An Ecological Approach to the Control of Jarrah Dieback

by Dr. S. R. SHEA

Jarrah dieback is a plant disease caused by the introduced soil-borne fungus *Phytophthora cinnamomi*. This pathogen has the capacity to kill jarrah (*Eucalyptus marginata*) and many of the components of the forest almost throughout its geographic range. (See *Forest Focus* No. 14.)

In addition to the loss of timber, recreation and conservation values, the disease poses a threat to the major water supply system of the south-west of Western Australia. (See *Forest Focus* No. 19.)

Large areas of the forest have been quarantined to restrict spread of the fungus in contaminated soil and to permit detailed mapping of the distribution of the disease. Quarantine and/or stringent hygiene does provide short-term control but in the long term, particularly if access to quarantined forest areas is to be permitted, methods of controlling the fungus other than by its exclusion must be developed.

Options for control

Despite considerable advances in plant pathology research in the last decade, soil-borne plant pathogens cause massive crop losses throughout the world each year. In some agricultural or horticultural situations where it is economically feasible to practice intensive cultural techniques, control of some soil-borne plant pathogens has been achieved.

In forests, however, such techniques are usually not practicable. For example, it is relatively easy to kill *P. cinnamomi* with a fungicide, provided the fungicide can contact the fungus. In a diseased area of jarrah forest many fungal spores occur within thick roots and the soil would have to be frequently saturated with a fungicide before contact with the fungus occurred. Even broad scale applications of fungicide in the jarrah forest would not eliminate all fungal spores and, particularly in catchments, fungicidal application could have damaging side-effects. Even if one spore remained viable in a treated forest area it is theoretically possible for the fungus to build up to pre-treatment levels.

Resistance to some plant diseases has been achieved by selection and breeding of resistant trees or plants. However, there is little evidence that there are strains of jarrah which are resistant to jarrah dieback. Even if successful, the development of resistant strains of jarrah would be very slow because of the relatively low growth rate of the species and the necessity to conduct extensive long-term field tests before resistance could be confirmed.

Replacement of jarrah with an alternative resistant tree species would partially compensate for the loss of some forest values. Extensive tree planting trials have shown that there are a number of eucalyptus and pine species which are resistant to the disease. In the valleys, where the disease is most prevalent and where the early trials are located, it is possible to grow some of these species to maturity where the soil moisture regime is favourable. It is only recently that trial plots containing a large number of tree species have been established on dieback-infested upland forest sites. Upland sites, which represent between 60-80 per cent of the forest, have harsh conditions for tree growth and it is not possible at this stage of research to specify which species could be successfully used to replace jarrah. Rehabilitation of diseased forest areas with alternative tree species is an option, but further research is necessary before it will be possible to undertake broad scale rehabilitation. Even when the correct techniques for rehabilitation have been developed, replacement of the jarrah forest with alternative tree species would be very expensive.

Direct attack on the pathogen or improvement or replacement of the susceptible host are not the only methods by which a plant disease can be controlled. There are three components of a plant disease— a pathogen, a susceptible host and an environment suitable for the pathogen to attack and damage the host. It is possible for a pathogen and a susceptible host to co-exist if environmental conditions are unsuitable for the pathogen. Thus, another control option is to change environmental conditions in such a way as to inhibit fungal pathogenicity. In this article a research programme aimed at determining if it is possible to manipulate the jarrah forest environment so that the forest can be made compatible with *P. cinnamomi* is described. The approach is based on the idea that promotion of native leguminous species in the forest would create environmental conditions which are unsuitable for activity and survival of the fungus.

◀ *Virgin jarrah forest. Banksia occurred only as a relatively minor component of the understorey in the virgin forest.*

(Les Harman)

Disease spread through banksia understorey. This species provides a highly susceptible food base for P. cinnamomi. *It is unlikely that jarrah dieback will ever be controlled while a dense banksia understorey is present.* (Les Harman) ▶

The physical environment

P. cinnamomi requires relatively high soil temperature conditions and moist soil before it is able to attack susceptible plants. Prolonged drying of soil can kill the fungus.

