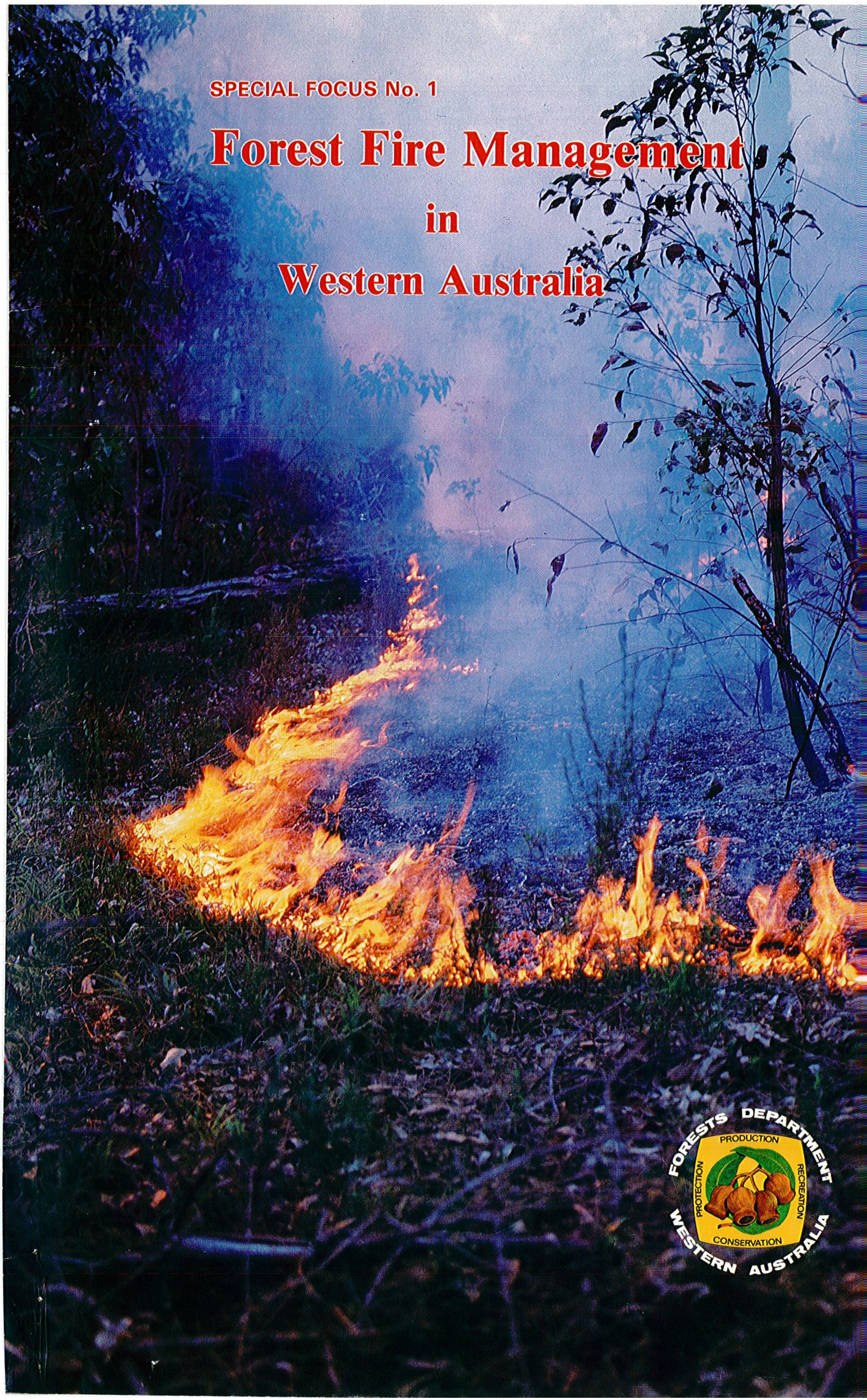
SPECIAL FOCUS No. 1

Forest Fire Management in Western Australia



FORESTS DEPARTMENT
PRODUCTION
PROTECTION
RECREATION
CONSERVATION
WESTERN AUSTRALIA

FRONT COVER

Low intensity burn

Photograph: Tom Leftwich

Printed in Western Australia
Published by the Forests Department of Western Australia
Text and page preparation by Filmset
Colour separations and offset plates by Art Photo Engravers Pty. Ltd.
Printed by the Government Printing Office
Editor: Marianne R. L. Lewis
Assistant Editor: Cefn R. Ridout

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1. INTRODUCTION

The jarrah (*Eucalyptus marginata*) and karri (*E. diversicolor*) forests of Western Australia cover approximately 1·9 million ha 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[20].

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[15] and the rapid accumulation of inflammable litter fuels on the forest floor[21].

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[11]. Secondly, carbon dating of charcoal from south-coastal swamps indicates that fires burnt through the forest frequently in the long-distant past[7].

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. In 1947, J. C. Foley[8] listed 127 serious fires that occurred 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.

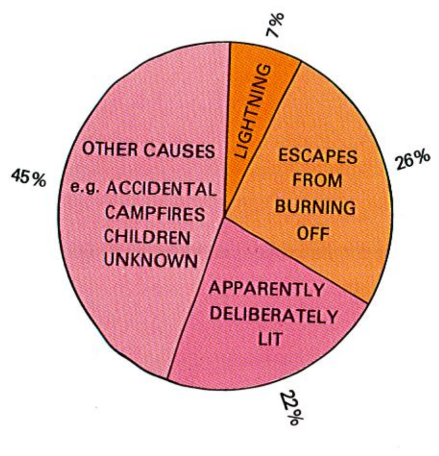
Despite these developments, experience has shown that intense fires burning in heavy fuels under adverse weather conditions cannot be readily controlled. Given present forest and community values, such a situation is intolerable.

Clearly, the policy for fire management adopted by the Forests Department must be effective in ensuring the suppression of major fires, particularly in multiple fire situations when fire-fighting resources are invariably over-stretched. The current management strategy involves a technique known as *prescribed* (or *controlled*) *burning,* which limits the accumulation of heavy forest fuels and thereby minimises 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 State forest that was burnt was restricted to approximately 6 800 ha of

Figure 1

Causes of wildfires in a ten year period ending June 1980.



▲ Today State forest, farms and townships often form a complex mosaic which creates fire protection problems. *(Neil Hamilton)*

▲ Before settlement by European man, vast forests of virgin jarrah (*E. marginata*) stretched unbroken for miles in every direction. (*Tom Leftwich*)

the total 51 000 ha burnt. Because there were multiple fires it was necessary to attack them on the basis of priority so that fire-fighting resources could be used to the best possible advantage. Priorities were established minimising 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.

Damage to life and property from the April 1978 fires 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 role 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[12]. Others, while 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.

2. *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 up to 30 million years ago*. 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[11].

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

Certainly the rapidity of fuel accumulation and the ready inflammability 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.

