35

WA REGIONAL FOREST AGREEMENT
WOOD PROFILE PROJECT

Productivity enhancement of native forests

(draft of 5 July 1997 *u:rfaprod.doc*)

Scope of document

To summarise the research and development activity that has been undertaken in Western Australia to enhance the productivity of native forests within the RFA region. This work provides a background to considering productivity enhancing practices that may be incorporated in calculations of future yield.

Length

5-8 pages of A4 text plus bibliography.

Suggested topics to be covered

- genetic improvement
- espacement
- thinning
- application of fertiliser
- major pests and diseases impacting on forest productivity

Timeline

Draft document to be available early July 1997

Karri and karri/marri forest

Overview of silviculture in the karri forest

The overall silvicultural goal for the karri forest is to maintain a sequence of age classes which ensures that 40 per cent of the forest consists of trees in mature and senescent stages of development (Department of CALM 1994). In order to achieve this goal the preceding stages of development must be represented in sufficient proportions to sustain the mature and senescent stages in perpetuity. Silvicultural strategies vary according to the structure and age of the existing forest.

Patches of even-aged and vigourously growing karri forest which are greater than two hectares in area are identified for thinning. Once these patches are old enough to yield saleable products they are thinned to an appropriate density by commercial harvesting.

Mature forests and forests of mixed structure created by past logging activities are harvested using a clearfelling system. Regeneration following harvesting is achieved within the following year or two by means of seed trees retained temporarily on the site, by planting with nursery raised karri seedlings, or by broadcast seeding. The seed tree method is used wherever possible in order to utilise on-site seed and minimise the cost of regeneration operations. Planting is used when the seed crop is inadequate. Broadcast seeding is only employed to a limited extent because of the high cost of karri seed.

Marri occurs in association with karri and may be the more abundant species on some sites, particularly in lower rainfall areas on the margins of the karri forest range. Marri regenerates readily from seed and ground coppice following fire or logging disturbance, and no silvicultural intervention is normally required to maintain the marri component of mixed karri/marri stands (White 1971).

Opportunites for enhancing the productivity of karri stands occur during the establishment phase when the density, genotype and nutritional status of the stand can be manipulated. The productivity and potential mixture of wood products available from stands can also be influenced by thinning during the juvenile and immature stages of stand development. Minimising losses caused by fire, disease and pest outbreaks is also an important step in maintaining and enhancing the productivity of the forest.

Silvicultural research conducted since the 1930's has contributed to a substantial body of knowledge about the regeneration, development and management of karri forest stands. This research has been reviewed in detail by Breidahl and Hewett (1995), and current developments have been described by McCaw and Rayner (1995). Detailed silvicultural specifications are available for all harvesting operations carried out in karri forest (Department of CALM 1990a, 1992, 1995)

Genetic improvement of karri

Most of the genetic variation in karri is due to variability within populations rather than to differentiation between populations (Coates and Sokolowski 1989), although certain outliers of karri do exhibit noticeable levels of divergence from populations in the main forest belt. The potential to achieve gains in vigour and form of karri by using seed from selected superior trees was first demonstrated by Schuster (1979). Further trials have been established to compare the performance of 120 families from 13 provenances of karri and provide a long term basis of assessment of variation in vigour, form and wood quality (Breidahl and Hewett 1995).

The potential to produce large quantities of karri seed from intensively managed seed orchards has been investigated since 1972, although these orchards have not yet produced any significant quantities of seed. Progeny trials have been planted in conjunction with the seed orchards to test the growth and form of the various families under normal operational conditions. Results from the progeny trials provide a basis for culling unsuitable and poor performing families from the seed orchards. Progeny trials also provide an ideal opportunity for selecting superior individuals for inclusion in clonal seed orchards. Initial results indicate that significant improvements can be achieved while still retaining a broad genetic base for selections. Seed orchards could in the future play an important role in producing improved seed for use in the annual regeneration program and facilitate more extensive use of direct seeding techniques.

Initial stocking and espacement

Initial stocking and espacement are important factors that may impact on growth and tree form. In most years more than half of the harvested area of karri forest is regenerated by planting with nursery-raised seedlings and so there is considerable scope to vary the stocking and espacement of regenerated forest stands. Since 1992 the planting density for regeneration operations has been 2250 plants per hectare. Observations suggest that, under some circumstances, the form of planted karri may be inferior to that of field-germinated seedlings and the extent to which this is attributable to planting density is a subject requiring further investigation.

