Eucalypt Ecology As Related to Fire

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THIS PAPER attempts to bridge some of the gaps in experience and in the literature and it reinterprets some eucalypt morphology in terms of its possible significance in a fire environment. It develops an ecological approach to understanding and managing both the eucalypts and their fire environment.

THE AUSTRALIAN FIRE CLIMATE

Australia's climate is to a great extent governed by the combination of a large land mass and descending dry air which produces a high pressure zone. In summer this zone moves south and the land-heated air spreads outwards to give Southern Australia a hot dry summer. This is replaced in the north by a low pressure area which develops over the heated land and moist air is drawn in from the tropics giving northern Australia a wet summer. In addition a north-east circulation between the large continental heat low, and a slow moving high on the Tasman Sea periodically bring this wet summer influence right down the east coast to Tasmania. Cold fronts and small depressions moving in from the west lift these moist air masses to produce thunderstorms.

In winter the high pressure zone moves north to produce a dry northern winter. This is accompanied by a more northerly course for outbursts of cold, dry, descending antarctic air which take the form of cold fronts. This cold air mixes with moist Indian and Southern Ocean air to produce a marked winter rainfall from S.W. Western Australia to most of Tasmania.

These cold fronts also occur in summer at about weekly intervals and cause the most serious fire weather in southern Australia. This is partly due to the fact that both the antarctic and the continental air masses are dry and the temperature drop associated with the change is frequently insufficient to cause rain. It is partly due to lightning storms that are associated with the front. However the most important effect is on wind. As the front moves eastwards very hot dry air is funneled from the dry centre across S.E. Australia.

Hence most of Australia that is wet enough to grow eucalypts also experiences marked dry periods, a chance of lightning ignition, and bad fire weather. It is therefore not surprising that every-where the eucalypts grow there is evidence of past fire at least in the form of charcoal on, or in the soil. This fire environment extends beyond the range of the eucalypts both at the wet and the dry end. Even the arid centre burned in January 1969 following a wet year, and the wet tropical rain forest near Cairns once burned after an unusually dry spell.

Lightning fires occur now (Luke, 1961) and no doubt occurred for a long time before the coming of man to Australia. The scale of climatic patterns that produce the Australian fire environment and the present widespread distribution of both the eucalypts (Fig. 1) and lightning fires make it likely that the eucalypts evolved in an environment that has always included lightning ignition.

The other major source of ignition, man, did not occur in Australia until millions of years after the eucalypts evolved and his effects will be discussed later.

THE EUCALYPTS AND FIRE WITHOUT MAN

Seedling Establishment:—Except for young stands of pure regrowth, eucalypt forests nearly always have some seed on the trees.

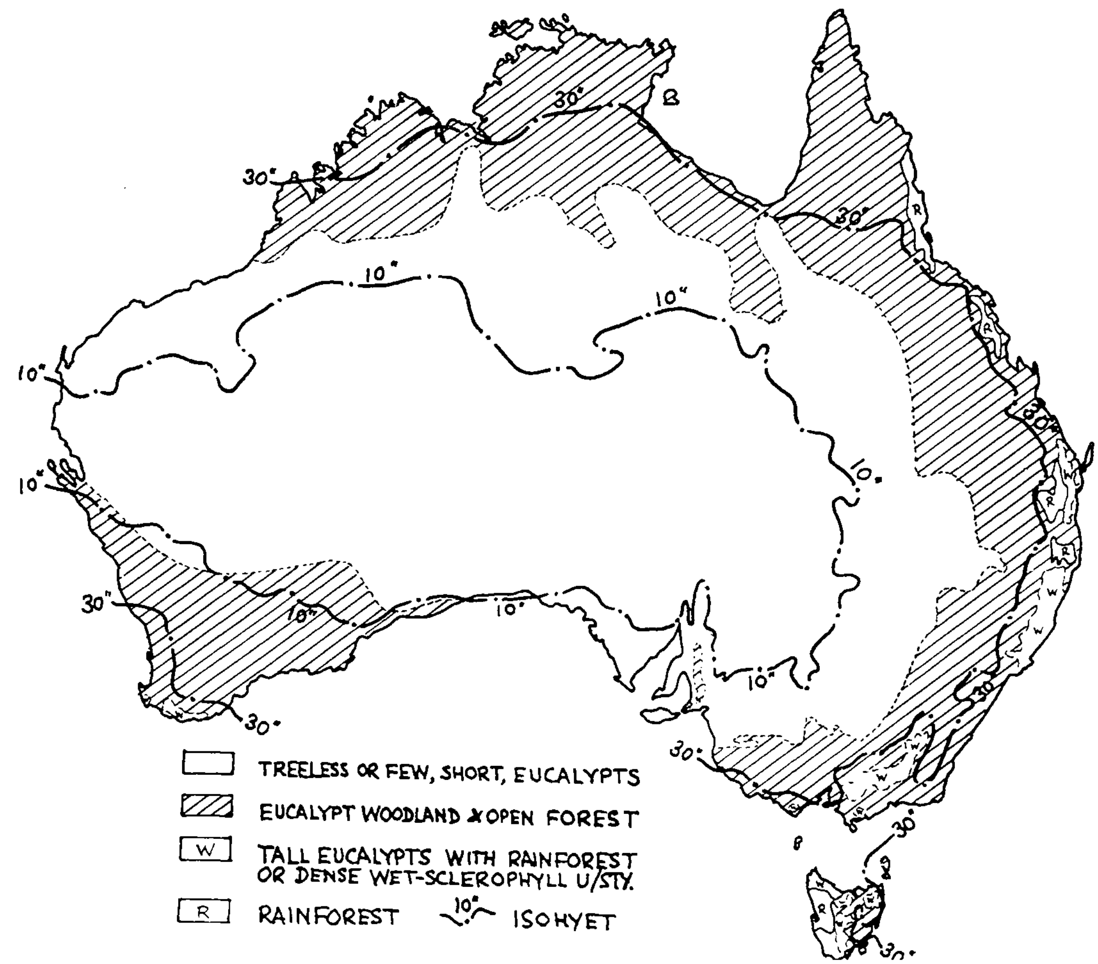


Fig. 1. Map of Australia showing the distribution of eucalypt forest and woodland. Adapted from "Forest Trees of Australia." Forestry and Timber Bureau 1957.

Without fire this seed is generally shed over a 2 to 4 year period after ripening but seed-shed is accelerated after fire depending on the damage suffered by the trees (See Cremer, 1962). The most intense seed fall occurs after severe fires.

Severe fires also prepare an excellent seedbed (Fig. 2). They consume all the organic material both above and within the upper layers of the mineral soil. This leaves a fine mineral tilth which collapses sometimes 2 or 3 inches when walked upon. Seeds that fall before the first rains consolidate the soil are buried up to ½ inch deep and they are protected from insolation, dehydration and seed robbing

FIG. 2. Eucalypt forest near Hobart after the 1967 wildfire. Note severe damage by crown fire but also note excellent conditions for regeneration. (see text).

insects. Cremer (1965) found the germination of *Eucalyptus regnans* seed sown at various depths was three times as great at ¼ inch deep as on the surface or at ½ inch. Lack of an organic substrate following the fire minimises fungal infections.