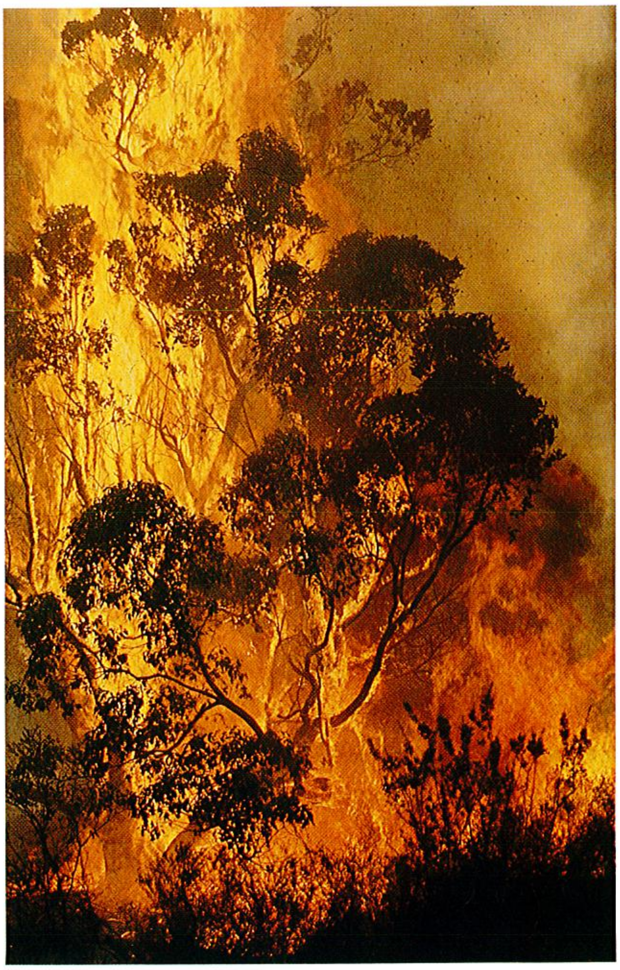
It is therefore reasonable to suppose that fires could and must have burnt through our forests under a very wide range of conditions. Fire behaviour varies day by day as the weather changes, and hour by hour according to variations in fuel, topography and many other factors, so that having started, a 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 burning in different seasons of the year and at almost any frequency where sufficient fuel had accumulated to support fire, usually a minimum of three to four years[26].

The coming of the aborigines

With the coming of the aborigines some 25000 to 30000 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

* Lange, personal communication, Department of Botany, University of Adelaide.

◄ Lightning is an integral part of the earth's electrical field and has been a source of forest fires for millions of years.
(Les Harman)



▲ Many forest fires are started each year by lightning strikes. *(Roger Underwood)*

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 of 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, 1827[12]:

> 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, re-assemble. . . . 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[12].

◄ A forest fire is an awesome sight. To many it would appear to spell total destruction. *(Tom Leftwich)*

Another observer, J. L. Stokes, who visited the south-west of Western Australia with Charles Darwin during the voyage of the *Beagle* (1837-43) gave the following description of burning by the aborigines:

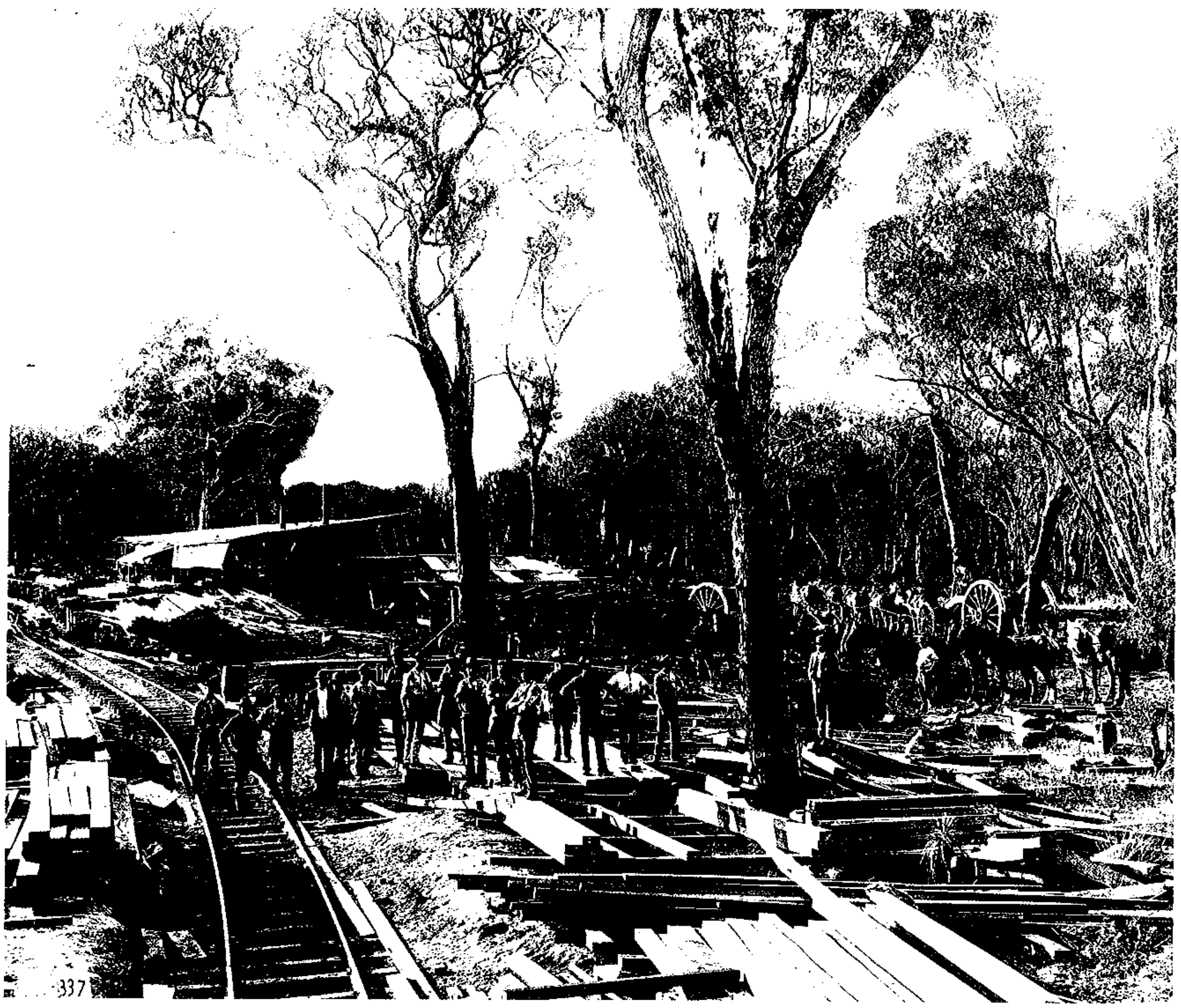
> On our way we met a party of natives engaged in burning the bush, which they do in sections every year. The dexterity with which they manage so proverbially a dangerous agent as fire is indeed astonishing. Those to whom this duty is especially entrusted and who guide or stop the running flame, are armed with large green boughs, with which if it moves in a wrong direction, they beat it out[12].

There is a considerable body of literature on this subject. S. J. Hallam reconstructs a picture of fire patterns in the south-west at the time of the first European colonisation. In those areas most intensively populated by the aborigines, a regular cyclic burning regime every three to five 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[35]. 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 completed within 50 years. Clearing of

▼ Small spot mills started to take advantage of the vast timber resources of the south-west. *(Forests Department)*



the forest for farmlands commenced, settlements and towns grew up and herds of animals were grazed 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 burnt 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[14].

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 forest fire control policy was exclusion of fire from regenerated stands. The strategy decided upon involved an "advanced" burn immediately prior to logging through the areas planned for cutting. This was followed by a second burn immediately after logging to dispose of the tops of felled trees and other logging debris. The young regeneration which became established after this treatment was then surrounded by narrow firebreak strips 100 m apart. Similar firebreak strips were located along bush railway lines. These strips were then subjected to a controlled burn on a rotation of about three to four years. Permanent exclusion of fire from the regenerated compartments was envisaged, although experienced officers at the time acknowledged that if this policy failed, "controlled burning with a light, creeping fire" would be advisable[34]. Indeed, the limited resources of the department in those days restricted the application of the fire exclusion policy mainly to the western jarrah forest. Elsewhere fires continued to burn over considerable distances before they were controlled, or eventually extinguished by winter rains.

Strict adherence to this regime was initially successful in reducing the number and size of destructive forest fires in the western jarrah forest. At the same time, great progress was made towards the development of a structured fire control organisation. The forest was mapped and access roads were constructed. A fire detection system based on a network of lookout towers was organised, 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 from 1934 to 1936.