In the jarrah forest the length of time when these soil physical conditions exist varies markedly on different sites. In the valleys which are moisture-gaining, soil moisture levels are high during considerable periods of the summer when soil temperatures are suitable for production of infective spores. These sites are highly susceptible to the disease. However, on the freely-drained lateritic and sandy soils which make up approximately 80 per cent of the forest, physical conditions for survival and infection by the fungus are only marginally suitable. In winter, soil temperatures are too low for the fungus to become active, while in summer, the soil is too dry. Optimum soil moisture and temperature levels for production of infective spores by the fungus occur only in spring and autumn.

Extensive trials both in the laboratory and in the field have shown that under a dense canopy and litter layer, soil temperatures are depressed in spring and autumn so that the periods during which there is a co-incidence of high soil moisture and high soil temperature —conditions which favour the fungus—are markedly reduced.

In some forests it is possible to change the canopy of the forest overstorey to create varying degrees of shade. Jarrah crowns, however, are not naturally dense and do not lend themselves to manipulation. However, native legume species can occur as a dense understorey in the jarrah and provide maximum shading.

Host susceptibility

The degree of host susceptibility has a very significant effect on the potential for controlling a plant disease by manipulation of the environment.

Although jarrah trees can be killed by *P. cinnamomi,* this species is not highly susceptible to the fungus. For example, in many disease areas it takes more than ten years after an infection has been initiated before all of the jarrah trees are killed. The fungus cannot invade the large roots of jarrah but causes death by repeated destruction of the fine root system.

Bull banksia (*Banksia grandis*), in contrast to jarrah, is highly susceptible to jarrah dieback and the presence of dense stands of this species in the forest is a major factor contributing to the spread and intensification of the disease. The fungus can move through very large banksia roots. In addition to providing a large food base, banksia roots protect the fungus from adverse conditions such as low moisture levels, which may occur in the soil outside the roots.

The ability of the fungus to spread through the roots of banksias even when environmental conditions are adverse in the soil outside has a further effect. As the banksias die, more sun reaches the forest floor and soil temperatures are raised. This creates more favourable conditions for spore production, which predisposes less susceptible species to attack.

It is highly unlikely that control of jarrah dieback will be achieved by any method unless the density of the banksia component of the forest is markedly reduced. Such a reduction in banksia density would tend to return the forest to a more "natural" condition because bull banksia occurred only as a minor component of the understorey in the upland virgin jarrah forest.

Extensive tests have been carried out on the relative susceptibility of native legume species to jarrah dieback since it would be pointless to replace banksias with other highly susceptible species. Some of the native legumes are susceptible, but most of those which germinate profusely after fires are resistant. Therefore, replacement of the bull banksia understorey with native legumes would reduce the highly susceptible food base currently present in the forest, which provides a haven for *P. cinnamomi.*

The microbiological environment

Soil plant pathogens, except in sterile laboratory-created conditions, do not operate in a vacuum. The soil contains vast numbers of micro-organisms—some beneficial, some detrimental—which interact with both hosts and the pathogen. *P. cinnamomi,* in particular, is unusually affected by other micro-organisms because in the absence of certain soil bacteria, it will not produce sporangia and zoospores, the spore types which are believed to be responsible for spread and infection.

It is obvious that on most jarrah forest sites the soil microbiological environment does not present an obstacle to the fungus and it is suspected that on many forest sites it favours *P. cinnamomi.*

If the soil microbiological environment can be changed it is possible that the microbiological conditions can be created which do not favour *P. cinnamomi.*

Preliminary studies suggest that a change from a banksia dominated understorey to one dominated by

▲ *This stand of prickly moses was regenerated by high intensity fire. Previously, the area had a dense banksia understorey and no live legume plants. The red plant is* Kennedia coccinea. *(Les Harman)*