Schuster (1978) found that initial planting density had no significant effect on the height or stem diameter of six-year-old karri planted on an ex-pasture site. This contrasts with results from six-year-old karri on a medium productivity forest site where both height and diameter growth were inversely related to initial planting density (Breidahl and Hewett 1995). Results from five-year-old karri planted on a high productivity karri site indicate that diameter growth but not height were affected by stand density (McCaw, unpublished data). The variability of response evident in the data from these three trials suggests that there is an interaction between site characteristics and the effects of stand density on the growth of karri. Low planting densities are consistently associated with short boles and the persistence of large live branches on karri (Breidahl and Hewett 1995). Both these characteristics are undesirable in stands managed for timber production.

Longer term effects of stocking and espacement on the growth and form of planted karri will be determined by periodic re-measurement of existing trials.

Thinning

Up until the mid 1970's seed trees provided the only reliable and practical technique for regenerating karri and karri/marri stands following timber harvesting (White 1974, White and Underwood 1974). Most of the stands currently in the immature stage of development were regenerated using the seed tree technique and are densely stocked. Although karri stands self-thin effectively in time, the desire to promote growth into larger diameter classes to maintain future sawlog supplies, coupled with the existence of markets for chipwood and small sawlogs makes commercial thinning an attractive option for immature stands. Since 1979 some 5750 ha of even-aged karri regrowth have been thinned (Department of Conservation and Land Management 1996).

Most of the even-aged regrowth stands in the Pemberton area that resulted from clearfelling between 1927 and 1940 were thinned for the first time at around fifty years of age. Thinning was carried out as a commercial operation which generated a substantial yield of sawlogs as well as chipwood. The basal area retained after thinning was varied according to the height of the stand in order to ensure that the residual stand was fully stocked (Bradshaw 1985). A replicated thinning trial was established in 50-year-old regrowth at Treen Brook forest in 1985 to investigate the effect of thinning to a range of residual basal areas on individual tree and stand growth (Table 1). Results from this trial have demonstrated a substantial response to thinning, with the diameter increment of retained trees thinned to a basal area of 20 m^2 ha^{-1} being about one third greater than that of corresponding trees in an unthinned stand (Breidahl and Hewett 1995). Thinning more heavily than this further increased the growth rate of individual trees, but at the expense of overall stand volume growth.

A number of trials have also investigated the response of younger stands of karri to thinning and associated treatments, including coppice control and fertiliser application. Breidahl and Hewett (1995) summarised the results of a number of thinning trials established before 1980, all of which showed a growth response to thinning. Some of these earlier trials were unreplicated or considered only a limited range of thinning intensities. Three comprehensive, replicated thinning trials have been established since 1985 and details of the treatments applied in each trial are provided in Table 1. The trial at Sutton block includes areas of predominantly marri forest that have been thinned to a range of residual basal areas. These trials have also demonstrated substantial diameter growth responses to thinning in stands spanning a wide range of site quality in the karri forest. Growth responses to applied fertilisers have also been confirmed for both thinned and unthinned stands (Breidahl and Hewett 1995).

Thinning operations have been undertaken on a limited scale in young even-aged stands (20-30 years old) that have attained a codominant height of 30 m or more, with several hundred hectares thinned in the last decade. Measurement of tree heights from large scale photographs has proved succesful in karri regrowth stands and a program of height stratification is underway in stands approaching thinning age. Photomeasurements may also be used to estimate retained stocking density following thinning.

Management of slash residues generated by thinning operations is an important consideration for maintaining stand productivity. The leaf component of thinning slash decomposes rapidly with up to 90 per cent of mass decayed within two years of felling, but woody components of slash may persist in the fuel bed for many years, adding substantially to the fuel load (O' Connell 1991). Slash residues can be effectively reduced using prescribed fire without causing significant damage to the residual stand, provided that fires are undertaken in spring when the litter profile is moist (McCaw *et al.* 1996, 1997). Burning slash residues under moist conditions also favours conservation of nitrogen stored in the litter layer (O' Connell and McCaw 1997).

An alternative strategy is to undertake prescribed burning prior to thinning. Prescribed burning has been undertaken in unthinned stands as young as 15 years with minimal crown scorch and damage to the stems of potential crop trees (McCaw 1986). Low intensity fires kill small suppressed and subdominant trees and are comparable to a very light thinning. However, there is no evidence that the growth rate of the retained trees is altered by low intensity fire (McCaw, unpublished data). Burning prior to thinning can improve access for harvesting machinery and trees damaged by burning can be targetted for removal during the thinning operation.