▼ Fires in the abnormally heavy fuels, which accumulated following early logging operations, were exceptionally fierce and more destructive than natural fires. *(Forests Dept.)*

By the 1940s, however, severe problems related to the policy of excluding fire from "protected" forest began to emerge. In these long-unburnt areas, 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 of 1939 to 1945, when manpower shortages were acute.

A crisis was reached in the summers of 1949 and 1950. By this time sections of the forest had been protected from fire for nearly 30 years and carried heavy tonnages of leaf litter and scrub. Under prolonged drought and heat wave conditions, uncontrolled fires developed all over the south-west and many of them reached an unprecedented size and ferocity: one fire starting on farmlands near Donnybrook eventually burnt to the sea at Denmark on the south coast, more than 200 km 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 under the severe

▲ The first fire towers were basic structures erected on hills or other points of vantage. *(Roger Underwood)*

▼ An early fire wagon. Mobility is essential in fighting forest fires and the automobile was soon put to use for this purpose. *(Forests Department)*

weather conditions experienced each summer. Research served to emphasise 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 situation quite different from that in forests in many other parts of the world where natural build-up and decomposition of litter tend to balance out.

It had become clear that effective control over forest fires must be improved for safety of the community as well as preservation of the forest. New problems had developed and new solutions were therefore required to deal with them.

Fighting fire with fire

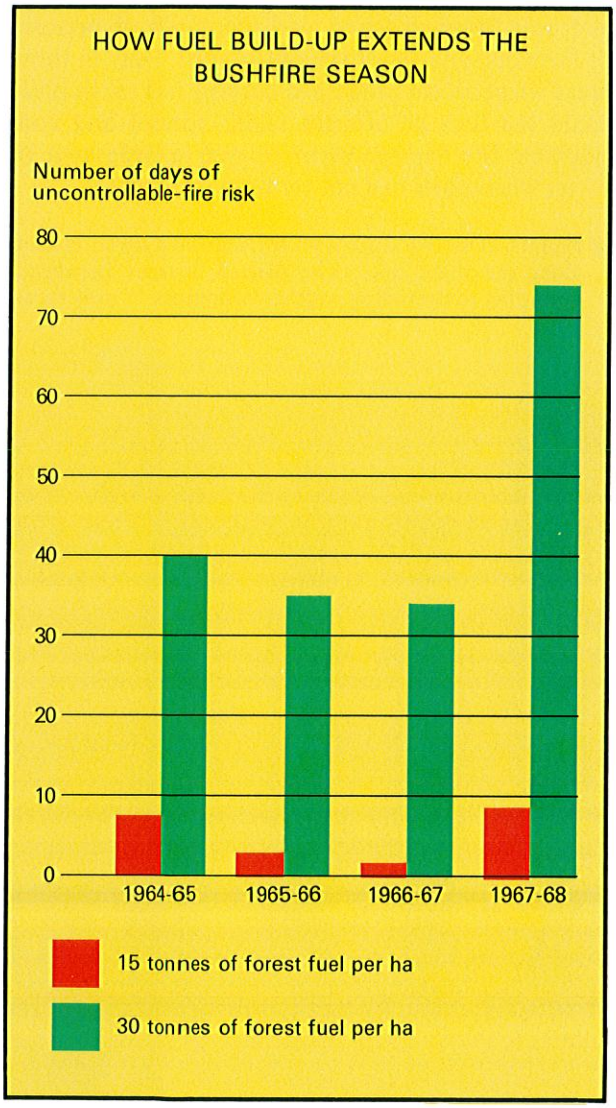
In 1953 the Forests Department took the innovative and at that time revolutionary decision to change from a policy of fire exclusion to one of broad-scale prescribed burning. A new policy for the management of fire in the forest was drawn up. While this policy still provided for advance burning before 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 four to seven years[23].

▼ Diamond tree. In the southern karri forests the huge trees themselves often provided the best point of vantage for a fire tower. *(Roger Underwood)*

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 upon air temperature and dryness, wind strength, fuel moisture, fuel quantity, and topography[22]. 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

Figure 2

Doubling the fuel quantity greatly increases the chance of fires that may be uncontrollable (more intense than 2000 kW per m). The figures shown here are for a central Victorian forest.



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 minimise 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, hugh 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 and considerable fire damage occurred over a large area of forest where fuels had not yet been reduced[24].

A Royal Commission inquired into the bush fires 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"[30].

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 decreased and they have become easier to control.

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, only 6 800 ha of State forest was burnt; many fires were brought under control because they burnt into areas where fuels had recently been reduced by prescribed burning[10].

▼ Plumes of smoke drift skyward following aerial ignition for a prescribed burn. Note the regular spacing of the smoke along the flight lines. The desired distance between the lines and the "smokes" is carefully calculated beforehand according to prevailing weather conditions. *(Gerry Van Didden)*

▲ Prescribed burns remove the scrub and litter layers (fuels) in jarrah forests, leaving the trees undamaged. *(Tom Leftwich)*

▼ The wandoo (*E. wandoo*) forests may be burnt less often since fuel in these forests accumulate more slowly. *(Tom Leftwich)*

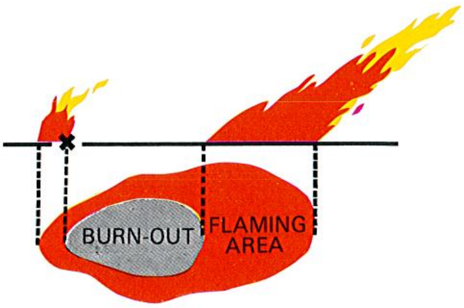
3. *FIRE BEHAVIOUR AND FIRE CONTROL*

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 recognisable parts: the headfire, the flankfires and the tail, or backfire (Fig. 3).

Figure 3
Initial stages of fire development under windy conditions.



Fire intensity is related to rate of spread, and therefore fires are most intense at the headfire and least intense 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 have been carried out by Western Australian foresters over the last 20 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*[9]. 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 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 inflammability of the forest increases as fuels dry out through the summer months. They are at their driest and most inflammable immediately prior to the opening rains of winter.

Two features in particular ensure that eucalypt forests do not remain unburnt for long, the inflammability of the leaves of many sclerophyll species and the rapid accumulation of fuels. The former is due to the high content of volatile oils and low levels of inorganic matter in the leaves[15], and the latter to low litter decomposition rates[21].

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 which range from about 1 to 3·5 tonnes on each hectare every year in jarrah forest and from 2·5 to 11 tonnes on each hectare every year in karri forest. 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[25, 32]. The rate of natural decomposition of dead plant material is slow, resulting in accumulations of inflammable material on the forest floor.

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 m from the ground, such spot fires in the tree crowns are totally inaccessible to the fire-fighter and will throw sparks and burning embers, causing new fires far ahead of the main fire front. To this can be added the high "spotting" potential of jarrah bark, particularly in forest which has not been 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 heights of 300 m to 400 m and will float downwind to start new fires. Spotting distances up to 30 km from the original fire have been recorded[20].

Finally, fires in the native eucalypt forest tend to be self-perpetuating. Scorched leaves or blackboy needles fall on to 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 of smouldering logs and burning trees must be carried out to distances of up to 100 m 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. Under natural conditions it is inconceivable that fires were completely doused by winter rains. With so many persistent ignition sources available, new outbreaks must have occurred whenever there was suitable weather.

The climate

The climate of southern Western Australia is typically Mediterranean, characterised by cool wet winters and hot dry summers. During the summer months a zone of high pressure lies across the southern half of the continent. This high-pressure zone is normally resolved into a series of intense highs or anticyclones, which move regularly from west to east on a cycle of about seven to ten 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 repeatedly in the south-west of Western Australia each summer[20].

Generally the worst fire weather occurs when, for some reason the easterly movement of the system 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. Under these conditions, fires simply cannot be controlled at the headfire.