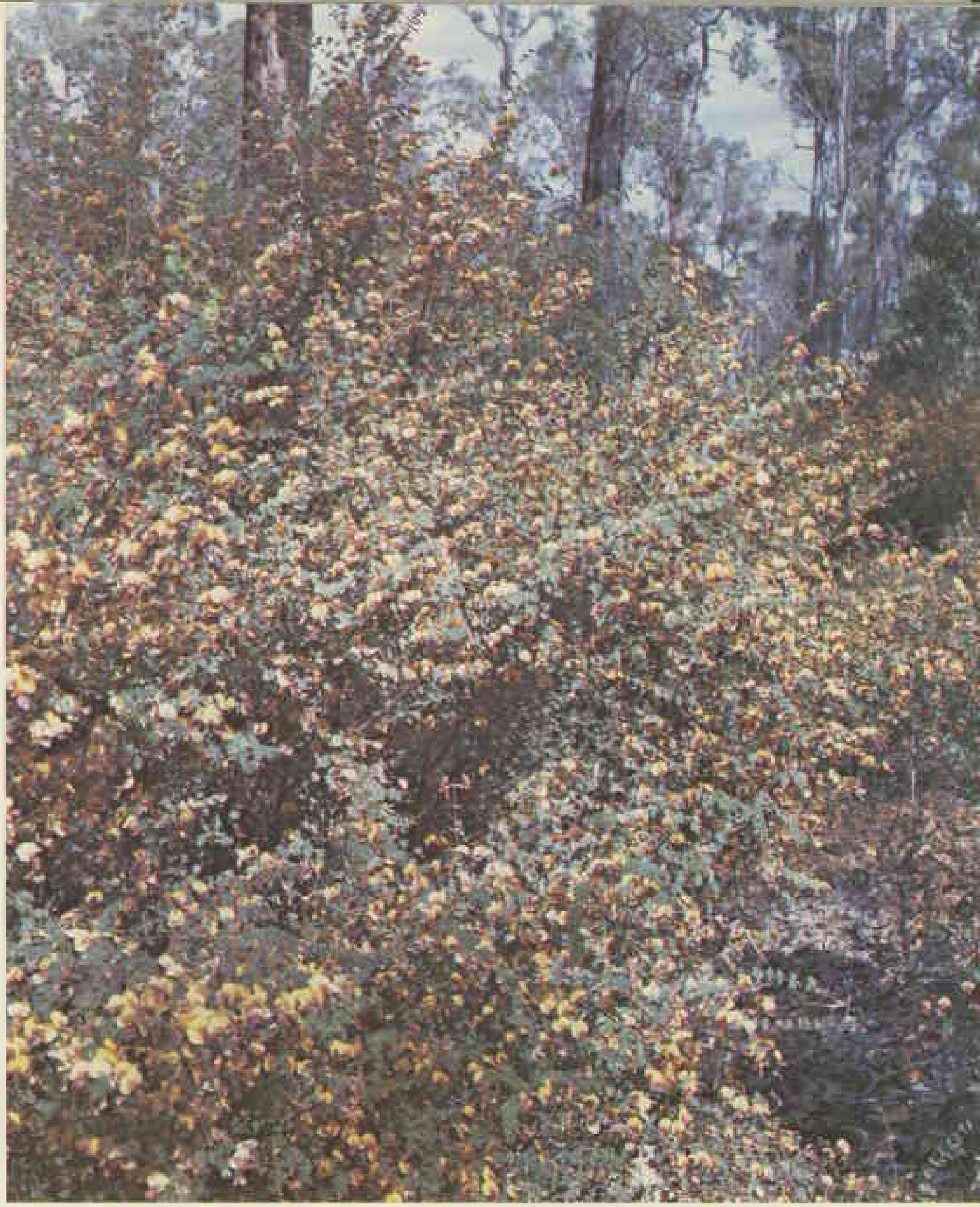
certain legume species could create a soil microbiological environment which is less favourable for *P. cinnamomi* activity and survival. The composition and quantity of micro-organisms in the soil is markedly influenced by the type of plant growing in the soil. Therefore, it is not surprising that the soil micro-organisms associated with the roots of legume species, which have the ability to add nitrogen to the soil, are different to those associated with banksia roots. Dr. N. Malajczuk from the C.S.I.R.O. has isolated micro-organisms associated with legume roots and banksia roots and examined their effect on *P. cinnamomi* in controlled laboratory studies. This work has shown that there are more than double the number of antagonistic micro-organisms in soils in which legumes have been grown, compared with soil micro-organisms isolated from soil in which banksias were growing.

More recently research which has been focussed on prickly mosses (*Acacia pulchella*) has shown that chemicals contained in volatiles emanating from roots and chemical extracts of the roots of this species have a highly suppressive effect on *P. cinnamomi.* This discovery parallels research carried out in other parts of the world which suggests that the chemical constituents of certain species is responsible for their resistance to *P. cinnamomi.*

Attempts are being made to isolate the chemical or chemicals responsible for suppression and to determine if they persist in the soil long enough to suppress the fungus.

