTURE

In the preceding chapters we have tried to emphasize that the role of fire in the forests of south-west Western Australia is a paradoxical one. Allowed to run its natural course, it can be an uncontrollable threat to lives, property and livelihoods. Yet it is a natural part of the forest ecosystem; to exclude it is impossible and indeed undesirable, for if it were excluded, present forest ecosystems would ultimately cease to exist.

And so it seems that, whilst fires will and must occur in the forest, nature cannot be allowed to run its course. As long as people live and work in the forest or value its productive and protective capacities, fires must be controlled.

In Western Australia, a point has now been reached in forest fire management where the frequency and intensity of fire in the forest can be manipulated to a very great degree. This position stems directly from the development of techniques of broad-scale short-rotation prescribed burning, which was introduced in the mid 1950s. As a result of this policy, planned, regular low-intensity burns have largely supplanted the chance occurrence of high-intensity wildfire in State Forests.

Under Western Australian conditions this prescribed burning has provided a means, both economical and effective, of coping with uncontrolled fire. To the best of present knowledge, it is the best and safest tool available; to forego its use would be foolhardy.

Nevertheless, it would be equally foolhardy to forget that the ecological position of fire in the forest is very complex. Its effects and influence are still far from fully understood. Present practice must therefore be seen as just a step in the evolution of forest fire management. It provides for adequate protection and at the same time allows for research as the basis of constant re-evaluation of management techniques and objectives.

Clearly, no single fire regime can satisfy equally all requirements of the forest system. At one extreme, short-rotation mild spring burning obviously maximizes protection of farms, towns and forest settlements, and at the other, such elements as the regeneration of Acacia thickets on certain jarrah forest sites can be more easily accomplished by less frequent, high-intensity burns. In between, there is a wide range of forest values to which a relatively wide range of fire regimes can be safely applied. The situation is illustrated for a theoretical forest site in Figure (X), which indicates how it is possible for the forest manager to nominate a fire regime that favours particular aspects of the system, once the primary land use for an area has been established.

And it is here that an idea emerges of the direction in which future fire management is likely to move. It is directly allied to the current practice of zoning the forest into a system of Management Priority Areas (MPAs).
Different areas of State Forest are designated with different sets of specific management objectives which receive priority over all others. MPAs for community values such as water, fauna, recreation, timber, conservation and so on have been established throughout State Forest. By this means, recognition is accorded to areas with special values that require special protection, or to areas whose particular attributes can be enhanced by special treatment.

Most research into fire ecology is now being concentrated within the SMPAs that represent the assets judged to be the most important. Research is focussed on fire effects at the species and population levels and on the complex relationship between fire, native legumes and dieback. Included in the research is work on the effects and practicability of hot fires at intervals longer than those currently in use over the general forest area. The overall aim of these programmes is to provide data on the basis of which decisions to vary burning practices can be made.

Three points must be stressed in conclusion:

1. The forest manager has a moral and legal responsibility to prevent uncontrolled wildfires threatening life and community assets in the State Forest region of the south-west of the State. At present the safest and most effective means of doing this is through the continuation of broad-scale rotational prescribed burning.

2. There is an equal responsibility to continue research into the complexities of fire ecology. However, simple solutions will not appear overnight,nor will any unilateral approach satisfy equally all the requirements of the ecosystem.

3. Management policies can never remain static. Dynamic policies, continuously updated and refined in line with advances in research and technology, must be expected and accepted by all sections of the community.

REFERENCES

BORNEMISSZA, G.F. (1969). The re-invasion of burnt woodland areas by insects and mites. Paper presented at Seminar on the Effects of Forest Fire, Ecological Society of Australia, Canberra Group.

BROWN, G.D. and MAIN, A.R. (1967). Studies on marsupial nutrition. V: The nitrogen requirements of the euro Macropus robustus. Australian Journal of Zoology 15, 7-27.

BUEHRIG, R.M. (1977). Acacias and heat. Forest Notes (Forests Department of Western Australia) 15(2), 60-61.

CHRISTENSEN, P. (1971). Stimulation of seedfall in karri. Australian Forestry 35, 182-190.