Periods of intense fire weather occur regularly 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 wildfires each summer, since the advent of broad-scale prescribed burning[20]. 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, while the metropolitan and outer suburban areas north and east of Perth abut the northern jarrah forest. Approximately 800 000 ha of farmlands directly adjoin State forest. This and a further 2 500 000 ha 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 per cent of which are in State forest), the timber resource, wilderness and scientific reserves

▲ Uncontrolled wildfires are destructive of life and property. *(Government Photographer)*

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, preparedness 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 preparedness involves training and equipping fire-fighters, establishing an effective fire detection system and communications network, maintaining access through the forest, and ensuring water supplies for fire fighting. Although new techniques are constantly being developed, these basic principles have 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 organisation is prepared for action. The second factor influencing the success of fire suppression is the organisation'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 organisation 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 (e.g. December 1974, February 1975 and April 1978). 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 dangerous 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 organisation 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

▲ Infra-red aerial photograph of a prescribed burn showing the mosaic of burnt, unburnt and scorched forest. 1—Unburnt; 2—Understorey burnt; 3—Canopy scorched; 4—Defoliation. *(Jack Bradshaw)*

California in the United States has a massive suppression force by Australian standards, with a current level of expenditure approximating $200 million a year and yet widespread damaging fires still occur with regularity. Comparable expenditure for Western Australia is only $2 million a year.

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 assets cannot be evaluated in monetary terms, they must be assessed subjectively; this wiil 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 treatment for areas

▼ Prescribed burning strategy is planned in detail at Protection Branch Headquarters in Perth, where a master burning plan is kept. *(Brian Stevenson)*

requiring particular fire regimes, such as fauna priority areas, dieback quarantine zones or karri regeneration.

The rate of accumulation of litter fuels largely determines the scheduled period between burns. Generally, the aim is to restrict the amount of flash fuels in jarrah forest areas to below eight tonnes a hectare, for experience has shown that beyond this figure, fires cannot readily be controlled. The location of the forest also influences the length of time between burns. For instance, a rotation of about four years may be prescribed for forests surrounding high-value or high-risk areas such as townships. In the cooler southern karri forests, burning rotations of seven to eight years have been used and regenerated areas of fire sensitive saplings following felling operations in karri are protected for longer periods.

The intensity of burns also varies. Normally, conditions are selected to ensure the "hottest" fire possible, consistent with safety and the desire to prevent undesirable damage to tree crowns and boles.

Very high intensity fires are nearly always avoided because they are difficult to control and cause severe damage, killing small saplings and causing bole and crown damage to large trees. 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, or for research purposes, including improving resistance of some jarrah forest sites to dieback disease.

However, within any large prescribed burn there is a wide range of fire behaviour, resulting from variations in the forest, the fuel and the topography 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 m an hour and up to 32 per cent of burn areas remained 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.

▼ Lighting fires by hand is still an important part of prescribed burning in spite of spectacular developments in aerial ignition techniques. *(Tom Leftwich)*

4. EFFECTS OF FIRE

Although fire may have a dramatic effect on the appearance of the forest, its effect is rarely catastrophic. Fire is a natural occurrence in the forest, and its permanent exclusion, if this were possible, could 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. Yet within weeks, vigorous new shoots sprout from the trunks and limbs of many trees, seedlings emerge from the blackened soil, bird calls are 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 crown damage, dead saplings and trees, 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[11].

Some species have thick bark, which insulates and protects the growing tissue (cambium) beneath it. Species such as jarrah (*E. marginata*), marri (*E. calophylla*), 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 rootstock or storage organ, which produces vigorous shoots when the above-ground organs of the plant are killed by fire. The lignotuber of jarrah is a good example.

Other 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. Furthermore, the heat of a fire stimulates them to open a day or two later, allowing the release of seed on to the cool ashes which provide a perfect seedbed[4].

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[6]. However, in the drier jarrah forests, legume seeds are often buried by ants[28] and an intense fire is therefore needed to generate sufficient heat to penetrate the soil and stimulate germination[3].

Many native shrub species produce prodigious quantities of seed. Seedfalls of up to ten million seeds a 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 a square metre of topsoil are not uncommon beneath wet sclerophyll karri forests[6].

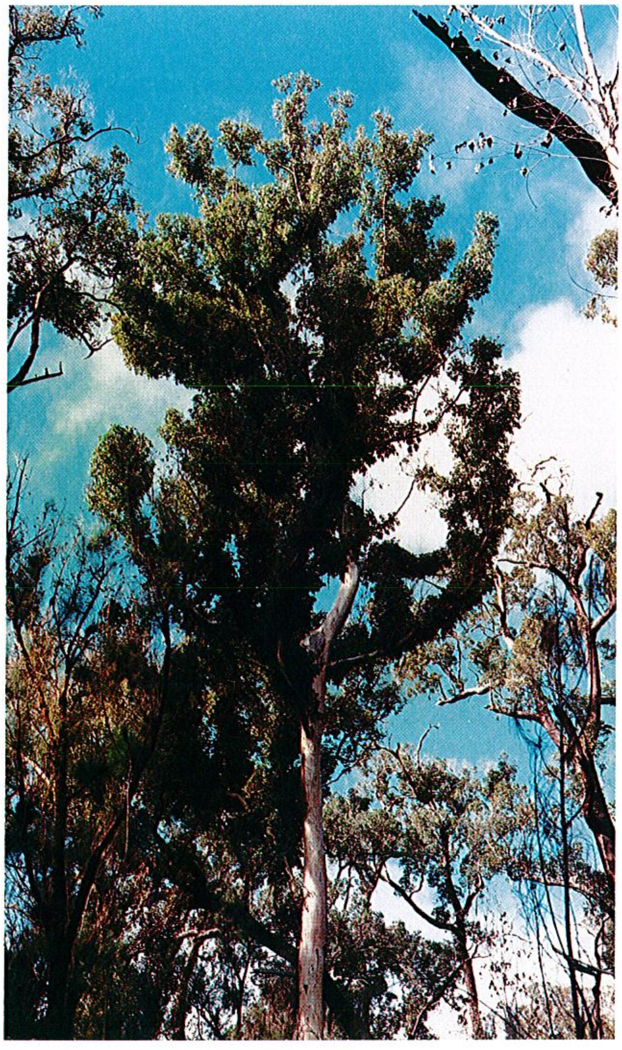
No two fires are ever the same. They vary in size, intensity and pattern of development and furthermore, as we have seen, different sections of the same fire can differ greatly in behaviour as a result of wind, day-to-night fluctuations in temperatures and humidity, or changes in fuels or slopes. This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

Apart from site effects, which can be over-riding, *fire intensity* is probably the most significant factor to consider when discussing the effects of fire on the native flora. For example, on certain sites in the jarrah forest, high intensity fires will germinate thickets of legumes. Low intensity fires, on the other hand, tend to encourage rootstock species and diminish legume thickets[25, 6]. When all other factors are more or less equal, fire intensity is determined by

▲ Following an intense fire the forest looks devastated. *(W. R. Wallace)*

▼ Nature is resilient and the forests of the south-west recover extraordinarily quickly following even the fiercest fires. Eighteen months later, tree crowns have recovered and a profusion of wildflowers appear. *(Tom Leftwich)*

▲ The monstrous woody fruits of the banksias protect their seeds even during the fiercest fire. (Dale Watkins)



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.

However, inside the forest, detailed 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[27].

A fire such as this also triggers a well-defined plant succession. Small colonising 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.