Some pot trial studies have produced further evidence that legumes will improve resistance to the disease. It has been found when certain legumes are grown in pots which have been infested with *P. cinnamomi* that after a period of time the fungus cannot be recovered from the soil. When jarrah seedlings were grown in conjunction with legume species in pots the mortality of jarrah was significantly reduced when compared to the mortality of pots where jarrah has been grown with bull banksia.

The most significant research finding to this date resulted from a series of field trails which have shown that sporangial production and infection by *P. cinnamomi* was markedly reduced beneath legume stands in comparison to jarrah forest where legume species were not present.



▲ *Waterbush* (Bossiaea aquifolium) *background. This stand of legumes regenerated following the 1961 Dwellingup wildfire.*

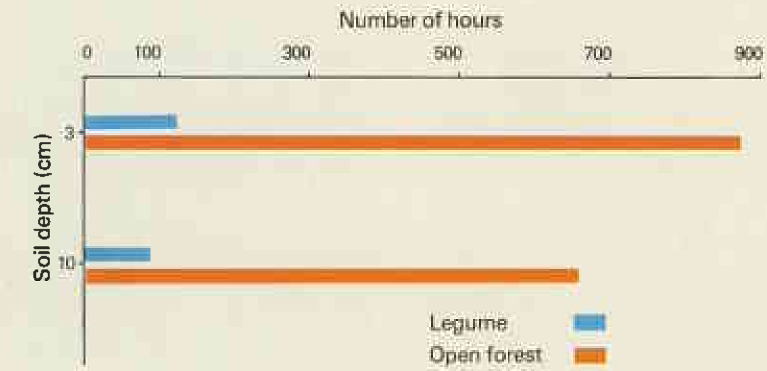
(Les Harman)

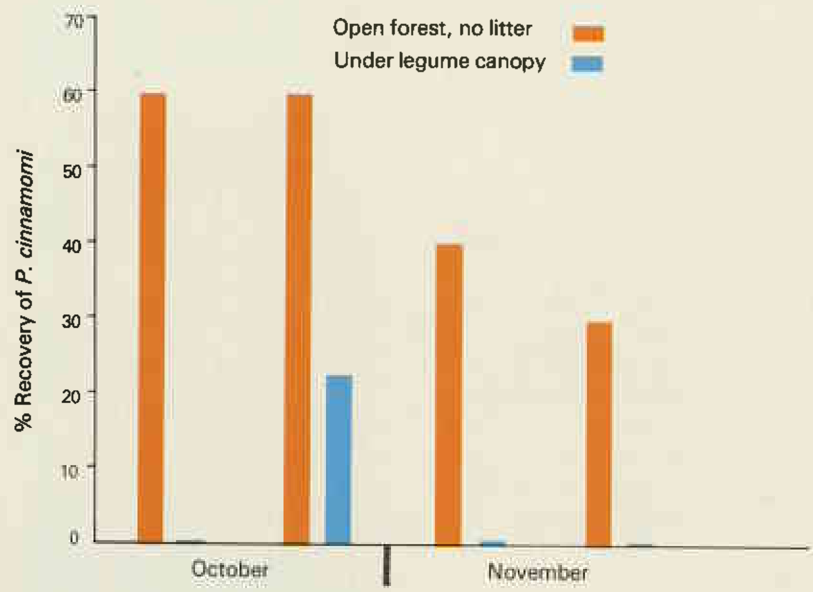
Improving forest vigour

There is increasing evidence, although it is still circumstantial, that native leguminous species may have additional beneficial effects on the jarrah forest ecosystem: studies carried out by Forests Department and C.S.I.R.O. research workers have shown that native legume species have a relatively high capacity to fix atmospheric nitrogen. Some of the species tested have almost as much capacity to fix atmospheric nitrogen as some agricultural species such as clover. It is possible that over a period of years considerable quantities of nitrogen could be incorporated into the soil and eventually be used by other species, such as jarrah, which are unable to obtain their own nitrogen

Top: It is possible by measuring soil moisture and soil temperature regimes, to estimate the number of hours that physical environmental conditions are suitable for infection. When a legume understorey is present, the number of hours when both soil moisture and soil temperature are suitable for infection is markedly reduced. (Les Harman)

Below: Field tests have shown that infection level is reduced when a legume understorey is present. (Les Harman)