The death of the previous forest brings transpiration to a halt and allows the rains that follow the fire season to bring the successive layers of the soil to field capacity ahead of the demands of seedling root development.

Severe fire and subsequent leaf fall increases light for germination and growth. However, the standing dead trees also provide a half shade that moderates the extremes of sun and wind and reduces both insolation and evaporation to some extent.

The summed effects of severe wildfire on seedfall, seed-bed, soil moisture, light and fungi, is to produce the optimum conditions for the establishment of eucalypt seedlings.

Seeds also germinate after light fires but in few numbers and they have to face much tougher conditions. Those that become established generally survive as slow growing or semi-dormant lignotubers and stunted seedlings (Jacobs, 1955). These are a source of regeneration

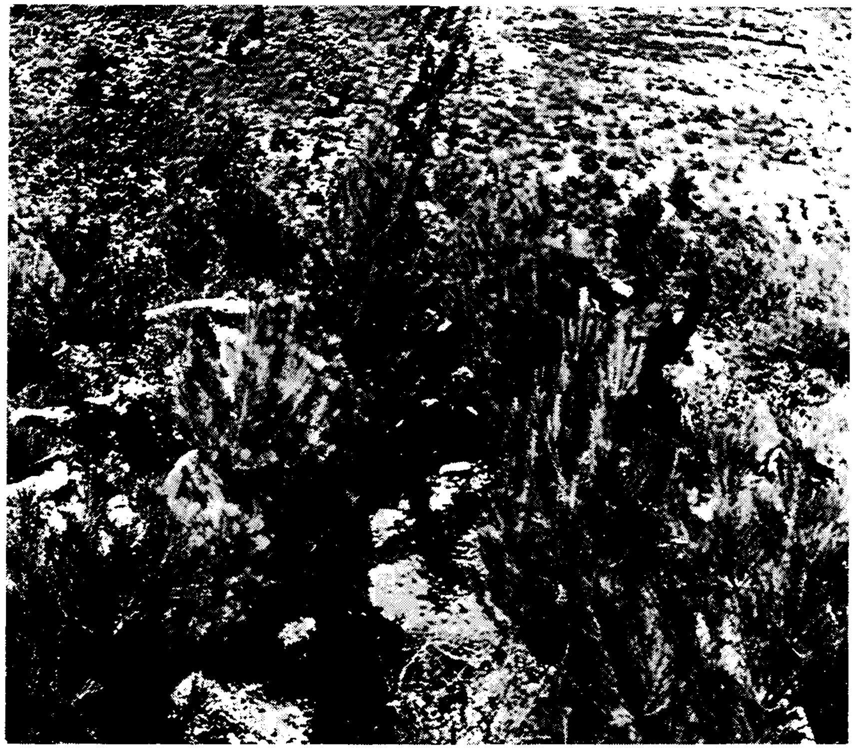


FIG. 3. The "ash-bed" effect. Eucalypt forest has been felled, burned, windrowed and burnt again prior to planting with *Pinus radiata*. Note the excellent growth of pines in the windrows and very poor growth elsewhere. Eucalypt seedlings exhibited the same differences in growth but have been removed because they overtopped the pines.

after subsequent light fires if large enough gaps develop in the canopy (Henry and Florence, 1966) but lignotubers surviving a long period without fire have little chance of regenerating the forest after fires intense enough to kill grown trees. This suggests that, before man's interference most mature trees in the eucalypt forest originated from seedlings that bypassed the stunted or lignotuberous stage.

With no fire at all, and in the absence of disturbance by man, regeneration is practically non-existent in the wetter forests (Ashton, 1956, 1962; Gilbert, 1959; Cunningham, 1960).

Fire and Growth:—The optimum conditions for eucalypt germination already discussed are also optimum for growth. Growth rates of both seedlings and surviving lignotuberous shoots seem to be related to fire intensity. This is particularly marked on dryer sites on which the eucalypt have been clear felled, windrowed and burnt in preparation for pine planting. Growth of both pines and eucalypts in the vicinity of the burnt windrows is spectacularly greater than between the windrows (Fig. 3). This has been called the "ash bed effect" and is described by several writers (Hatch, 1960; Pryor, 1960; Cromer, 1967). Part of this effect is apparently the removal of some organic inhibition in the surface soil rather than just a direct fertilising effect. This same organic inhibition may be the cause of the semi-dormant lignotuber or stunted seedling stage already described. The inhibition is removed by the greater heating of the soil under windrows. On sites with a better overall distribution of heavy fuel (i.e. longer unburnt—generally wetter sites), the growth after fire can be uniformly good and "wheat-field" regeneration results. But poor burns on these wetter sites also produce extremely slow growing eucalypt seedlings.

The stimulation to growth after severe fire is very marked and it lasts for at least 20 years (Hatch, 1960). Seedlings on severe burns grow straighter and faster in height and in volume, than those on mild burns. Where there is a mosaic of light and intense burns (i.e. dry logs in sparse fuels) the seedlings on the intense burns quickly dominate the site.

Early Competition:—In the wetter eucalypt forests (Fig. 4) many of the wet sclerophyll understorey species regenerate after fire from seed that is stored in the ground. (This is not so for the eucalypts which germinate from seed shed after the fire). Germination of the ground stored seed is very much stimulated by light fire. The combined effect of slow eucalypt seedling growth and a dense crop of understory seedlings following a light fire can reduce the eucalypt stocking appreciably and prevent the survivors dominating their competitors for many years (Cunningham and Cremer, 1965). On the wetter southern aspects in Southern Tasmania this is a serious problem to foresters because the site may remain understocked for a whole rotation. Unfortunately the situation is to a large extent self-perpetuating as the wet site, low eucalypt stocking, and high proportion of easily decomposed understorey leaves in the litter, combine to slow down the rate of fuel accumulation. When fires do occur they tend to be light and the cycle is repeated.

On the other hand severe fires, which consume most of the organic material and destroy a high proportion of the ground-stored seeds, also reduce competition and the eucalypts grow rapidly and soon dominate the site.

Fig. 4. Left. Tall Eucalypt forest with wet sclerophyll understorey. Without man-made fuels this type is difficult to burn under 20 years. Burnt by past fires at about 50–100 year intervals.

Fig. 5. Right. Open eucalypt forest with short dry sclerophyll understorey. Fires are quite frequent (4–10 years) but not as damaging as those in the wet sclerophyll.

A somewhat similar situation occurs with the dry sclerophyll understorey species in the dryer forests (Fig. 5). There, in addition to ground-stored seeds, many of these species shoot strongly from the base after light fires but are killed by severe fires.