◀ Buds protected deep beneath the bark sprout epicormic shoots which form a new crown on karri (*E. diversicolor*) trees following a hot fire. (Dale Watkins)

▲ It is possible to accurately prescribe the intensity of fires. The photographs illustrate a low intensity fire with low flame
▼ height and a fire of higher intensity with flames of a metre or more high. *(Tom Leftwich)*

▲ Many species of acacia require heat stimulation of their seeds to germinate. In the jarrah forests seeds are often buried by ants and high intensity fire is necessary to create enough heat to penetrate to the buried seed. *(Les Harman)*

◀ Coral creeper (*K. coccinea*) germinates and grows vigorously during the first two years following high intensity wildfires. *(Tom Leftwich)*

Fire and animals in Western Australia

Like the flora, the native fauna has incredible tenacity and is able to survive the fiercest holocausts. The historic 1967 Tasmanian bushfires burnt about 250 000 ha at extremely high intensities and destroyed much wildlife, yet the remarkable feature of this fire was not the deaths but the survivals. Although hundreds of birds, caught up by the strong winds, were killed by heat suffocation and carried out to sea, and many kangaroos and other animals were incinerated, 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 found in less severely burnt areas soon after the fires had passed. Similar observations were made after a wildfire in Nadgee nature reserve in New South Wales[29].

Data from experiments investigating the effects of cooler fires on the animals in the forest is increasingly available. It has been shown that some 80 to 90 per cent of the insects and other tiny inhabitants of 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[19,1]. 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 special techniques when animals are captured, tagged, released and then later recaptured again, 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[6]. In any case, population numbers increase rapidly through breeding and through recolonisation of the burnt areas by animals from neighbouring unburnt areas[5].

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 30 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

Figure 4

Sightings of kangaroos and wallabies in forest areas are related to the time since the last prescribed burn. Kangaroos in particular show a very distinct preference for the fresh grass shoots on recent burns.

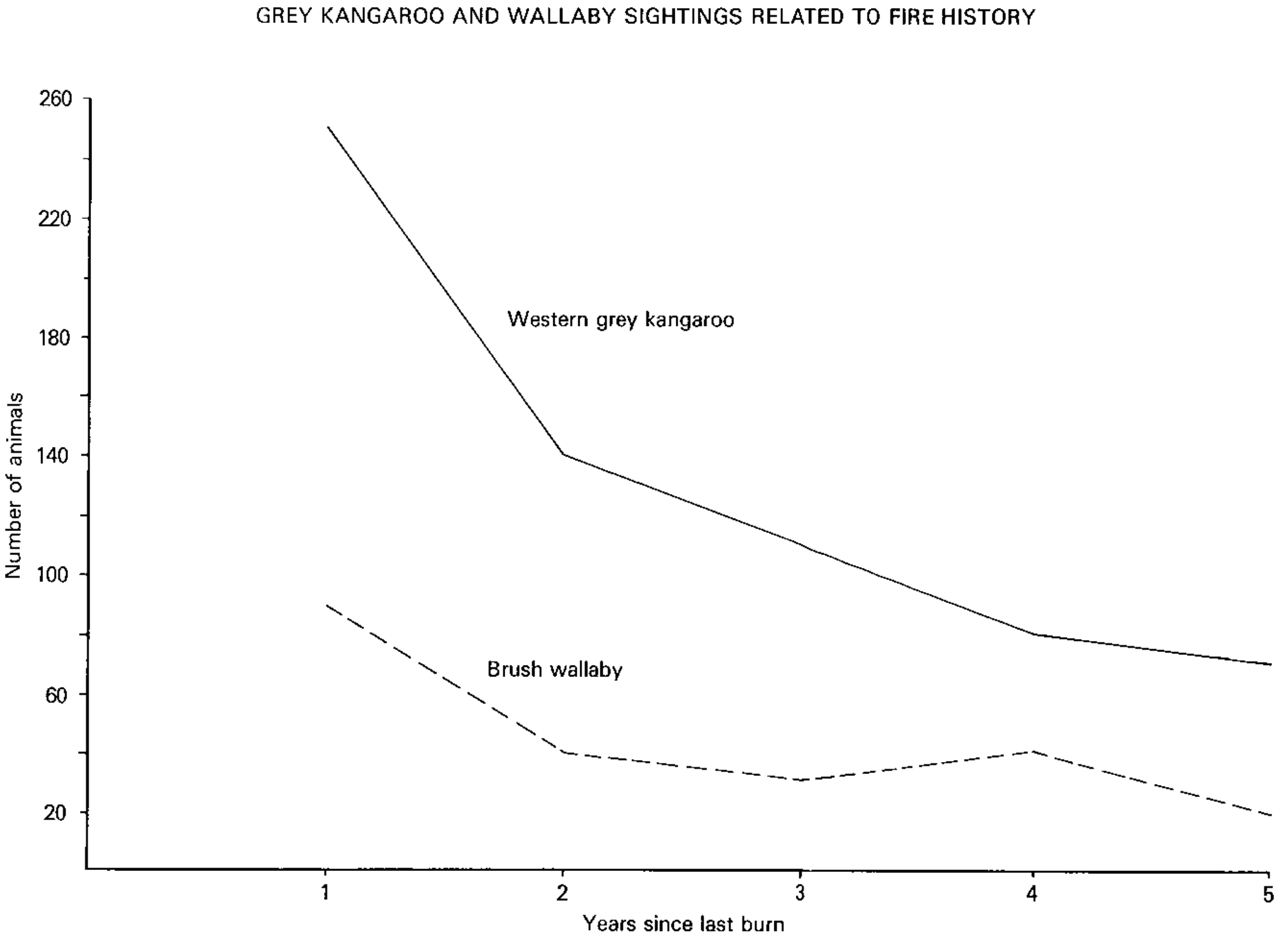
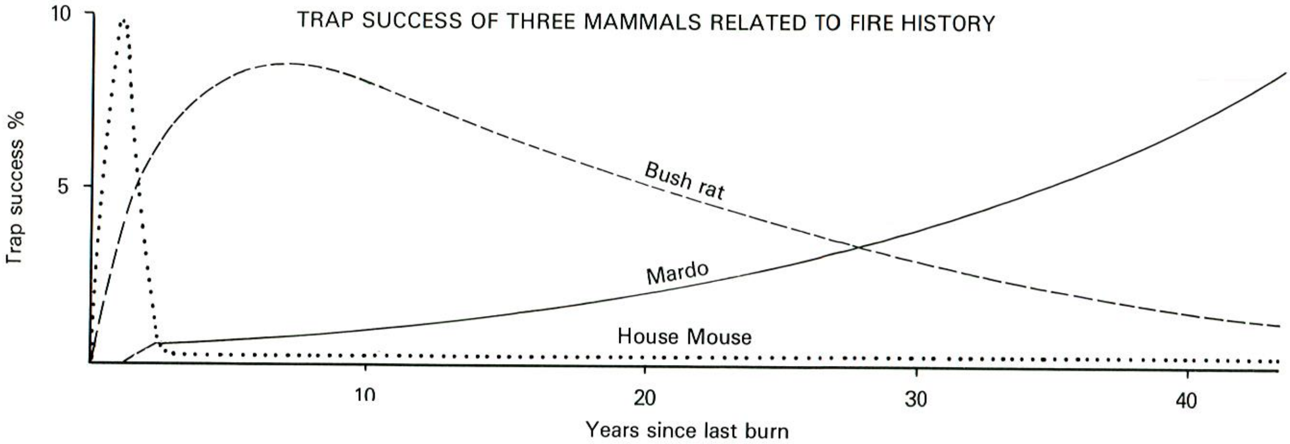


Figure 5

Small mammal trap success in relation to time since the last burn. Introduced mice prefer recent burns, the bush rat population is highest a few years later and the mardo prefers unburnt areas.