Table 1. Summary of current experiments investigating growth response of seed-tree regenerated karri stands to thinning, applied nutrients and coppice control. All experiments include replicated treatments and unthinned control plots.

Experiment location	Regeneration year	Experiment established	Treatments applied		
			Thinning	Coppice control	Nutrients applied
Treen Brook	1934/37	1985	Retained basal areas of 10, 15, and 20 m^2/ha	no	no
Warren	1972	1985	Retained stocking of 200, 400 and 600 stems/ha	yes	Nitrogen
Poole	1969	1989	Retained stocking of 300 stems/ha	yes	Nitrogen Phosphorus K, Zn, Cu, S
Sutton	1969	1992	Retained basal areas of 7, 10, 13, 16 and 20 m^2/ha	yes	no

Application of fertiliser

The beneficial effect of ashbeds on the initial growth of karri has been recognised for a long time and was first investigated in detail by Hatch (1960) and Loneragan and Loneragan (1964). Grove (1988) demonstrated that the supply of nitrogen and phosphorous can be limiting to growth of karri and understorey species on karri forest soils. Application of these elements singly and in combination to an 18-month-old naturally regenerated stand of karri accelerated the establishment of dominance and increased mortality, thereby stimulating the growth of the larger trees. Understorey composition in older stands was also shown to be responsive to levels of nitrogen and phosphorous, with the growth of leguminous species stimulated by the addition of phosphorous.

The benefits of adding fertiliser at the time of establishment were investigated by Christensen (1974) using karri wildings planted on red loam soil. This study confirmed that addition of phosphorous could significantly increase height growth during the first year after planting, giving seedlings a competitive edge over the understorey species. Subsequent work by Schuster (1982) investigated aspects of the type, rate, timing and cost efficiency of fertiliser application on gravelly yellow podzolic soils typical of karri/marri stands.

Use of container-grown seedlings instead of open rooted karri seedlings has prompted continued investigation of optimum fertiliser regimes, including top-dressing treatment in the nursery prior to planting (Hewett, unpublished report). Substantial cost savings at establishment can be achieved by eliminating the need to apply fertiliser in the field.

Pests and diseases

Armillaria luteobubalina is a fungal pathogen with a wide but discontinuous distribution across the karri forest and throughout the south-west of Western Australia (Pearce *et al.* 1986). The fungus has a wide host range and spreads below ground by root contact. In the karri forest it causes root and butt rots and is capable of killing seedlings, saplings and even mature trees. Stumps resulting from harvesting operations can increase the inoculum base of *A. luteobubalina*, encouraging the fungus to spread and infect otherwise healthy trees. Impacts of *A. luteobubalina* in the karri forest and strategies to minimise disease are currently being investigated (R. Robinson, pers. comm.).

Wood boring insects, principally the bullseye borer (*Tryphocaria acanthocera*) and cossid moths (*Xyluetes* sp.) may create extensive galleries in the stems of karri and marri resulting in wood degrade. Aspects of the life history of the bullseye borer, its distribution and extent of infestation in the karri forest were investigated by Abbott *et al.* (1991). Ongoing research is aimed at understanding the behaviour of the insect and factors that affect the level of infestation in different stands (J. Farr, pers. comm.).

Jarrah, jarrah/marri and wandoo forest

Overview of silviculture in jarrah and associated dry forests

Structural goals have been set for each of four categories of disturbance recognised in the jarrah forest. These categories range from Minimal Disturbance (eg. conservation reserves) to High Disturbance (eg. forest areas subject to mining). Forest available for timber harvesting is predominantly within the Moderate Disturbance category where the structural goal is to convert no more than 1 per cent of the forest to the establishment phase each year. In time, this would provide for 40 per cent of the forest in this disturbance category to be dominated by trees in the mature and senescent stages of development, 40 per cent by immature, 15 per cent by juvenile and 5 per cent by establishment stages of development respectively.

Timber harvesting in the jarrah forest is undertaken using a variety of silvicultural objectives. Where there is a predominance of vigourously growing trees, the stand is thinned. Where this is not the case, stands are harvested with the object of promoting regeneration. This is achieved either by harvesting in a way that will release existing lignotubers to grow unimpeded into saplings; or, where there are insufficient lignotubers, by harvesting to create a shelterwood under which seedlings can establish. Within a particular area of forest the proportion that is harvested to each of these objectives, and the degree of intermixing, vary according to the existing stand structure and condition.