Fire and Native Browsing Animals:—In mild fires the native browsing animals appear to be able to take shelter in damp or stony places and they quickly re-invade the burnt area to feed on the resulting "green pick." In this situation slow growing eucalypt regeneration is often completely eaten out.

With large intense fires these animals are killed or driven off huge areas. Re-invasion is slow and browsing severe only on the edges of the burnt area. These intense fires produce dense stands of fast-growing seedlings which are soon out of reach of browsing animals (Fig. 6).

This interaction of fire and browsing results in the preservation of the fast growing seedlings on large and intense burns and the elimination of lesser seedlings on lesser burns.

Resistance to Fire:—For eucalypts to survive in a fire environment there must be some natural systems of fire protection in the seedling stage until they are old enough to seed. After severe fire there is very little fuel and conditions are optimal for decomposition. Available nitrogen and other nutrients are high. In the early stages of growth the seedlings form part of a green carpet of live, moist, leaves in good contact with an abundant soil water supply. After 2 or 3 years the first leaves fall off and rapidly decompose. In the fourth year the second year leaves become fuel and they also decom-

FIG. 6. Eucalypts eliminated by browsing outside fence. However once over 3′ high the seedlings are not browsed even though the fence has been removed.

pose rapidly, and so on. It is not until about the tenth year that appreciable quantities of dead materials start to be produced and to accumulate. Put another way, it has been found that litter production is proportional to basal area (Reukema, 1964), and for the first 10–15 years there is little basal area. In the wetter forests (e.g. Fig. 16) this fuel-free-period may approach 100 years because of good decomposition (Mount, 1964). On the other hand, it may be as little as 6 months with some annual grasses in Northern Australia (Stocker, 1966). In the drier eucalypt forests it probably averages 10–15 years after severe wildfires.

This fuel free condition is much shorter after light fire when the previous crop of trees is still alive. In this case the seedlings have a poor start because of a lesser ash-bed effect. They have to compete with mature trees. They have to survive more intense browsing and grow in litter being shed from the surviving mature trees and accumulating at the rate of ½–1 ton/acre/year. This litter not only depresses growth directly through litter leachates (Ashton, 1962) (Florence and Crocker, 1962) but is fuel for fire long before the seedlings are big enough to survive fire.

Juvenile leaves which are very different from the mature leaves are characteristic of many of the eucalypts. They are especially common on species that grow in dryer areas. These leaves are often glaucous and reflect more lateral radiant heat than the green adult leaves. It is possible that they decompose more rapidly. The change to adult leaves appears to take place at a certain height above ground level for a particular species rather than at a certain age or stage of development (Fig. 8). These observations suggest that juvenile leaves may be an adaptation to improve the survival of seedlings in light fires.

In larger trees, fire resistance is very much a function of bark thickness (Vines, 1968; Gill and Ashton, 1968). Moreover, bark thickness appears to be related to fire frequency. Thin barked species occur where fuel accumulation rates are low and fires less frequent. This can be explained quite well in terms of plant wastes as dead bark and dead leaves are both waste products of the living organism (see later).

For the eucalypts, crown damage occurs at lower fire intensities

FIG. 7. The open crowns and pendant leaves of the eucalypt allow much light through to dry out the forest floor and stomates on both sides of the leaves allow rapid transpiration. Both factors assist ground fire. On the other hand the effect of radiant heat from ground fire is reduced by the vertical leaves and the chance of crown fire reduced by the discontinous canopy.

than stem damage and MacArthur (1962) showed that scorch height was related to flame height. This means that rapid growth to great heights is an important fire resistance characteristic. Contributing features are branch-shed and the location of the live crown at the branch extremities. Even the leaves hang vertically and so minimise the effects of radiant heat from below (Fig. 7).

In contrast to the coniferous forests of western U.S.A. and Canada, running crown fires are relatively uncommon in eucalypt forests. This is partly due to the general lack of fuel between the forest floor and the live crown and partly to the more open nature of eucalypt crowns and their large leaves (Fig. 7). Crown fires do occur in stringybark stands where there is fuel all the way up the tree trunk. They can also occur in dense regrowth stands in exceptional fires (Fig. 2) but they tend to collapse at each lull in the wind or change of forest type.

FIG. 8. Left. *Eucalyptus globulus* sapling recovering from 1967 fire. Note different form of juvenile leaves and the way they appear to be limited to a certain height above the ground. These may be fire resistance adaptations.

FIG. 9. Right. Notice how the tall straight trees are being bent over by a Force 7 wind (about 35 mph) in the tree tops. However at 5′ there is only a back draft of under 2 mph. In the absence of crown fire such forests have a marked effect on wind and fire behaviour.

The seed for the next crop is protected from destruction by fire in three ways:—lack of fuel for crown fires; location of capsules below the leaves so that even if a crown fire does occur the heat flux received by the capsules is minimised; and the nature of the capsule itself. The mature capsule is particularly fire resistant because of its thick woody structure surrounded by moist living tissue. The valves that seal the capsule only open when the tree is killed or an abscission layer cuts off the sap from this live cover.

In the absence of crown fires, forest structure has a marked effect on fire behaviour by reducing the force of the wind. Wind speeds are reduced to between ⅓ and $\frac{1}{20}$th of the wind above the canopy depending on its height, density and number of layers (MacArthur, 1968; Luke, 1961; Tasmanian Forestry Commission 1968). In the dense forest, wind has little direct effect on the behaviour of the ground fire which is dominated by fuel quantity and moisture conditions (Fig. 9).

The massive fuel reduction that occurs in severe wildfires, the good decomposition that follows for several years, the form and colour of the juvenile leaves, rapid growth to a great height, branch-shed, pendant leaves located at the extremity of the branch, the woody capsules protecting the seed and the forest structure itself all help to resist fire. Paradoxically, given time, the same forests also produce the major part of the fuel for the next fire.

Pre-disposition to Fire:—A large part of the fuel produced by the eucalypts is leaf litter which in most forests accumulates about

FIG. 10. Forty years accumulation of fuel in a dense *Eucalyptus obliqua* regrowth stand. Note the long strips of "candlebark."