CHRISTENSEN, P.E.S. (1977). The biology of Bettongia penicillata Gray, 1837 and Macropus eugenii (Desmarest, 1804) in relation to fire. PhD thesis, University of Western Australia.

CHRISTENSEN, P.E. and KIMBER, P.C. (1975). Effect of prescribed burning on the flora and fauna of south-west Australian forests. Proceedings of the Ecological Society of Australia 9, 85-106.

CHURCHILL, D.M. (1968). The distribution and prehistory of Eucalyptus diversicolor F. Muell., E. marginata Donn. ex Sm., and E. calophylla R.Br. in relation to rainfall. Australian Journal of Botany 16, 125-151.

FOLEY, J.C. (1947). A study of meteorological conditons associated with bush and grass fires and fire protection strategy in Australia. Bulletin 38, Meteorological Branch, Department of Interior, Australia.

FORESTS DEPARTMENT OF WESTERN AUSTRALIA (1976). Forest fire behaviour tables for Western Australia.

GILL, A.M. (1975). Fire and the Australian flora: a review. Australian Forestry 38, 4-25.

HALLAM, S.J. (1975). Fire and Hearth. Australian Institute of Aboriginal Studies, Canberra.

HATCH, A.B. (1977). Some effects of external factors on nutrient cycling in the jarrah forest ecosystem. In: Papers presented to Symposium on Nutrient Cycling in Indigenous Forest Ecosystem, Perth, Western Australia, 1977. Division of Land Resources Management, CSIRO, Perth, pp 105-111.

KING, A.R. (1963). Report on the influence of colonization on the forests and the prevalence of bushfires in Australia. (Mimeographed report.) Division of Physical Chemistry, CSIRO, Melbourne.

KING, N.K. and VINES, R.G. (1969). Variation in the flammability of the leaves of some Australian forest species. Division of Applied Chemistry, CSIRO, Melbourne.

KINNEAR, J.E. and MAIN, A.R. (1975). The recycling of urea nitrogen by the wild tammar wallaby (Macropus eugenii), a "ruminant-like" marsupial. Comparative Biochemistry and Physiology, 51A, 793-810.

LEEPER, G.W. (editor) (1970). The Australian Environment. 4th edition. CSIRO and Melbourne University Press, Melbourne.

LEONARD, B. (1972). The effect of fire upon selected small mammals and leaf litter fauna in sclerophyll forest in southern Australia. MSc thesis, Monash University, Victoria, Australia.

LUKE, R.H. and McARTHUR, A.G. (1978). Bushfires in Australia. Forestry and Timber Bureau and Division of Forest Research, CSIRO, Canberra.

McARTHUR, A.G. (1967). Fire behaviour in Eucalypt forests. Leaflet 107, Forestry and Timber Bureau, Australia.

PEET, G.B. (1965). A fire danger rating and controlled burning guide for the northern jarrah (Euc. marginata Sm.) forest, of Western Australia. Bulletin 74, Forests Department of Western Australia.

PEET, G.B. (1967). Controlled burning in the forests of Western Australia. (Paper prepared for 9th Commonwealth Forestry Conference, 1968). Forests Department of Western Australia.

PEET, G.B. (1971). A study of scrub fuels in the jarrah forest of Western Australia. Bulletin 80, Forests Department of Western Australia.

PEET, G.B. and VAN DIDDEN, G.W. (1973). Fire effects on understorey shrubs. Research Paper 8, Forests Department of Western Australia.

PORTLOCK, C.E. (1977). Native legume seed predation, collection and dispersal mechanisms. Forest Notes (Forests Department of Western Australia) 15(2), 55-59.

RECHER, H.F. and CHRISTENSEN, P.E. Fire and the evolution of the Australian biota. In: Biogeography and Ecology in Australia. Ed. A. Keast, W. Junk, The Hague (in press).

RODGER, G.J. (1961). Report of the Royal Commission appointed to enquire into and report upon the bush fires of December 1960 and January, February and March, 1961 in Western Australia.

SHEA, S.R. and KITT, R.J. (1976). The capacity of jarrah forest native legumes to fix nitrogen. Research Paper 21, Forests Department of Western Australia.