In many areas the desired silvicultural objective is largely achieved by the harvesting operation itself. A proportion of the remainder is completed by silvicultural tending operations one or two years after harvesting. In forest types that are regarded as marginal for long term production harvesting may be done by selective cutting.

Marri occurs together with jarrah in varying proportions throughout the main jarrah forest range, and is more abundant in the southern forests. Relationships between forest composition and site characteristics have been described by Havel (1975) and Strelein (1988). WA Blackbutt occurs in association with jarrah and marri on moist sites throughout the jarrah forest, while wandoo is generally confined to the lower rainfall eastern forests. Both these species have been harvested on a significant scale in the past, but constitute only a small proportion of the timber removed in current jarrah forest harvesting operations. Existing silvicultural prescriptions cater adequately for the requirements of WA Blackbutt, and a specific prescription has been prepared for treemarking and regeneration in wandoo woodlands (Department of CALM 1989).

Given the reliance on natural regeneration processes in the jarrah forest, opportunities for enhancing the productivity of the forest revolve around manipulating the growth rate and quality of existing growing stock. As with the karri forest, minimising losses caused by fire, disease and pest outbreaks is also essential for maintaining and enhancing productivity.

There is a long history of silvicultural research in the jarrah forest dating back to the early years of organised forest management in the 1920's. Abbott and Loneragan (1986) reviewed a large body of published and unpublished research on the ecology and silviculture of jarrah, and Stoneman *et al.* (1989) discussed the silvics of jarrah and the application of silvicultural systems to meet various land use objectives. Detailed silvicultural specifications are available for all harvesting operations carried out in jarrah forest (Department of CALM 1989b, 1989c, 1990b, 1995a)

Genetic improvement of jarrah and marri

Experience with planting jarrah in forest situations shows that although survival may be satisfactory, dynamic shoot growth is unlikely to occur within several years of planting or even longer. Shoot growth may be stimulated by heavy applications of fertiliser, although the form of the resulting saplings is often poor (Abbott and Loneragan 1986).

Some success has been achieved with selecting jarrah resistant to *Phytophthora cinnamomi* (Stukeley and Crane 1994) and operational scale plantings have been undertaken to test resitance in the field. Jarrah resistant to defoliation by Jarrah Leafminer have also been observed, although the genetic basis for this has not been investigated (Abbott 1992).

Kino viens are a major cause of wood degrade in marri. Seed has been collected from a number of kino free marri throughout the south west forests and there has been some preliminary investigation to determine the extent to which wood quality is genetically controlled.

The opportunity for using genetically improved stock in regeneration operations is greatest on highly disturbed sites such as bauxite pits, log landings and gravel pits. Improved seed could also be sown in jarrah stands cut to shelterwood to promote development of lignotuberous seedlings. Opportunites for manipulating genetic composition of areas with an existing stocking of ground coppice are limited.

Initial stocking and espacement

As already discussed, the reliance on natural regeneration processes means that there is little opportunity to control the initial stocking and espacement of jarrah in forest situations. Manipulation of initial density and spacing is only feasible in highly disturbed sites that are planted with seedling stock or spot seeded. Nevertheless, several spacing trials have been established with planted jarrah to investigate the effects on growth rate and form (Strelein, pers. comm.).

Thinning

The response of jarrah to thinning has been investigated in a number of studies initiated since the 1930's, with most attention focussed on sapling and pole stands. Based on a detailed review of this work Stoneman *et al.* (1989) concluded that thinning of sapling stands could result in a moderate (55 per cent) increase in the diameter increment of retained trees, although at the expense of total stand increment. They argued that the loss of some stand increment was inconsequential, as many of the stems on which this increment accrued would ultimately be non-commercial. Thinning of sapling stands could also alleviate the phase of intense competition that would otherwise be experienced.

Thinning of pole stands can produce substantial benefits, and can double the diameter increment of the fastest-growing 200 stems per ha without any loss of stand increment (Stoneman *et al.* 1989). Growth potential is simply tranferred to the retained trees. Thinning from below results is more effective in maximising individual tree growth than thinning from above because increment is closely linked to initial tree diameter. Growth of smaller sub-dominant and suppressed trees in densely stocked pole stands is negligible (<1 mm per annum).