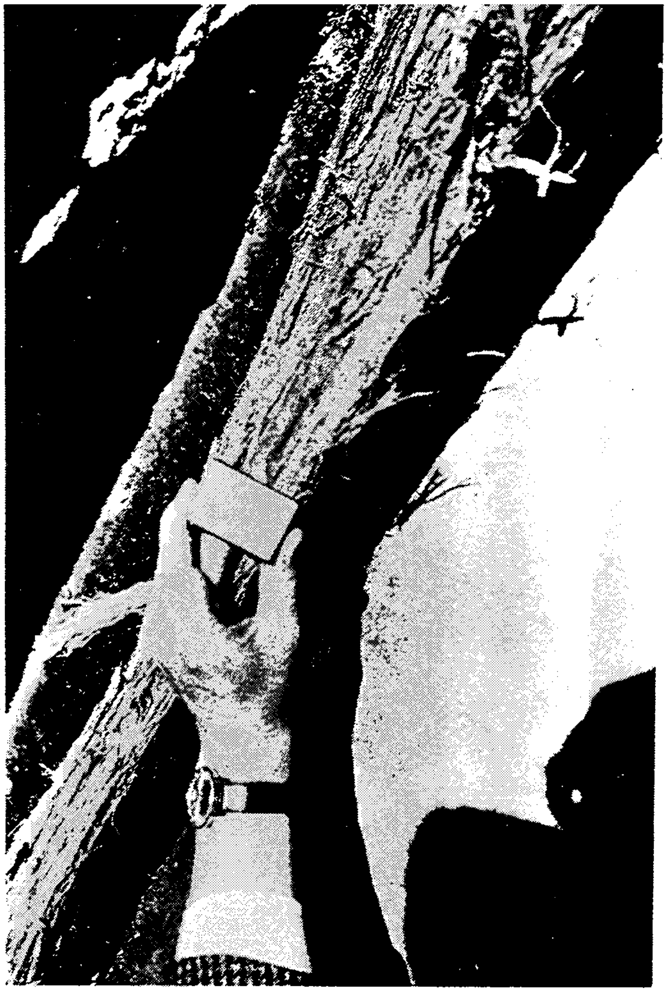


FIG. 11. Left. "Stringybark" from *Eucalyptus obliqua*. Such bark enables flames on the ground to travel up to where the wind can get at them and blow live sparks ahead of the main fire. It also provides excellent tinder for such sparks to start spot fires up to 1 mile ahead.

FIG. 12. Right. Spot fire caused by a stringybark spark from a fire ½ mile away.

½ ton/acre/year for at least 25 years (Hodgson, 1967; MacArthur, 1962; Peet 1965) (See Fig. 10) and even in the wettest forests Frankcombe (1966) has measured a duff accumulation of 64 tons/acre in forests 150–300 years unburnt. No-where in eucalypt forests is decomposition as complete as occurs in tropical rain forests.

Additional fuel occurs as dead twigs and branches and dead trees, but the most significant fuel is the dead bark. In some species this falls off the tree as plates or ribbons that form part of the forest floor litter. In other cases the ribbons hang on the trees and in the crotch of the branches and are the main source of fire brands for long distance spotting. In the case of the stringybarks this fuel takes

FIG. 13. Left. Fire in eucalypt forest. Note the bark burning on the left hand tree.

FIG. 14. Right. Recovery 9 months after the 1967 Hobart fire (Compare with Fig. 2). The lower epicormic shoots will eventually be suppressed and drop off as a normal crown shape re-develops.

the form of a thick clothing of the finest fluffy tinder ideal for mass short-distance spotting (Fig. 11, 12). These barks enable the fire on the ground to burn up into the top of the tree where the wind can get at it (Fig. 13) and blow sparks onto other stringybarks and dead trees ahead of the fire. This is especially important in the denser forests where the wind has little direct effect on fire spread at ground level.

Mass short distance spotting is probably the major cause of spread of the really big forest fires in Australia (Luke, 1961; Cheney and Barry, 1969). When combined with the less common long distance spotting it is not difficult to see how lightning and spot fires can ignite the whole eucalypt environment given time and fuel. The longer the time between fires the more fuel there is to burn. Lightning fires that start in deep heavy fuels can survive light rains (MacArthur, 1962) and stay alight for a long time. If bad weather occurs these fires develop high intensities, do much damage, and move quickly to cover great areas.

Recovery after Fire:—The eucalypts are particularly well adapted to recovery after fire. If the fire is severe, seedling regeneration is excellent. If it defoliates, but does not kill, the tree epicormic shoots sprout profusely (Fig. 14) (Jacobs, 1955; Cochrane, 1968).

Where light fires are common, so also are eucalypt species that produce lignotuberous seedlings which are capable of surviving frequent fires and which can fill the larger gaps that develop in the forest canopy by means of dynamic shoots (Jacobs, 1955).

One interesting point to consider is that as the eucalypts all regenerate from seed it can be assumed that there has always been seed of the species now present available after every great fire. This suggests that the factors that pre-dispose a forest to fire, (i.e. the accumulation and drying of fuel) may, at an earlier stage and in lesser quantities, initiate flowering and seed production.

Waste Disposal and Nutrient Recycling with Fire:—Unlike many European broadleaf forests there is usually not much organic material incorporated in eucalypt forest soils, even those unburnt for 300–400 years. Instead the more durable fraction of the litter accumulates as a duff layer (sometimes up to 12 inches thick) on the soil surface. This accumulation appears to be detrimental to the health of the eucalypts as seedling germination and rapid growth is associated with its absence. Experiments and observations by Florence and Crocker (1962), Attiwill (1962), and Ashton (1962) demonstrate the existence of some substances in litter leachates capable of halting seedling development. In periods of high rainfall these leachates are probably washed right out of the soil, but in drought their concentration in the soil solution increases. This concentration also increases with time as the depth of the litter layer increases. It probably changes in composition as some of the more durable fractions of the litter begin to decompose.

It has been observed by many authors that insect infestations are associated with mature, well stocked, stands and drought, which suggests that stand age and density are pre-disposing factors. This supports the hypothesis of plant wastes and indicates that the operative wastes are in the litter leachates "or root exudates."

It is interesting to note that the more durable eucalypt woods come from dryer, and the less durable from wetter, areas (Rudman, 1964). This suggests that the wood durability results from the accumulation, in the dead part of the tree, of wastes taken in by the roots in time of water stress. In this way, between fires, plant wastes are kept out of circulation in the durable part of the litter, in the bark and heartwood of the tree, and in the lignotubers of some seedlings (Mount, 1968). However, this disposal system may breakdown after many years without fire. For example, Ellis (1964) showed that the "die back" and death of *E. delegatensis* was associated with a cessation of frequent fire some 80 years previously

Fig. 15. "Dieback" of eucalypts over rainforest. The dead stags in the background are *Eucalyptus delegatensis* trees that have died 20–40 years ago about 80 years after the last fire. Treatment for this condition is seen in the foreground where live eucalypts have been logged, the stags and rain forest understorey felled, the area burnt and sown with *E. delegatensis* seed resulting in excellent regeneration.

(Fig. 15). Bowling and McLeod (1968) showed that "die-back" of *E. obliqua* in Southern Tasmania which is associated with *Armillaria mellea* is also correlated with lack of recent fire.

In the drier forests even shorter periods without fire can pre-dispose the forest to insect infestation as in the case of phasmids which spend part of their life cycle in the litter layer (Campbell, 1961).

The effect of most forest diseases is to open up the canopy and pre-dispose the stand to fire which in turn regenerates or rejuvenates the stands. In this way fire does the work that microorganisms fail to complete and is especially efficient in disposing of the more durable lignins and tannins.