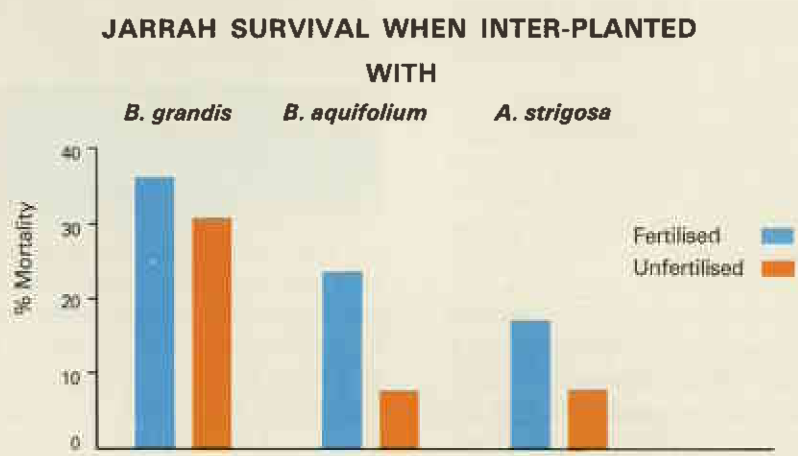


from the atmosphere. This could significantly improve the health and vigour of the forest.

Jarrah does not respond to phosphate fertilisation but in field and pot trial studies significant increases in growth due to nitrogen fertiliser application have been demonstrated. Application of mineral nitrogen fertilisation to legume species inhibits their capacity to fix nitrogen from the atmosphere, however, they respond markedly to phosphate. It is possible that a single application of phosphatic fertiliser to legumes in the forest could be used to increase legume growth which, in turn, would result in higher additions of nitrogen and organic matter to the soil. The effect is likely to be sustained for a number of years because in forest ecosystems nutrients are constantly recycled. There is, therefore, the potential to raise the overall fertility of the jarrah forest ecosystem.

Manipulation of forest environment

It is relatively easy to manipulate the environment in agricultural or horticultural situations where it is practical and economic to employ intensive cultural techniques. For example, avocado growers in Queensland have been able to control *Phytophthora* root rot by large



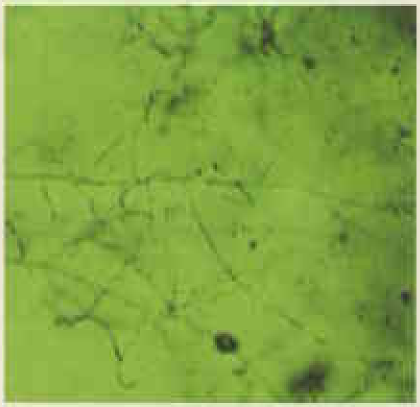
In pot trial studies it has been found that some legume species, when interplanted with jarrah, increase jarrah's resistance to dieback. (Les Harman) additions of fowl manure and by intensive cultivation of agricultural legume species beneath the trees. But there are severe constraints when the technique must be applied in a susceptible forest extending over more than 1 000 000 hectares. Currently, there is only one tool available to jarrah forest managers which could be used on a broad scale—fire.

There is abundant evidence that fire is a natural factor in the jarrah forest environment. Apart from the demonstrated ability of the forest to tolerate fire, it is impossible to conceive that even in the absence of man, lightning did not cause ignition of the dry sclerophyll forests during the hot summer months. Although fire was a factor in the forest environment it is only possible to speculate on the frequency, intensity and season of the firing regime in pre-colonial times. In the 1950s and early 1960s broad scale mild prescribed burning, carried out principally in spring, was introduced in the forest. This was necessary to reduce the fuel hazard so as to give a better chance of controlling wildfires. Perhaps more than in any other forest area in the world, necessity has led to the development of a highly organised and efficient hazard reduction burning system.

Without a hazard reduction burning programme, the forest inevitably would be subjected to severe destructive wildfire such as that which occurred in the forest areas surrounding Dwellingup in 1961. However, the technology of prescribed burning has now advanced to the stage where it is possible to use fire for management objectives in addition to hazard reduction. By using various combinations of fire frequency, intensity and season of burning the forest manager has the potential to change the structure and composition of the forest.