The response of larger sized jarrah (>45 cm dbhob) to thinning has not been investigated extensively. A study by Stoneman (1986) found that the diameter growth of jarrah piles and trees did increase substantially following thinning, but there was much greater variability in response than was apparent for pole sized trees. This variation was attributed to differences in crown vigour between trees.

Early thinning of stump coppice has been found to have little effect on height or diameter growth of retained stems (Chandler 1939, Bednall 1942), although Stoneman *et al.* (1989) speculated that later thinning of pole-sized coppice stems could be beneficial to growth.

Extensive areas of sapling and pole stands treated during the unemployment relief programs of the 1930's received some thinning, and a further 25 000 ha of pole stands were thinned in the 1960's and 1970's following development of herbicide thinning techniques (Kimber 1967). Jarrah stands containing groups of vigorous, well-formed poles are routinely thinned during current timber harvesting operations.

Application of fertiliser

A number of studies have been undertaken to determine whether application of fertiliser could stimulate dynamic shoot growth from ground coppice. The results of these various experiments have been reviewed by Abbott and Loneragan (1986). Most of these studies have shown a strong shoot growth response to application of nitrogen and phosphorous in combination, but only limited response to application of either element alone. Root and lignotuber growth has not generally been substantially increased by fertiliser application.

Fertiliser application to pole stands has also been investigated. Abbott and Loneragan (1986) concluded that there was limited response to fertiliser application unless stands had also been thinned, although Hingston and Dimmock (1984) did record a response to fertiliser in an unthinned stand. This difference may reflect the lower stand density at the site in the latter study. The most comprehensive study to date of the interaction of thinning and fertiliser is that of Stoneman *et al.* (1996). This study demonstrated that both thinning and application of fertiliser increased the growth rate of a jarrah pole stand, although the growth increase was limited to the fastest-growing 200 stems per ha. Thinning reduced leaf area index and plant water stress, and increased growth efficiency. Fertiliser application increased growth efficiency and tended to increase the leaf area index of moderately to heavily thinned stands, but not of lightly thinned or unthinned stands. Application of fertiliser had no effect on water stress of heavily thinned stands, but increased water stress in unthinned stands.

Another important mechanism for reducing nutritional constraints on the growth of jarrah is to promote understoreys of native legumes which are capable of fixing substantial quantities of atmospheric nitrogen (Hansen *et al.* 1987). This could be achieved through a combination of prescribed fire in autumn to stimulate legume germination, and application of phosphorous to promote legume growth and fixation of nitrogen.

Pests and diseases

Jarrah dieback is a destructive disease which is capable of killing jarrah and a wide range of understorey species in the jarrah forest. Marri, wandoo and WA Blackbutt are relatively resistant to the disease. Jarrah dieback is caused by the soil-borne fungus *Phytophthora cinnamomi* which is an introduced pathogen to Western Australia. The disease has been extensively researched in Western Australia (Shearer and Tippet 1989) and is an important consideration in timber harvesting operations (Underwood and Murch 1984). Recent work by Bunny *et al.* (1995) has confirmed host water potential as a major factor affecting the rate of growth of *P. cinnamomi* lesions on jarrah, independent of site characteristics. Reduced water defecits as a result of thinning may increase disease expression. Caution is therefore required in undertaking thinning or other harvesting operations on sites where *P. cinnamomi* is present, or is likely to be introduced.

Growth of jarrah can be reduced as a result of defoliation by Jarrah Leafminer (*Perthida glyphopa*) and Gum Leaf Skeletoniser (*Uraba lugens*) (Abbott 1992). Abbott *et al.* (1993) summarised the results of 25 investigations into the ecology of jarrah leafminer in relation to fire and logging, and concluded that scarcity of extensive crown scorch from forest fires since the 1950's may have facilitated the spread of the outbreak. They recommended more extensive use of autumn burning to promote crown scorch on codominant trees. There was no consistent association between leafminer outbreaks and timber harvesting operations in the jarrah forest.

Factors responsible for outbreaks of Gum Leaf Skeletoniser in the jarrah forest are not well understood, although there may be a link to warm dry conditions over the winter months (Abbott 1992). Gum Leaf Skeletoniser populations have been monitored annually since 1986, but there have not been any major outbreaks since 1986 (J. Farr, pers. comm.)

References

Abbott, I. (1992). Ecological implications of insect pests in jarrah and karri forests. In: Research on the impact of forest management in south-west Western Australia. Department of Conservation and Land Management, Occasional Paper No. 2.