SNEEUWJAGT, R.J. (1971). Understorey fuels in karri forest. Research Paper 1, Forests Department of Western Australia.

SPECHT, R.L., RAYSON, P. and JACKMAN, M.E. (1958). Dark Island heath (Ninety-Mile Plain, South Australia). VI. Pyric succession: changes in composition, coverage, dry weight and mineral nutrient status. Australian Journal of Botany 6, 59-88.

UNDERWOOD, R.J. (1978). Natural fire periodicity in the karri (Eucalyptus diversicolor F. Muell.) forest. Research Paper 41, Forests Department of Western Australia.

VINES, R.G., GIVSON, L., HATCH, A.B., KING, N.K., McARTHUR, D.A., PACKHAM, D.R., and TAYLOR, R.J. (1971). On the nature, properties and behaviour of bushfire smoke. Technical Paper 1, Division of Applied Chemistry, CSIRO, Melbourne.

Photographs for Fire Booklet

1.

Cover photo. (i) Photo relevant to theme. i.e. Prescribed burning In progress.

(ii) Collage of photos showing different aspects of fire management. e.g. Heavy duty, fire tower, animals, etc.

Back cover perhaps with burnt out town.

2.

I Introduction

(i) Photo of virgin karri forest.

(ii) Photo of virgin jarrah forest.

(iii) Map showing - forest areas, agricultural areas and towns of the south-west.

3.

II Historical Review

Before Man

(i) Good lightning shot (J. Stewart, Manjimup)

(ii) Flammable fuels, Perup (Research, Manjimup)

The Coming of the Aboriginal

(i) Etching from journal of early explorers showing column of smoke.

European Man

(i) Plate 1 and Plate 31 from '50 Years of Forestry'.

(ii) Photos of early settler, farm carved from bush, ringbarked bush etc. (Pemberton museum).

Forestry Begins and Protection Era

(i) Plate 37 and Plate 39 '50 Years of Forestry'.
Plate 32

Fighting Fire with Fire

(i) Graph - How fueld build-up extends the bushfire season, Ecos. No. 7 (1976) P. 7.

(ii) Photo of men control burning.

(iii) Photograph of Dwellingup and Karridale fires. Aerial shots.

III - Fire in the Forest

(i) Graphs to cover occurrence and size of fires for the last 20-30 years. (G. Peet).

Values Endangered by Wildfire.

(i) Photo of burnt livestock or farm buildings, etc. Try paper (West Australian) (something horrific!)

Fire Suppression

(i) 'Pie chart' showing causes and numbers of fire/year.

(ii) Map of south-west showing lightning strike fires in 1977-78.

Prescribed Burning

(i) Photo of 'master burning plan'.

(ii) Men or planes engaged in control burning.

(iii) Mozaic effect of burn - (infra red photo Forest Focus).

IV - Fire Effects (many of these photos can be obtained from Manjimup Research)

(i) Photo of recent hot burn.

(ii) Photo of hot burn 8 months later.

(iii) Photo of fire adaptations e.g. lignotubers or Banksia nut, thick bark, epicormic crown in burnt tree.

(iv) Photo of dense *Acacia* thickets.

(v) Photo of low intensity creeping fire and one of a high-intensity blaze.

(vi) Photo of prolific wildflower regeneration, after fire.

(vii) Photo of legume germination in clumps (ant burial) (S. Shea).

Fire and Animals

(i) Graph of animal population/time since burning (P. Christensen).

(ii) Photo of woylie with radio transmitter.

(iii) Photos of animals - preferably in relation to fire.

Fire and Nutrient Cycle

(i) Photo of dense fuel in long unburnt area. e.g. Amphion 6 Block or Karri.

(ii) Before/after fire in jarrah showing the difference in the 'lushness' of the vegetation. (Christensen and Shea).

Fire and Forest Disease

(i) Standard photo of dieback area.

(ii) Banksia stand produced by logging and mild fire compared with Acacia stand produced by hot fire.

V The Future

(i) Photo of map of major MPAs.

(ii) Photo of Research on Fire Behaviour. e.g. term meaning fire spread.

(iii) Photo of Research - fire effects e.g. Radio tracking.