▲ *Sporangial breakdown caused by volatile components of legume roots.* (Les Harman)

▲ *Viable sporangia releasing zoospores.* (Les Harman)



▲ *Destruction of* P. cinnamomi *mycelium caused by micro-organisms associated with legume roots.* (Les Harman)

▲ *Healthy mycelium.* (Les Harman)

▲ *In recent field tests it has been shown that spore production by* P. cinnamomi *is markedly reduced when in soil beneath an understorey of legumes, compared with spore production when in soil beneath an understorey of banksias as indicated in the graph.*

▲ *Stimulation of legume growth by phosphate fertiliser. Application of phosphate to legume stands could raise the overall fertility of the forest ecosystem.* (Les Harman)

▲ *Nodules found on legume roots. Native legume species can fix atmospheric nitrogen and this may significantly improve the fertility of the forest.* (Les Harman)

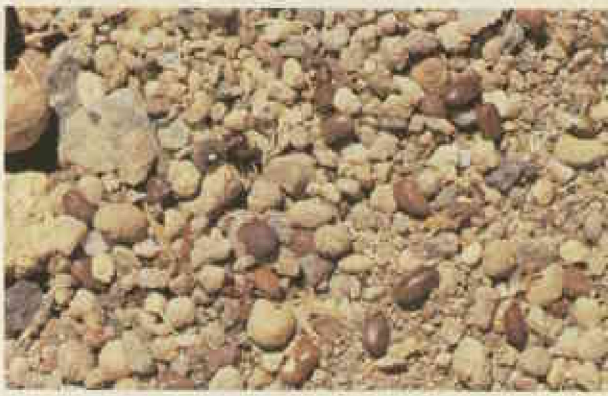
Relationship between fire and native legumes

One of the most spectacular and rapid changes in the composition and structure of a forest was observed following the Dwellingup wildfire in 1961. Approximately 30000 hectares of forest regenerated with dense stands of native legume species. Following mild hazard reduction burning, these stands failed to regenerate and tended to be replaced by species more susceptible to the disease.

The association between fire and regeneration of leguminous species

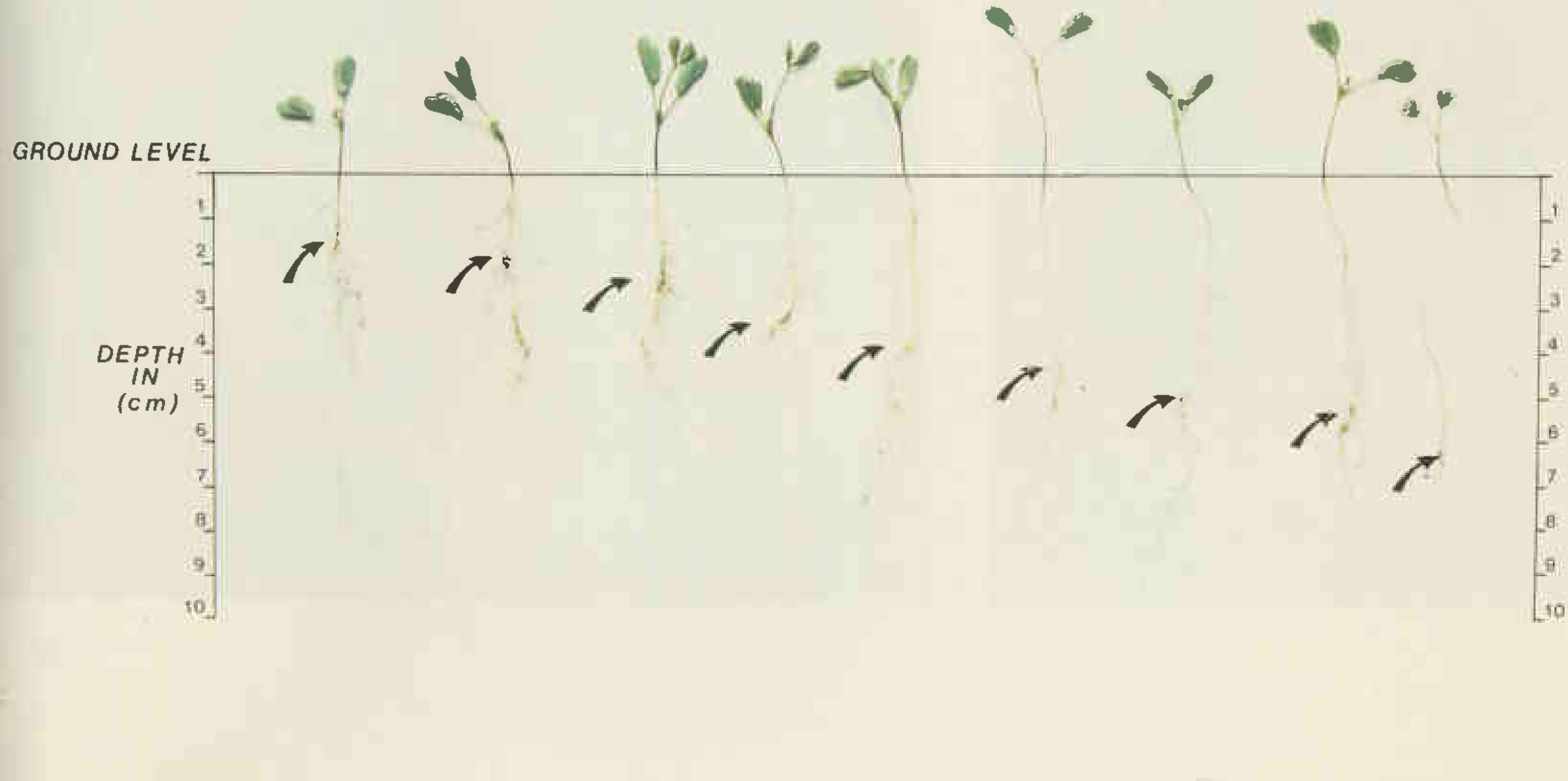
▲ *Clumped regeneration of acacia species following high intensity fire. Ant species collect acacia seed and store it in their nests. This burial of seed explains why it is necessary to burn the jarrah forest with high to medium intensity fire to stimulate acacia regeneration.* (Les Harman)