Abbott, I. and O. Loneragan (1986). Ecology of jarrah (*Eucalyptus marginata*) in the northern jarrah forest of Western Australia. Department of Conservation and Land Management, Bulletin 1.

Abbott, I., Smith, R., Williams, M. and R. Voutier (1991). Infestation of regenerated stands of karri (*Eucalyptus diversicolor*) by bullseye borer (*Tryphocaria acanthocera*, Cerambycidae) in Western Australia. *Australian Forestry* **54**: 66-74.

Abbott, I., VanHuerck, P. and T. Burbidge (1993). Ecology of the pest insect jarrah leafminer (Lepidoptera) in relation to fire and timber harvesting in jarrah forest in Western Australia. *Australian Forestry* **56**: 264-275.

Bednall, B. H. (1942). Jarrah coppice cleaning. *Australian Forestry* **6**: 104-111.

Bradshaw, F. J. (1985). Silvicultural guidelines for the treatment of even-aged regrowth and two-tiered karri forests. Department of Conservation and Land Management, Technical Report No. 1.

Breidahl, R. and Hewett, P. J. (1995). A review of silvicultural research in the karri (*Eucalyptus diversicolor*) forest. *CALMScience* **2**: 51-100

Bunny, F. J., Crombie, D. S. and M. R. Williams (1995). Growth of lesions of *Phytophthora cinnamomi* in stems and roots of jarrah (*Eucalyptus marginata*) in relation to rainfall and stand density in mediterranean forest of Western Australia. *Canadian Journal of Forest Research* **25**: 961-969.

Chandler,W. G. (1939). Thinning experiments in jarrah coppice (*Eucalyptus marginata*). *Australian Forestry* **4**: 69-78.

Christensen, P. (1974). Response of open-rooted karri (*Eucalyptus diversicolor*) seedlings to nitrogen abd phosphorous fertiliser. Forests Department of Western Australia, Research Paper 12.

Coates, D. J. and R. E. Sokolowski (1989). Geographic patterns of genetic diversity in karri (*Eucalyptus diversicolor* F. Muell.). *Australian Journal of Botany* **37**: 145-156.

Department of Conservation and Land Management (1989a). Treemarking and regeneration in wandoo woodlands. Silvicultural Specification 2/89. CALM Western Australia.

Department of Conservation and Land Management (1989b). Treemarking in jarrah forest affected by *Phytophthora cinnamomi* in the Central and Northern Forest Regions. Silvicultural Specification 3/89. CALM Western Australia.

Department of Conservation and Land Management (1989a). Regeneration in forest affected by *Phytophthora cinnamomi*. Silvicultural Specification 4/89. CALM Western Australia.

Department of Conservation and Land Management (1990a). Karri regeneration surveys. Silvicultural Specification 1/90. CALM Western Australia.

Department of Conservation and Land Management (1990b). Jarrah regeneration surveys. Silvicultural Specification 3/90. CALM Western Australia.

Department of Conservation and Land Management (1994). Forest Management Plan. CALM Western Australia.

Department of Conservation and Land Management (1995a). Silvicultural practice in the jarrah forest. Silvicultural Specification 1/95. CALM Western Australia.

Department of Conservation and Land Management (1995b). Silvicultural practice in the karri forest. Silvicultural Specification 2/95. CALM Western Australia.

Department of Conservation and Land Management (1996). Annual Report 1995-96. CALM Western Australia.

Hansen, A. P., Pate, J. S., Hansen, A. and D. T. Bell. (1987). Nitrogen economy of post-fire stands of shrub legumes in jarrah (*Eucalyptus marginata* Donn. ex Sm.) forest of SW Australia. Journal of Experimental Botany **38**: 26-41.

Hatch, A. B. (1960). Ashbed effects in Western Australian forest soils. Forests Department of Western Australia, Bulletin 64.

Havel, J, J. (1975). Site-vegetation mapping in the northernjarrah forest (Darling Range). 1. Definition of site-vegetation types. Forests Department of Western Australia, Bulletin 86.

Hingston, F. J. and G. M. Dimmock (1984). Perturbations of a jarrah (*Eucalyptus marginata*) forest site due to fertiliser application. Proceedings of the Fourth International Conference on Mediterranean Ecosystems (edited by B. Dell).

Kimber, P. C (1967). Thinning jarrah with hormone herbicides. *Australian Forestry* **31**: 128-136.