When fire occurs it destroys the litter and duff and converts it back to CO_2 and H_2O and a very little NO_3 or NH_4. It consumes the dead outer bark and the wood of dead trees. The ashes produced are leached through the soil replacing hydrogen ions of organic origin and recharging the soil cation exchange capacity.

The success of the eucalypts is probably due to efficient waste disposal. The excellent growth after severe fire is a result of the massive destruction of wastes in the regenerating fire, while survival between fires is related to continuous waste storage in durable litter, bark and heartwood. In addition, periodic light fires can reduce wastes and the associated effects of drought, fungi and insects.

Long Term Competition:—Few species of the wet sclerophyll or dry sclerophyll understories occur naturally outside the eucalypt forest and these vegetations can hardly be considered as alternative cover. However, grass, bracken and rain forest can occur either under eucalypt or outside them and are presumably competitors for the site.

The eucalypts dominate most Australian forests because they are adapted to respond to the conditions that follow severe fire. But so are grass or bracken. Frequent burning favours these two types of vegetation which in turn produce fuels that favour frequent burning. The annual grasses are shallow rooted and dry out for most of the fire season. This can result in annual fires that, although light, are a major obstacle to the establishment of most eucalypt seedlings. Bracken produces a durable fuel that accumulates rapidly after age 2 and can carry intense fires at 4 to 5 year intervals. Bracken has the further advantage of 3–4 ft height growth in the first year which is enough to prevent eucalypt regeneration even in the absence of further fires where the bracken is dense (i.e. wetter sites). However the eucalypts are able to survive for long periods between fires and can shade out both grass and bracken in the absence of fire. But the rain forest is even better adapted to survive in the absence of fire.

Rain forest grows where the soil is seldom waterlogged but remains moist for most of the year. The trees have dense canopies of leaves horizontally oriented, with stomates only on the lower side, which effectively keep the wind and sun away from the forest floor and maximise air humidity under the canopy. These leaves, when they fall, are not in themselves durable and they decompose readily in the moist conditions. In the temperate rain forest this decomposition does not entirely keep pace with production because of the relatively cool conditions, and fuel gradually accumulates as a duff layer on the forest floor and as rotten wood, mosses, and lichens in the crowns. However, in tropical rain forests such accumulations are uncommon.

In the tropics and subtropics there is generally a sharp boundary dividing the eucalypt forest from the rain forest and there is little doubt that this boundary is determined by fire. The fire is determined by fuel which in turn is a function of soil moisture and the vegetation. But soil moisture changes gradually while fire boundaries have sharp edges. In this situation it is quite possible that the eucalypts stand their ground because better drying occurs beneath them than beneath the rain forest. This is due to their sparser, more open crowns of pendant leaves having stomata on both sides that maximise transpiration and that allow the sun to dry out the forest floor (Fig. 7). This drying slows down the decomposition of the large quantities of the relatively durable eucalypt fuels.

In the wetter parts of Tasmania there are many thousands of acres of "Mixed Forest" (Gilbert, 1958) where the eucalypts grow above temperate rain forests (Fig. 16). Gilbert suggested that this was evidence of active succession and Jackson (1965) postulated climatic change from dry (favouring the eucalypts) to wet (favouring the rain forest). However, in terms of a fire environment, an alternative explanation of dynamic equilibrium is suggested below.

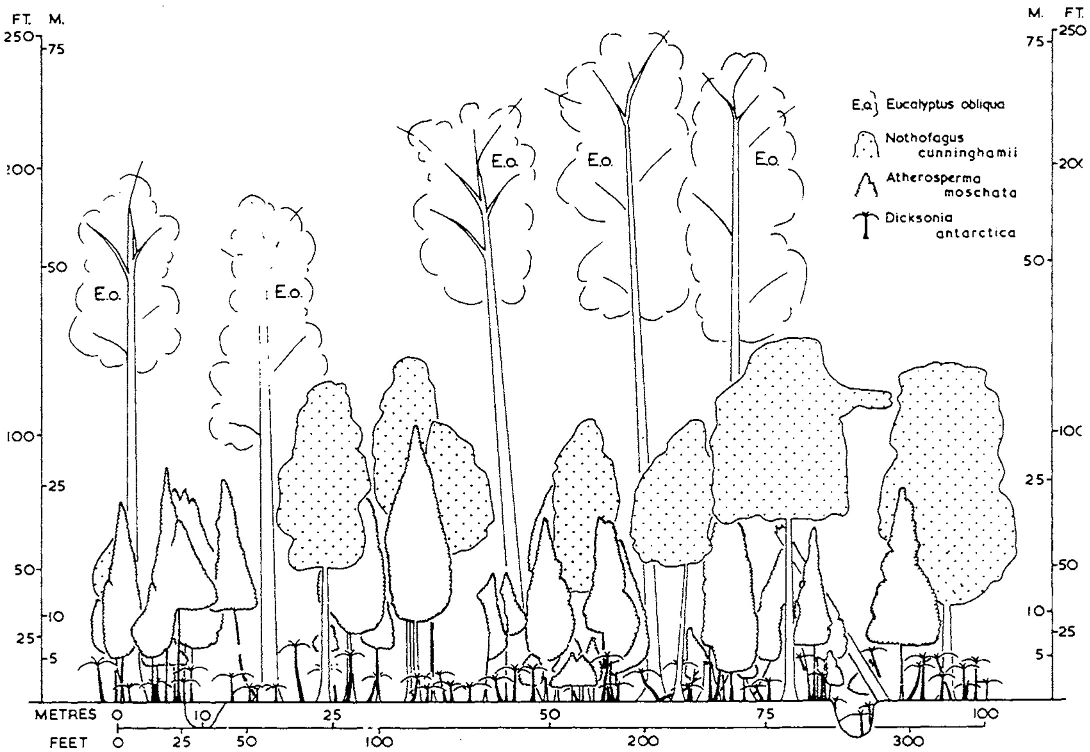


FIG. 16. Profile diagram of transects in "mixed forest" in Tasmania. Transect 50′ wide. The eucalypts originated from a very severe fire about 300 years ago. However a lighter fire about 150 years ago destroyed and regenerated the rain forest without destroying the eucalypt forest. In this type, quite near this transect, Frankcombe (1966) measured 64 tons (O.D.W.) of duff per acre. From "Eucalypt-Rainforest Relationships and the Regeneration of the Eucalypts" by J. M. Gilbert, Ph.D. thesis, University of Tasmania, Hobart 1958.

There also occur in Tasmania pure stands of temperate rain forest species that have been burnt at 100 to 600 year intervals. As the forests become decadent they open up and the duff layer and other fuels dry out. The most probable explanation of the Tasmanian mixed forests is that some eucalypts can tolerate 400 years without fire and most of the pure temperate rain forests burn at intervals of 400 years or less, hence both can occupy the same site as mixed forest.