Ants collecting legume seed, which they bury in nests soon after it has fallen. This places it below the zone of heat penetration during normal mild fires and so does not germinate. During higher intensity fires heat penetration is sufficient to stimulate germination. (Les Harman)



Legume seedlings regenerating from a range of depths. Original location of seed is shown by the arrow. (Les Harman) ▼

in forest ecosystems is not unusual. Legume seed has a hard coat and it generally will not germinate until it has been heated. For example, laboratory trials have shown that the best way to germinate jarrah forest legumes is to pour boiling water on the seed and allow it to stand in the water for 15 minutes. In the long leaf pine (*Pinus palustris*) forests of the south-east of the United States of America, frequent mild fire has been used over a number of years to promote the regeneration of a shrubby leguminous layer.



The relationship between legume regeneration and higher intensity fire in the jarrah forest, although not unique, is unusual. Recent research has shown why hotter fires are necessary to regenerate legumes in the jarrah forest whereas in other forest, including the wet sclerophyll karri forests, regeneration of legumes occurs after mild fire.

Following the initial burning trials it was noticed that frequently legumes regenerated in clumps. This suggested that the seed was redistributed following seedfall. Subsequent studies showed that ants are the major agents responsible for legume seed redistribution. In addition to horizontal redistribution, ants also bury the seed. Careful examination of newly regenerated legumes have shown that some originated from as deep as 9 cm below the surface of the soil.

During normal mild spring burns soil temperatures rarely rise above 40°C in the top 1 cm of the soil. Legume seed which is below the surface of the soil does not receive enough heat to stimulate germination. During higher intensity burns, heat penetration is considerable and frequently a large proportion of the seed which has been buried by ants to varying depths in the soil, is stimulated.

Although the research carried out so far has contributed to the understanding of the effect of fire on legume regeneration and survival, the understanding of this relationship is still only partial. However, the results of the study to illustrate the complexity of the ecosystem and that apparently disjunct components such as legumes and ants are, in fact, closely inter-related.

Although mild hazard reduction burning is not the only factor affecting regeneration and survival of bull banksia it does favour this species. Mild burns in spring have little effect on the banksia understorey but they provide an excellent seedbed for the seeds which are released from cones the following autumn. Thus, under a mild burning regime banksia population levels increase. Current research indicates that medium to high intensity fire in autumn and late summer when banksias are under drought stress, can kill over 50 per cent of the banksia understorey. The research suggests that series of these type of burns over a period of twenty years would reduce banksia numbers to low levels comparable with the virgin forests.