▲ Ring-tail possum (*Pseudocheirus peregrinus*) photographed during a spotlight survey two years after a fire. *(P. Skinner)*

▲ Tammar wallaby (*Macropus eugenii*) trapped during fire ecology research. Note numbered, metal ear tags. *(Tom Leftwich)*

▼ In some areas tammars live in thickets of heartleaf (*Gastrolobium bilobum*) which require periodic fire every 20 to 30 years to regenerate. *(Tom Leftwich)*

▼ The small marsupial mouse (*Sminthopsis murina*) has been found breeding prolifically in forest burnt only two years previously. *(Tom Leftwich)*

Figure 6

The frequency in terms of years are only very approximate. Fires of higher intensity may occur at lower frequency intervals, and it is also possible for lower intensity fires to occur at the higher frequency intervals, depending on climate and other factors.

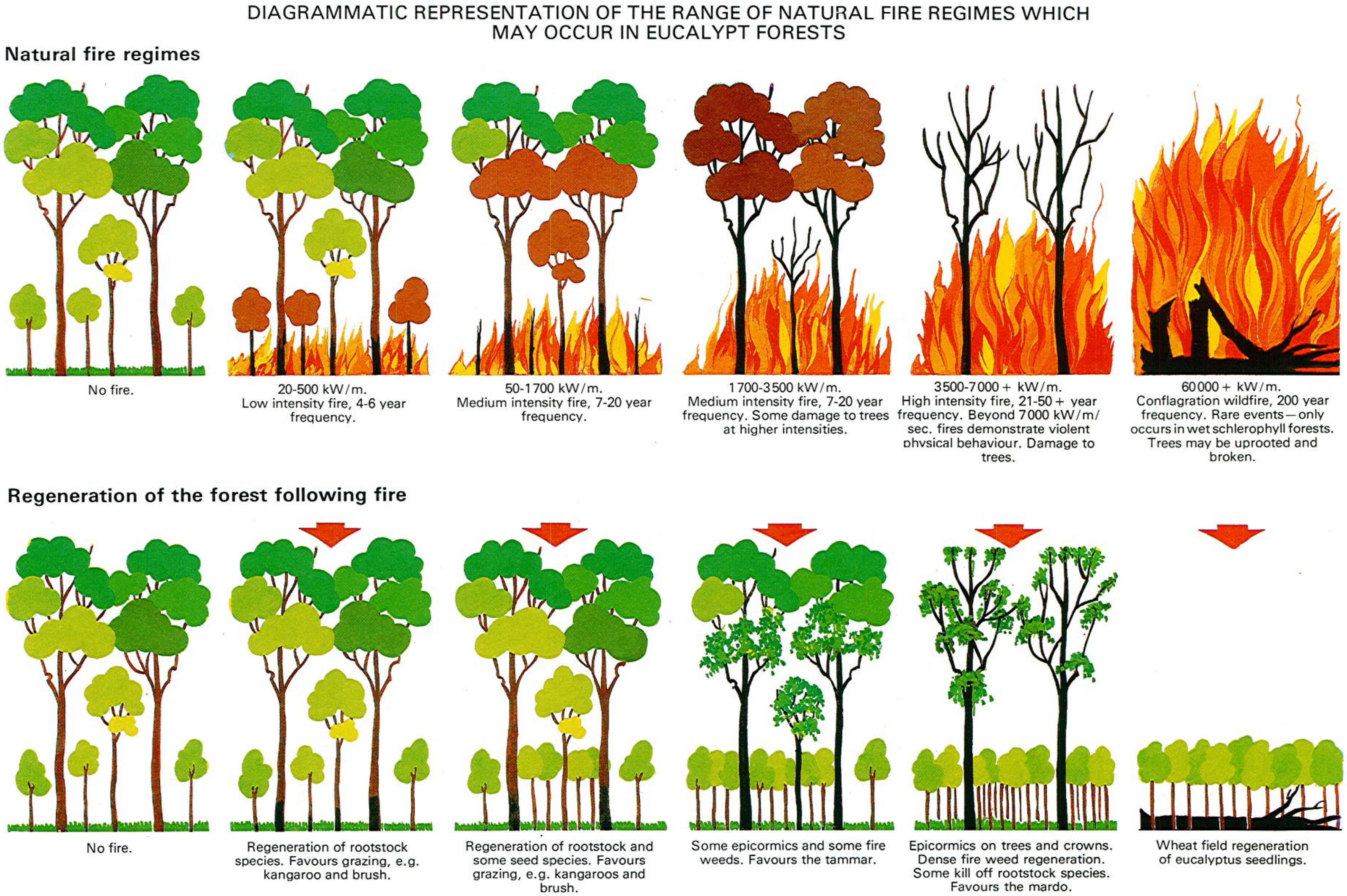
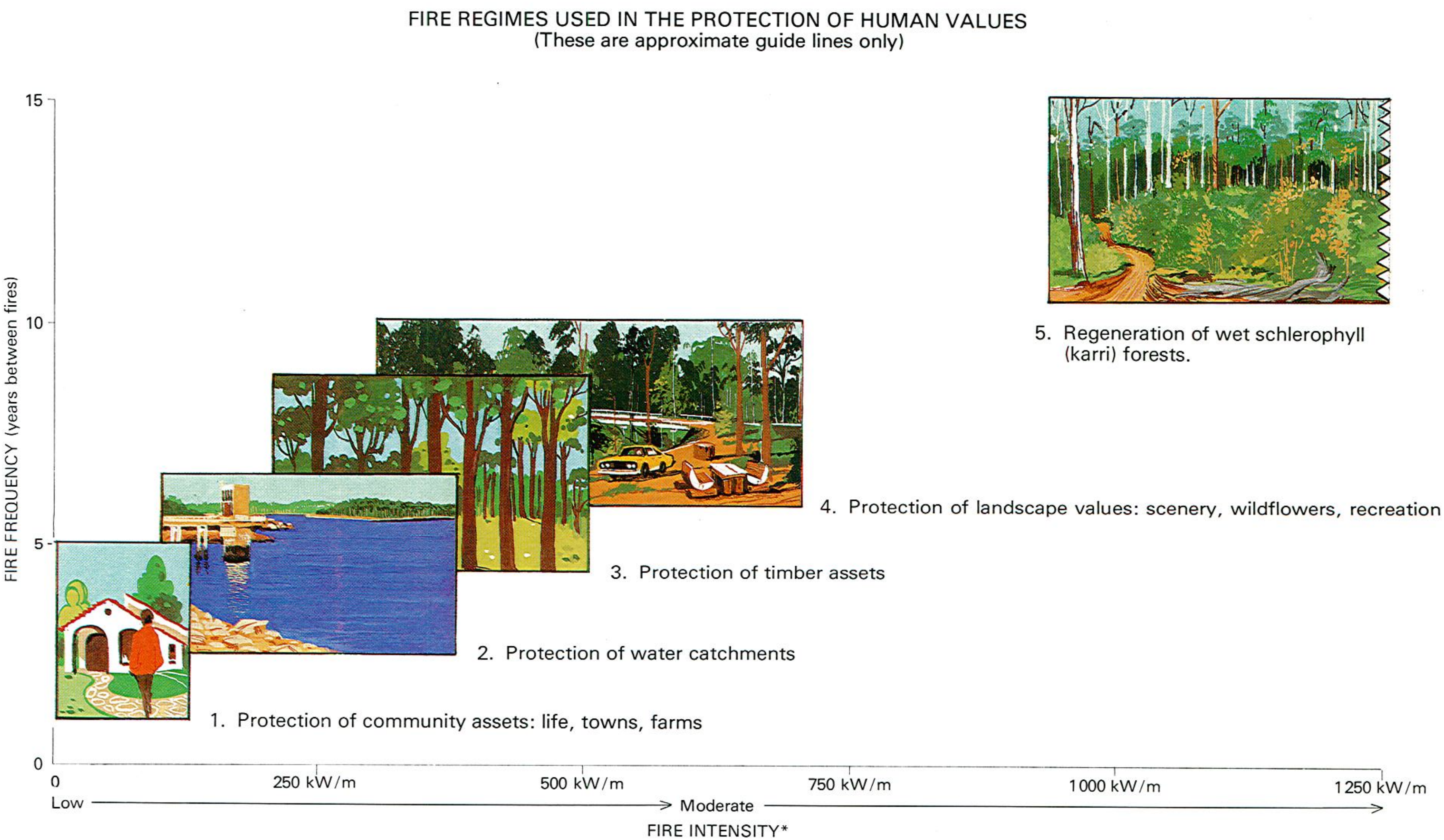


Figure 7

This diagram illustrates how different fire regimes (i.e. fire of different frequency and intensity) may be used for protection of different human values. For example, frequent low intensity fires offer the safest means of maintaining low fire hazard around towns and farms. Less frequent fires of higher intensities may be used in the regeneration of karri. Fires in between these extremes may be used to protect other values, e.g. water, timber and landscape.