Fires burn differently in different fuels and the reason that the patches of pure rain forest remain is probably because of the dense shade that is often found under fire-killed rain forest trees. This condition is unfavourable for eucalypt regeneration but suitable for regeneration of the rain forest species from seed or coppice (Mount, 1965).

In other areas fires may fell the rain forest and the site revert to grass. Where this occurs there appears to be a cyclic succession from grass to eucalypts, to mixed forest, to pure rain forest. Although both Gilbert (1959) and Ellis (1964) believed that the rain forest was the "climax" vegetation there is no evidence of successful regeneration of this type except after fire. The open conditions associated with decadence which might be suitable for rain forest regeneration are even more suitable for ignition by spot fires.

It seems likely that the eucalypts compete so successfully against alternative vegetations because they have evolved adaptations that enable them to flourish after severe fire and survive for a long time between fires.

The Inter-dependence of the Eucalypts and Fire:—On the one hand fire creates the conditions most suitable for regeneration of the eucalypts, hot fires for the best regeneration and growth and least competition, big hot fires to reduce browsing and to remove accumulated wastes. Subsequent light fires reduce competition and the effects of drought, insects and fungi.

On the other hand, the eucalypts provide the bulk of the fuels for forest fires. Not only more fuel than alternative forest species but more durable fuel and in some cases special distributions of fuels that aggravate fire spread.

Without fire there would be no forest eucalypts. Without the eucalypts there would be fewer or smaller forest fires.

The Eucalypt Forests Without Man:—It is likely that the climate that produced the fire environment before man arrived in Australia was not very different from that which exists today. Lightning caused the primary, and spot fires the secondary ignition and, in the forests, the eucalypts provided most of the fuel.

Electrical storms are not as common in Australia as in many other parts of the world (Komarek, 1964). For lightning to cause fire there has to be enough fuel and little moisture. Because of the shorter "fuel-free" period in the dryer forests, the greater rate of fuel accumulation and the generally lower rainfall, there is a relatively good chance of lightning causing ignition.

In the wet forests on the other hand, the fuel is dry enough for lightning to start a fire on relatively few days each summer. This is in spite of the greater interception of rain by the dense canopies and a probably higher frequency of lightning in the hills where most of the wet forests occur.

Once alight, the fire has to survive mild conditions before the arrival of bad fire weather. This is almost entirely a function of fuel quantity and moisture. In the dryer forests, the fuels are relatively undecomposed, burn only below 20 percent M.C. and are quickly consumed. In the wetter forests, duff layers are able to burn slowly at M.C.'s up to 50 percent and stay alight for a very long time.

If the fires are still alight on the next hot dry windy day they spread more rapidly in the dry forest than in the wet because of the better access to wind, better drying and generally more rapid combustion. On any one day, spotting is probably more intense in the dry types than in the wet and the total spread of fires is generally greater in the dry forests.

Fire intensity is related to fuel quantities and enough fuel to cause large fires in wet types also causes much damage and provides excellent conditions for regeneration. It is very likely that practically all fires in the wet forest were big and severe and that they occurred relatively infrequently when enough fuel had accumulated. The wet forests were therefore most likely even-aged or occasionally 2 or 3-aged stands quite like they are today.

In the dry forests there are many days each summer on which the fuel is dry enough to ignite but without man ignition must have been infrequent and irregular. Unlike those in the wetter forests, the eucalypts are more fire resistant and light fires in light fuels do little damage. Stands produced by lightning and spot fires alone were probably even-aged or with few ages because only after many years of fuel accumulation were fires severe enough to effectively reduce the previous canopy and allow regeneration.

It is therefore likely that before man's arrival most of Australia's eucalypt forests were essentially even-aged. Once an even-aged forest was established it would tend to be self-perpetuating. This is because of the "fuel-free" period and because if the period between successive lightning fires was short the second fire would tend to cover a small area or do little damage, whereas if there was a long period without fire the stand would be severely damaged and a new even-aged crop become established.

THE EFFECT OF MAN

Aboriginal Man:—Aboriginal man probably arrived in Australia about 18,000–20,000 years ago (Tindale, 1964). He was a nomadic hunter and gatherer who inhabited all but the dense wet forests and who carried fire with him wherever he went, generally in the form of a bundle of lighted sticks (Jackson, 1968). He used fire for warmth, to drive game and to attract game to recent burns. Intentional and accidental fires must have occurred wherever he wandered in search of game. In this way fire was well distributed over most of the open (dry) forests.

This meant that whereas lightning fires in the dry forest had been occasional and generally huge and severe, early man's fires were many and often, small and light.

Aboriginal man had few cutting tools and it is doubtful if he ever ventured far into the dense forest except shortly after the occasional fires there (Mount, 1965). He did not fell the forest and produce additional fuels. Because of the difficult access it is likely that the fire frequency in the wetter forest was little changed. These forests had a greater chance of being lit from the dry forests burning at their edges, but those burns that occurred early in the summer could have acted as fire breaks by the time the wet forests had dried out.

Over thousands of years the effects of aboriginal man in the fire environment of the eucalypts were probably as follows:—in the more populated, drier areas much of the regeneration was from lignotubers, growth was relatively poor because of a lack of an "ash-bed effect," the trees relatively crooked and multi-aged. In the wet forests and occasional unfrequented patches of dry forest, most of the seedlings germinated on the best "ash-bed" following severe wildlife. Stems were straight and the stands essentially even aged.

A change to frequent light fires in the places most visited by aboriginal man could help to explain the great variability in morphology of juvenile leaves between species that have very similar adult leaves. Juvenile leaves possibly evolved in the last 20,000 years.

Early Settlers:—European man has been in Australia less than 200 years and most of the bigger trees now present regenerated before his arrival. His early burning was more local than that of the aborigines because he was less nomadic. Near farms and populated areas fire frequency probably increased, elsewhere it may have decreased.

Prospectors and explorers made slight inroads on the wetter forest, which were seldom visited by the aborigines, and increased fire lighting in these areas. However, as the major spread of fires in these types is more or less fuel-controlled, the frequency of large fires was probably little altered before being logged or cleared for agriculture.

Much of the early clearing was done by ringbarking and burning. If the fire occurred while there was still seed on the trees dense regeneration often resulted and in a few places this regeneration has escaped browsing or a second early burn and now forms excellent stands. This was not the usual result. Generally the clearings were intensively browsed by both native and introduced animals who ate the regeneration as soon as it appeared. This prevented the re-establishment of the eucalypts which were replaced by more browse-resistant plants such as grass or bracken.

Changes in the Understorey:—In the wetter forest where lignotubers are less common the end results of clearing and grazing was all too often a sea of bracken providing little feed for either native or introduced animals. Once established this bracken produces fuel every 4–5 years for a fierce fire on a site that previously burnt only once in 20 to 400 years (Fig. 17). These more frequent fires often result in the wet forest being driven back well past the limits of the original clearing.