Loneragan, O W. and J. F. Loneragan (1964). Ashbed and nutrients in the growth of seedlings of karri, *Eucalyptus diversicolor* (F.v.M.). *Journal of the Royal Society of Western Australia* **47**: 75-80.

McCaw, W. L. (1996). Behaviour and short term effects of two fires in regenerated karri (*Eucalyptus diversicolor*) forest. Department of Conservation and Land Management, Technical Report No. 9.

McCaw, L. and M. Rayner (1995). Research for management of regrowth karri forest in Western Australia. Institute of Foresters of Australia Newsletter **36**: 2-6.

McCaw, W. L., Smith, R. H., and J. E. Neal (1996). Prescribed burning of thinning slash in regrowth stands of karri (*Eucalyptus diversicolor*) - an operational trial using helicopter ignition. *CALMScience* **2**: 133-140.

McCaw, W. L., Smith, R. H., and J. E. Neal (1997). Prescribed burning of thinning slash in regrowth stands of karri (*Eucalyptus diversicolor*) 1. Fire characteristics, fuel consumption and tree damage. *International Journal of Wildland Fire* **7**: 29-40

O' Connell, A. M. (1991). Management of slash residues after thinning of regrowth karri forest. In: Productivity in Perspective (edited by P. J. Ryan), Proceedings of the Third Australian Forest Soils and Nutrition Conference. Forestry Commission of New South Wales, Sydney.

O' Connell, A. M. and W. L. McCaw (1997). Prescribed burning of thinning slash in regrowth stands of karri (*Eucalyptus diversicolor*) 2. Nitrogen budgets in pre- and post-burn fuel. *International Journal of Wildland Fire* **7**: 41-49.

Pearce, M. H., Malajczuk, N. and Kile, G. A. (1986). The occurrence and effects of *Armillaria luteobubalina* in the karri (*Eucalyptus diversicolor* F. Muell.) forests of Western Australia. *Australian Forest Research* **16**: 243-259.

Schuster, C. J. (1978). The effect of plant spacing on the early development of karri (*Eucalyptus diversicolor* F. Muell.). Forests Department of Western Australia, Research Paper 44.

Schuster, C. J. (1979). An initial study of provenance variation in karri (*Eucalyptus diversicolor* F. Muell.). Forests Department of Western Australia, Research Paper 55.

Schuster, C. J. (1982). Fertilising planted karri. (*Eucalyptus diversicolor* F. Muell.) seedlings. Forests Department of Western Australia, Research Paper 70.

Shearer, B. L. and J. T. Tippett (1989). Jarrah dieback: the dynamics and management of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia. Department of Conservation and Land Management, Bulletin 3.

Stoneman, G. L. (1986). Thinning a small jarrah forest catchment: streamflow and groundwater response after two years. In: Hydrology and Water Resources Symposium, Australian Institute of Engineers national Conference Publication Number **86/13**: 223-227.

Stoneman, G. L., Bradshaw, F. J. and P. Christensen (1989). Silviculture. In: The Jarrah Forest - a complex mediterranean ecosystem (edited by B. Dell, J. J. Havel and N. Malajczuk). Kluwer Academic Publishers, Dordrecht, The Netherlands.

Stoneman, G. L., Crombie, D. S., Whitford, K., Hingston, F. J., Giles, R., Portlock, C. C., Galbraith, J. H., and Dimmock, G. M. (1996). Growth and water relations of *Eucalyptus marginata* (jarrah) stands in response to thinning and fertilization. *Tree Physiology* **16**, 267-274.

Strelein, G. J. (1988). Site classification in the southern jarrah forest of Western Australia. Department of Conservation and Land Management, Bulletin 2.

Stukeley, M. J. C. and C. E. Crane (1994). Genetically based resistance of *Eucalyptus marginata* to *Phytophthora cinnamomi*. Phytopathology **84**: 650-656.

Underwood, R. J. and J. H. Murch (1984). Hygeinic logging in the northern jarrah forest. *Australian Forestry* **47**: 39-44.

White, B. J. (1971). Regeneration methods in mixed karri-marri stands. Forests Department of Western Australia, Research Paper 4.

White, B. J. (1974). Clearfelling with seed trees in karri (*Eucalyptus diversicolor*). Forests Department of Western Australia, Research Paper 13.

White, B. J. and Underwood, R. J. (1974). Regeneration in the karri forest community. Forest Department of Western Australia, Perth.