* Notice that the fire intensities used by man are within the low to medium intensity range when compared to fires in nature.

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. 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. One species is known which appears to be ill-adapted to frequent fires—the mardo or marsupial mouse (*Antechinus flavipes*). Dense populations of this species 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 colonise 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[18], 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[33]: its productivity declines and the diversity of plant and animal species is reduced.

In the eucalypt forests of south-west 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[36], and others can be leached from the ash and carried away from the site in rainfall run-off. While 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[13, 31].

In the northern jarrah forest, where intense 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 essential basic data on which to make management decisions.

The importance of nitrogen in the ecosystem is perhaps most evident among 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 kangaroos 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[2]. 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[16]. 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[5].

▲ The mardo (*Antechinus flavipes*), another marsupial mouse, favours forest areas unburnt for long periods.
(*Tom Leftwich*)

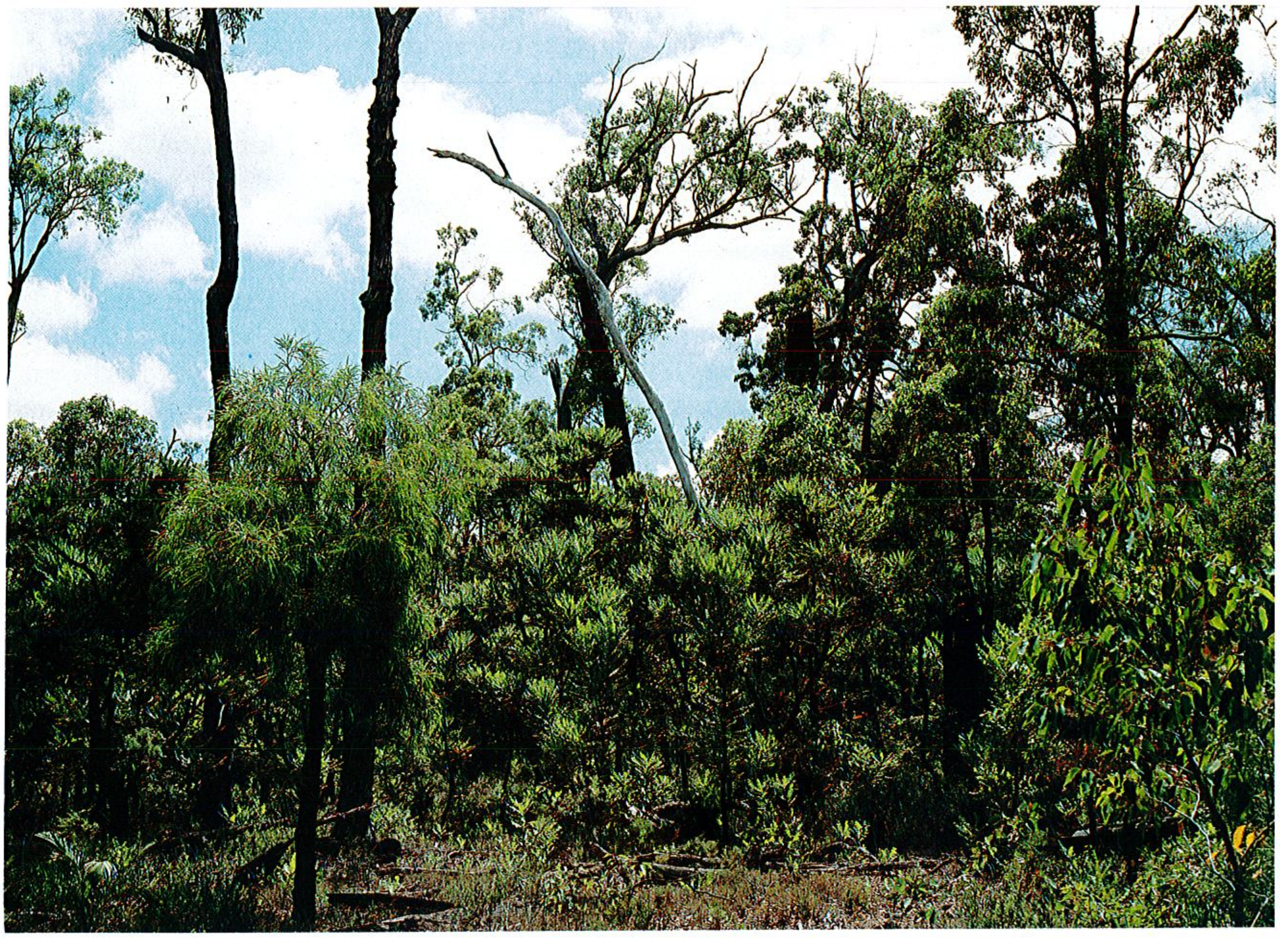
Fire and forest disease

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 per cent 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 while this work is still in its infancy, it has nonetheless revealed the following two points: First, 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 disease resistant native legumes. The banksias provide a good food source for the fungus and thus favour its spread and survival. Second, 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[31].

The inter-relationships 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 changes in fire policies in the future.

▼ Dense thickets of leguminous understorey (*Bossiaea laidlowiana*) provide an input of nitrogen in the karri forest. Such species germinate best following intense fires. (*Tom Leftwich*)



▲ Opening of the forest by logging, together with repeated cool fires has encouraged, in places, an understorey of *Banksia grandis,* a species which harbours the jarrah dieback fungus *Phytophthora cinnamomi.* *(Tom Leftwich)*

Nodules on roots of native legumes contain bacteria which fix atmospheric nitrogen and improve soil fertility. *(Les Harman)* ▶

5. THE FUTURE

In the preceding chapters we have tried to emphasise 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.

It seems that, while 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 most effective and safest tool available; to forego its use would be foolhardy.

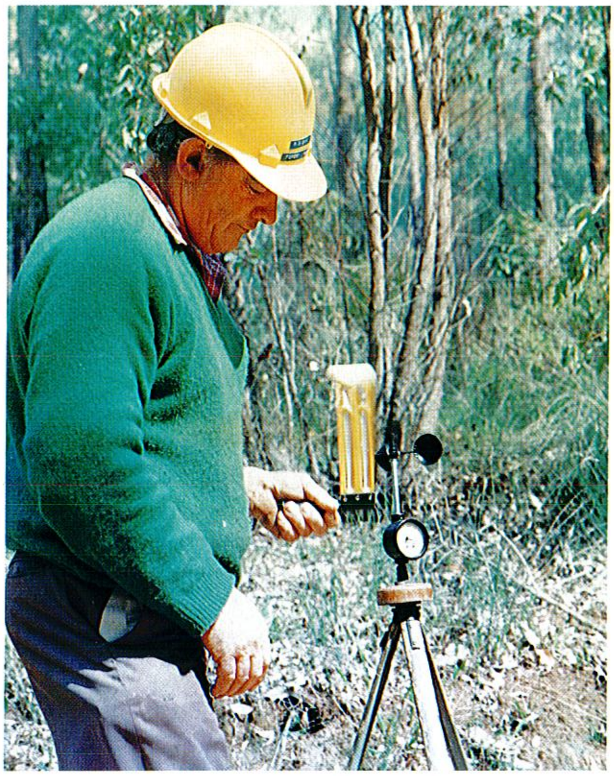
It would be equally foolhardy to forget that the ecological position of fire in the forest is very complex. Its effects and influence are still far from fully understood. Present practice must therefore be seen

▼ A sea of bright yellow, an *A. pulchella* thicket resulting from an intense fire three years previously. Such thickets may inhibit the spread of the dieback fungus. *(Tom Leftwich)*

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 equally satisfy all requirements of the forest system. At one extreme, short-rotation mild spring burning obviously maximises 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 Fig. 5, 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.