In the dryer forests the change is more subtle because of the greater resistance to both fire and browsing found there. Grass rather than bracken invades the clearing which is then gradually extended by browsing and repeated fire.

Stocker (1966) describes some Northern Territory eucalypts that are apparently in equilibrium with annual burning of native annual grasses. This is not the case further south where the native understorey is difficult to burn at less than 3 year intervals. Where this understorey is replaced by the more shallow rooting annual grasses

FIG. 17. In 1934 a fire here killed 250′ eucalypts and their rain forest understorey. In the foreground a second fire killed the regeneration and produced a dense stand of bracken which now produces fuel for man-made fire at 4–5 year intervals. This area was never logged. In the background can be seen dense stands of regeneration that followed the 1934 fire and which have resisted subsequent bracken fires.

more frequent fires occur. Eucalypt seedlings have difficulty surviving such frequent fires and the more intense browsing that follows.

Each fire fells an occasional old tree and the canopy gradually opens up while intense grazing prevents new seedlings from filling the gaps. In this way millions of acres of the more open dry eucalypt forests outside the tropics are disappearing and being replaced by grassland (Fig. 18).

Logging and Fire:—In the dryer forests logging has practically always been of the "sawmiller selection" variety. Disturbance of the forest is not great and small holes are made in the canopy. Fires that follow logging burn fiercely in the felled heads and often enlarge

FIG. 18. The last survivors of a once continuous eucalypt forest. Here introduced grasses have allowed more intensive grazing and more frequent fires than the previous native understorey. Eucalypt seedlings that regenerate after one fire are destroyed by the next fire or by sheep. The old trees eventually die or are occassionally felled by fire. Some old trees have been pollarded to induce small, dense, vigorous crowns but this will not greatly prolong the lives of the tree. In 100–200 years the combined effects of new grasses and grazing animals introduced into a fire environment will remove the eucalypts completely.

the holes and stimulate regeneration. But this regeneration has to compete with many mature trees which provide fuel for fires long before the seedling is fire resistant, and with litter which further suppresses its growth. In addition the seedling has to survive intense browsing and further slash fires when other trees in the vicinity are felled.

In the wetter forest the stands are generally of better milling quality and logging tends to cause more disturbance. Fires that follow logging are especially fierce because of both natural and unnatural fuel accumulations and because of easier access for wind. From these post-logging wildfires originated some of the best stands of eucalypts that exist today.

After the 2nd World War the market for pulpwood developed and more clear-felling of the wetter forest occurred. At first, fire-damaged veterans were expected to provide seed, and regeneration was regarded as being inevitable. Some slash-burning was carried out for fire protection purposes while other logged areas were protected from fire. Fairly soon it became obvious that except on the burnt areas regeneration was practically absent and that many of the burns produced bracken rather than eucalypt regeneration.

Burning for Regeneration:—That regeneration of the wetter forests is dependent upon burning and early protection from browsing animals was clearly shown by Gilbert (1958). Some of the first silvicultural burns were on clear felled areas (coupes) small enough to seed in from the edges. These were partially successful while animal populations were low but failed as the population increased due to the increasing food supply provided by this treatment i.e. the burns although intense enough for seedling establishment were too small for seedling survival.

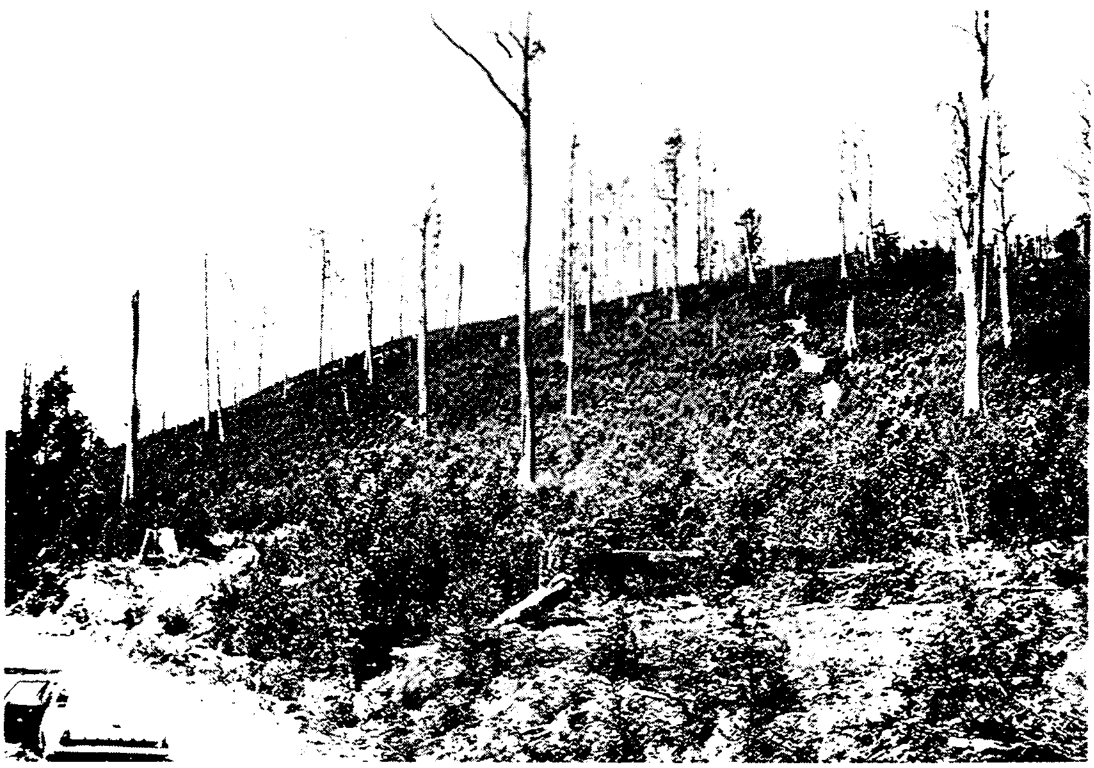
To solve this problem the logging coupes were enlarged and many seed trees left scattered through the area (Figs. 19, 20). This resulted in good regeneration after burning but subsequent seed-tree salvage often produced fuel that caused a second burn which in turn destroyed the new crop.

Current practice is to clear fell large coupes (leaving only one or two veteran culls per acre), burn and sow where necessary (Figs. 21, 22). Pulpwood operations are now expanding into the dryer eucalypt forests which will probably be regenerated with a similar combination of clear-falling and fire.