It would obviously not be feasible or desirable to carry out burning at the intensity of a wildfire. Apart from the danger to human life, the Dwellingup wildfire of 1961 caused extensive mortality of jarrah and many of the surviving trees were severely scarred. However, it is possible to carry out fires at intensities above those used commonly for hazard reduction but below the levels causing damage to the overstorey.

Over a period of years Forests Department research workers have developed a set of tables with which, over a range of meteorological and fuel conditions, it is possible to predict the intensity of fire resulting from a particular pattern of ignition. These tables were used to conduct a series of experimental high and medium intensity prescription burns which have shown that it is possible on many forest sites to bring about regeneration of native legumes where previously they were observed to occur only as a minor component of the understorey, and markedly reduce the density of the banksia understorey. These fires, although of higher intensity (and expense) than normal burns, have been controllable and except for jarrah saplings, which in pole stands will not form crop trees, there was no significant damage to jarrah trees. In fact, at least in the short term, growth of jarrah poles has been stimulated by these burns.

Although much more research is required it is conceivable that changes in the structure and composition of the forest (that is from a banksia-dominated understorey to one dominated with legumes) can be achieved on many forest sites by the strategic use of prescribed fire.

Implementation

Intensive research, both in Australia and overseas, is continually improving our knowledge of *P. cinnamomi* and diseases caused by the fungus. This research has shown that plant diseases caused by *P. cinnamomi* are affected by a number of factors and it is unlikely, particularly in a forest situation, that control will be achieved by any single

method. The use of leguminous species to control jarrah dieback is only one of a number of lines of research being investigated. This approach to control of jarrah dieback, however, is attractive because a change to a legume understorey will increase resistance to the fungus in several different ways and it has the potential to be applied on a broad scale. It is important, however, to emphasise that this approach to control of jarrah dieback is still in the experimental phase. Despite the positive results that have been achieved so far, however, it is essential that the system be thoroughly tested in the field before it is adopted for broad scale application.

It is possible to accurately prescribe the intensity of fire as is illustrated by these photographs of experimental fires. The intensity, frequency and season of burning determine the effect of fire on an ecosystem. (Les Harman)

▲ *Forest burnt 12 months previously with fire intensity which resulted in full crown scorch. Note crown vigour.* (Les Harman)

▲ *Adjacent forest burnt with a normal low intensity burn. Growth rates of scorched trees have been shown to be significantly higher than trees which have been burnt with low intensity fire.* (Les Harman)

Although there is little doubt that a legume understorey will reduce the susceptibility of the forest to jarrah dieback, it is not known if the reduction in susceptibility will have practical significance. Prolongation of the survival of a horticultural crop such as avocado, which is being attacked by *P. cinnamomi* for ten years is a significant advance. However, in a forest crop such as jarrah the effect of a cultural technique must be permanent. Thus, it is necessary for careful long-term field trials to be carried out before the legume approach to control can be implemented on an operational scale.

It is also important to ensure that high intensity fire does not have serious adverse effects on the forest. For example, what will be the effect on native animals and wildflowers? What will be the effect of the changed burning regime on the beekeeping industry? Although the preliminary studies indicate that forest areas which have been subjected to high intensity fire are more vigorous than those which are protected or burnt mildly, it is not certain that this vigour can be maintained. It is also not known if there is a store of legume seed in the soils on all jarrah sites—it may be necessary to apply seed directly on some sites. High intensity prescription burning is also more hazardous and as a consequence more expensive than mild burning in spring. Will the costs be prohibitive? All these questions must be resolved before changes in existing management practices are made.

Even though this approach to control of jarrah dieback is being treated with caution, a number of large scale trials have been initiated to determine the practical problem of high intensity burning. The decision to move to large scale trials, even though fundamental research has not been completed, has been made deliberately. This approach to control of jarrah dieback is based on the concept of forest manipulation—it cannot be implemented if there is no forest to manipulate. Once the disease extends to the overstorey mortality stage it would be difficult to reverse the decline in forest health.

The large scale trials being carried out will ensure that if it is found a legume understorey *will* confer permanent resistance of the forest to jarrah dieback, the technique can be implemented rapidly. The maintenance of stringent hygiene and in some forest areas, quarantine, will provide the maximum length of time to develop and test jarrah dieback control techniques.