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 (M.P.A.s). Different areas of State forest are designated with different sets of specific management objectives which receive priority over all others. M.P.A.s 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

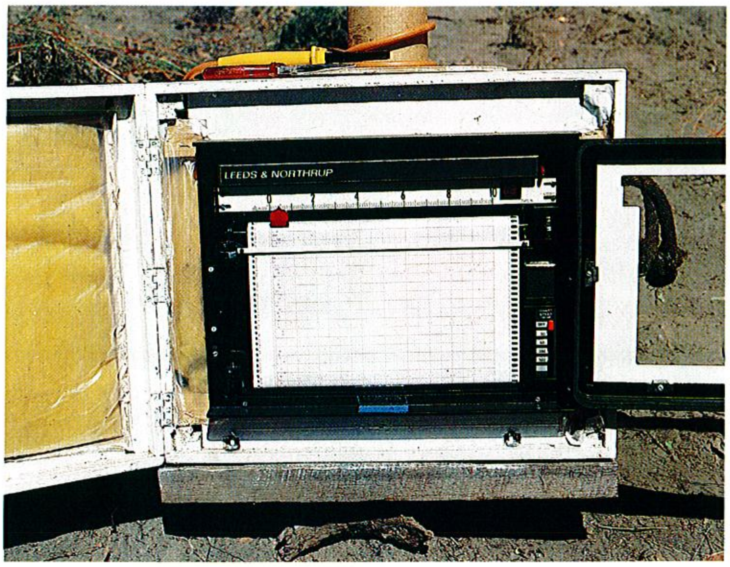


▲ A hygrometer measures wind speed during an experimental fire lit by a research team to collect data on fire behaviour. *(Tom Leftwich)*

particular attributes can be enhanced by special treatment.

Most research into fire ecology is now being focussed on fire effects at the species and population levels and on the complex relationship between fire,

▼ Multi-point data logger. Used to measure soil temperatures during fire behaviour studies. *(Tom Leftwich)*



▼ Tammar with radio tracking transmitter and collar. Radio tracking is one technique used by fire ecologists. *(Tom Leftwich)*

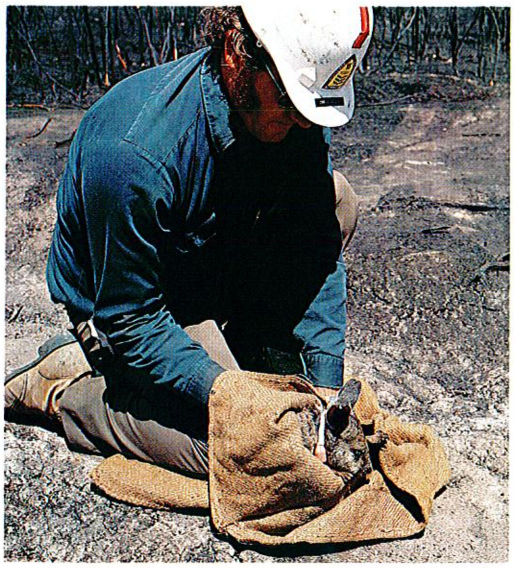
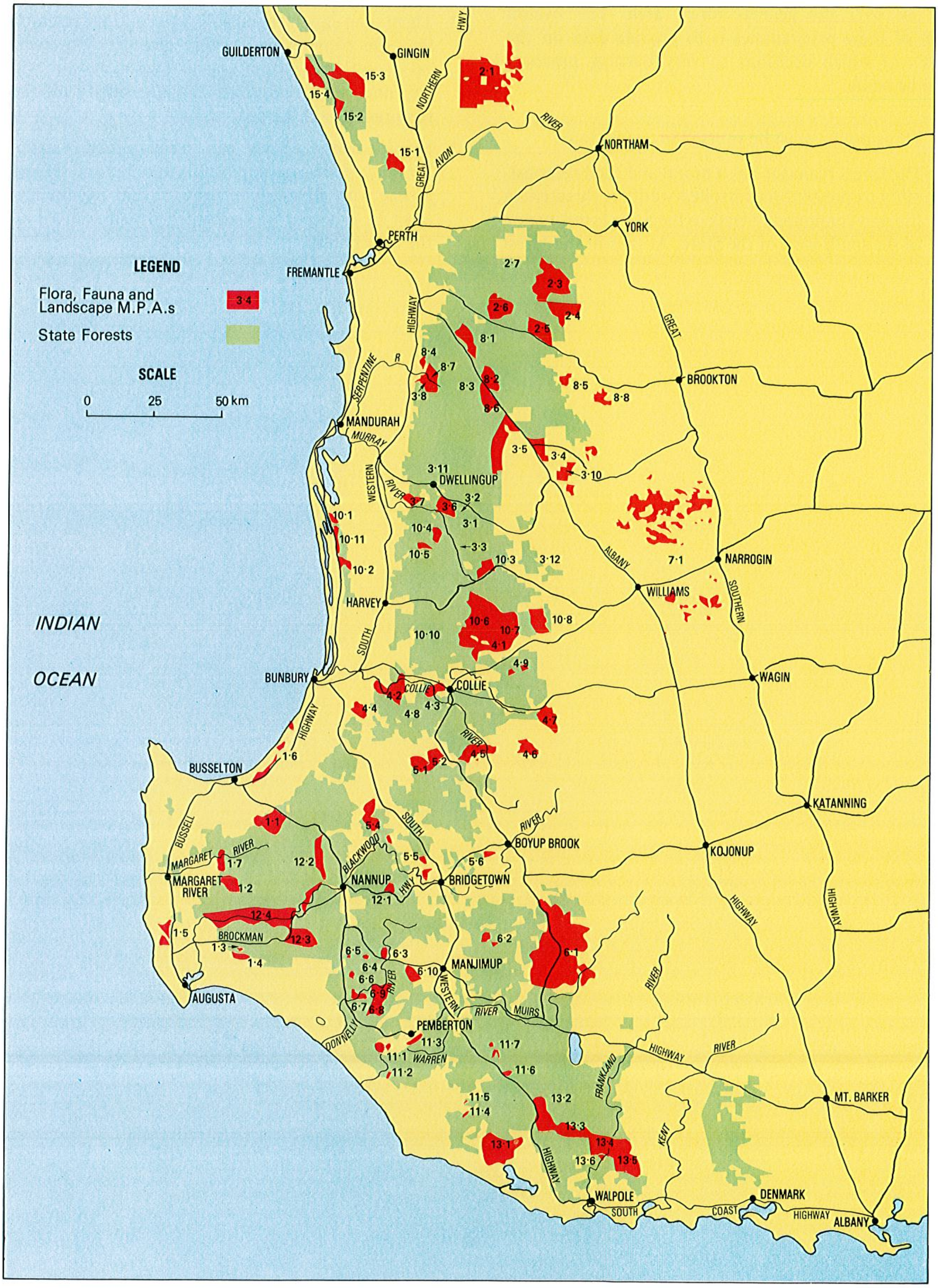


Figure 8

Some of the areas set aside in which the management priority is conservation of flora, fauna and landscape values. Such areas may receive special individual fire treatment in the future.



native legumes and dieback. Included in the research is work on the effects and practicability of more intense 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, easy solutions will not appear overnight, nor will any one simple approach equally satisfy 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.

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