Fire Protection:—During the early days of settlement, forests were considered more an impediment to agriculture than a valuable asset and large areas were burnt by clearing fires. As the value of the forests became better recognised forest authorities were set up and fire protection developed. At first, there seemed to be a general tolerance of forest burning either for slash disposal or in connection with grazing. However, this attitude changed to one of total protection in most States and there were 20–30 years of increasingly large areas protected from fire. While selective logging predominated, the effects of fire protection on the dryer forest were not obvious

Fig. 19. Top. Forest similar to Fig. 16. but with the rain forest understorey felled in preparation for burning. All the eucalypts have been retained for seed. Past wildfires in these forests were coalescing spots of slow burning ground fire which occurred only rarely in extremely dry conditions. We cannot afford to copy nature entirely and we expect the felled fuels and removal of shade to produce a more intense fire than nature did and so compensate for the moister soils. (However this felling can cause the soil to become even wetter than in the surrounding forest, if left too long before burning, because of reduced transpiration).

Fig. 20. Bottom. Eucalypt silviculture. This regeneration burn simulates past natural regeneration conditions. More recent treatments favour clear felling of all trees (to maximise fuel and minimise shade) followed by aerial sowing.



because it usually proved impossible to keep fire out for very long. However, one change has become apparent in the dryer mixed species forests where the trees preferred by the sawmiller are the faster growing species best adapted to the "ash-bed" effect. Where logging causes much soil disturbance and the area is protected from fire the bulk of the regeneration may be of less desirable species tolerant to nonashbed conditions. Examples of this are found in some of the better protected forest in Tasmania where *Eucalyptus ovata* and *E. dalrympleana* regeneration predominates over the preferred *E. delegatensis* on sites where the former used to be relatively uncommon. It is significant in this context that *E. dalrympleana* is apparently unaffected in areas of severe "die-back" of *E. delegatensis.*

Except for regeneration treatments, total protection is still the policy of the Queensland and Tasmanian Forest Services possibly because of the relatively high rates of litter decomposition found there.

In other states it became increasingly obvious that too much fuel was accumulating and the policy has swung back to a very active programme of area control burning for fuel reduction. Although very successful for fire protection, if controlled burns are regularly done when the soil and lower litter layers are moist it is possible that wastes will accumulate in the soil and no "ash bed" effects occur to produce vigorous regeneration. The same accumulations could cause the existing forest to deteriorate and become predisposed to disease.

The effect of these changes on fire frequency are significant. In the case of total protection the forest probably experiences periodic severe fires as before the advent of man. In the case of area control

FIG. 21. Top. Excellent seedbed for eucalypt regeneration produced by an intense burn on relatively dry soils (an overall "ash-bed effect"). The retained seed trees will be subsequently logged.

FIG. 22. Bottom. Uniform, fast growing, regeneration of *Eucalyptus regnans* following clear falling and burning of mixed eucalypt and rain forest leaving one or two cull eucalypts per acre as seed trees.

burning they are quite likely being burnt more often and more gently than by the aborigines and may never experience a severe fire.

The Eucalypts and Fire Today:—Since man arrived in Australia, especially in the last 200 years, the relationship between the Eucalypts and fire has been greatly complicated. Aboriginal man increased the frequency and reduced the intensity of fire in the dryer forests but had little effect in the wetter forests. European man introduced new browsing animals and his clearing and logging changed the pattern of browsing by the native animals. He introduced new plants and changed the distribution of existing ones. Fuel accumulation patterns were changed and the fire frequency generally increased.

Man's activities led to the degeneration of the original eucalypt forests but unlike many parts of the world the fire stick alone was not responsible. The outstanding characteristic of the eucalypts is their resilience in a fire environment. It was only with the help of sheep, introduced grass, axe, saw and lately the bulldozer that the eucalypt really gave way to the settlers.

Gradually the value of the forest began to be realised and man started to protect it from damaging wildfires, all too often aggravated by his logging slash. Where total protection was imposed on the wetter forests it often succeeded but in the dryer forest initial success was generally rewarded with fiercer wildfires because of the failure to recognize that the natural fuels did not rot away. This problem was overcome by frequent light burning which resembled aboriginal burning.

European ideas prevailed, and generally failed, when foresters first became interested in eucalypt regeneration. Only when it was realised that intense fire was an integral part of the environment did regeneration treatments begin to succeed.

AN ECOLOGICAL APPROACH TO MANAGEMENT

For Wood:—Seedling establishment and early growth is favoured by the "ash bed effect." To maximise this effect there should be maximum fuel, very dry soil and a severe fire. To obtain the fuel quantities there should be a long period of protection followed by clear felling. But too long a period without fire may reduce growth and it is likely that light protective burns should be carried out at intervals. Also to be taken into account is the natural fuel-free period which follows a good burn.

A forest managed on a 40 year rotation on a site where decomposition is slow (normal dry eucalypt forest) might be burnt at age 0 (very hot regeneration burn), at age 15, 25 and 30 (light, protective, fuel-reduction burns) and then protected until clear felled at age 40. Forests on wetter sites may require no fire after the regeneration burn if managed for pulp production on a 40 year rotation. However, longer rotations may indicate light burns at 10 year intervals after the initial fuel-free period especially if the stand is well stocked with eucalypts.

For Water:—On stable soil there is little incompatibility between wood and water production and severe regeneration burns can be generally accepted. On more mobile soils clear felling and severe burns should probably be avoided and a poorer wood production be tolerated.

For animals:—Most native animal browsing appears to be an edge phenomenon. It is associated with young vegetation. To maintain both animals and their habitat some balance has to be struck between regeneration and browsing. Too severe browsing may produce a sea of bracken. Too light browsing will allow the forest to shade out much of the understorey feed. The most likely approach would be to actively control game at critical periods so that forest development is slowed down but not prevented. This should be matched with a mosaic of burnt clearings of different ages so that there are always regenerating areas available for feed.

For Recreation:—The wetter eucalypt forests are not easy to walk through because of dense undergrowth. Over about age 5 they provide little food for game. This makes these forests a poor prospect for recreation except as roadside scenery. For this reason they are better managed for wood or water.

The drier forests can be kept open by light burning which makes access easy and game plentiful.

CONCLUSIONS

The Eucalypts have evolved in a fire environment and are adapted to resist fire in the early stages of their development while being the major source of fuel for fire at a later stage. To artificially exclude fire from this environment will eventually cause a lack of regeneration, deterioration in the health of existing trees and a change in their waste-disposal systems, favouring micro-organisms. Some of these micro-organisms may include diseases that flourish on the weakened eucalypts and the site may be taken over by other species. To burn too often will favour plants such as grass and bracken adapted to frequent fire and may eventually remove the forest.

Burning at regular intervals is also questioned. Instead, burning should be tailored to the species, the stage of its development and to the rate of litter decomposition.

Burning intensity should be varied. Light burns after clearing can cause regeneration to fail. Severe burns except for regeneration can destroy the forest.

The season of the year is very important; Spring burns in a Winter rainfall area are not good for regeneration but are good for survival and recovery of fire damaged trees.

Keeping these inter-actions of site, vegetation, time, fire-frequency and fire intensity always in mind it is possible to modify the fire environment to favour desired forest products such as wood, water, animals and recreation.

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