Old Growth Mapping

A report prepared for the Western Australian Regional Forest Agreement

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CONTENTS

Old Growth Mapping for the Western Australian Regional Forest Agreement

INTRODUCTION

One of the objectives of the Regional Forest Agreement is the protection of old growth forest consistent with the criteria established by JANIS[1]. These nationally agreed criteria call for the reservation of 60% of the extant area of old growth within each forest ecosystem, except for ecosystems where old growth is rare or depleted in which case 100% reservation is required (see Box 1 for detail).

A universally agreed definition of old growth forest has been a source of disagreement and confusion since the concept of old growth came to prominence in the early 1980's. The term was originally coined to describe those old, long undisturbed, late succession forests of the Pacific Northwest of America. In these particular forests the co-incidence of these characteristics is axiomatic, but it is not necessarily so in other forest communities where age and lack of disturbance are not so clearly linked. There has been a great deal of controversy about the essential elements of old growth in the extension of the concept to other forest types. Definitions that are in common usage fall into three broad groups:

- forest which is old and structurally mature and where past disturbance does not necessarily preclude it from old growth or it is not explicitly stated. (Govt of Victoria 1987, Nyberg *et al* 1987, Gruen *et al* 1989, AHC 1990, Franklin and Spiers 1991, Scotts 1991, Peterken 1996)

- forest which is unlogged, regardless of its age or its structure i.e. virgin forest. Fire as a disturbance agent is ambiguous (Kirkpatrick 1990, ACF 1991, Burgman 1996)

- forest which is old, structurally mature and is undisturbed, little disturbed or there is little evidence of recent disturbance (NFI 1990, RAC 1992, NFPS 1992, Meagher 1991, Juday 1988, SAF 1983, Hunter 1989, IFA 1990, Baur 1990, Woodgate *et al* 1994, JANIS 1996). In this group harvesting is regarded as disturbance by all, while there is considerable variation in the interpretation of fire, including wildfire, as a disturbing agent. Understorey fire disturbance is considered by some but not others (Bradshaw and Rayner 1997b).

[1] Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee

The definition to be used for the mapping of old growth for Regional Forest Agreements throughout Australia has been established by the 1992 National Forest Policy Statement (NFPS). The NFPS definition of old growth forest is:

> *Forest that is ecologically mature and has been subjected to negligible unnatural disturbance such as logging, roading and clearing. The definition focuses on forest in which the upper stratum or overstorey is in the late mature to over mature growth phases.*

The criteria developed by JANIS provides the following interpretation of disturbance:

> *Old growth forest is ecologically mature forest where the effects of disturbance are now negligible.*

The JANIS criteria acknowledges the differences which occur in the interpretation of old growth for forest of different ecological characteristics such as exist, for example, between rain forest and dry sclerophyll forest, and the need to develop working definitions within these criteria which reflect regional and species differences. The working definition for mapping old growth for the WA Regional Forest Agreement has been developed within this framework.

Box 1.

JANIS criteria for the reservation of old growth forest

It is necessary to approach old growth criteria in a flexible manner according to regional circumstances, especially where forest ecosystems are still relatively widespread and retain large areas of old growth. Wherever possible, areas of old-growth requiring protection should be included in the area identified to meet bio-diversity criteria.

- Where old growth forest is rare or depleted (generally less than 10% of the extant distribution) within a forest ecosystem, all viable examples should be protected, where possible. In practice, this would mean that most of the rare or depleted old growth forest would be protected. Protection should be afforded through the range of mechanisms (i.e. dedicated reserves, informal reserves or prescription).

- For other ecosystems, 60% of the old growth forest identified at the time of assessment would be protected, consistent with a flexible approach where appropriate, increasing to the levels of protection necessary to achieve the following objectives: the representation of old growth forest across the geographic range of the forest ecosystem; the protection of high quality habitat for species identified under the biodiversity criterion; appropriate reserve design; protection of the largest and least fragmented areas of old growth; and specific community needs for recreation and tourism. (JANIS 1997)

A major justification for the emphasis on the reservation of old growth is that some species of plants or animals may be restricted to areas of old growth or are dependent on old growth for some of their habitat requirements. While there are some elements of habitat that are more common in old growth forest, there have been no comprehensive studies done in Western Australia (or Australia for that matter) to determine the importance of old growth *per se* relative to other growth stages or disturbance history, or the importance of the understorey development or disturbance relative to the overstorey. Time prevented such a study being undertaken for the RFA. In the absence of comprehensive studies of functionality, identification and mapping of old growth for the purposes of reservation is based directly on a determination of development stage and the history and intensity of disturbance in the overstorey.

The forests of Western Australia (both wet and dry sclerophyll) have had a history of regular fire disturbance in the understorey. While there is no definitive answer to the question of how frequently these forests were burnt during the pre-European era, there is no doubt that fire occurred many times during the natural life span of the overstorey (Underwood 1978). This is quite unlike the forests of the Pacific Northwest of America mentioned earlier or of the rainforests of the east coast of Australia, where the same disturbance initiated the overstorey and the understorey. There are no areas of forest in WA where mature forest overstorey is accompanied by an overstorey of the same age. Fire in the understorey is therefore regarded as a regular source of disturbance characteristic of forests growing in a Mediterranean climate and for the purposes of old growth mapping in these forests, understorey status should be ignored. The role of fire as a disturbance agent of the overstorey is discussed in more detail under the next section.

METHODOLOGY

The JANIS criteria recognizes the need to develop a methodology for mapping old growth that is specific to the characteristics of the forest community and the region, within the broader context of the definition described above.

Because of their ecological differences the methodology used in Western Australia for wet sclerophyll forest (karri and its mixtures) differs from that used for the dry forests (jarrah and wandoo and their mixtures). The identification of development stages (to determine late mature to over mature growth phases) and disturbance history are discussed separately.

Development stages

Wet sclerophyll forest

Structural dynamics

Following germination, even-aged stands of karri (*Eucalyptus diversicolor*) forest develop through several distinct stages—establishment (nominally 0 to 8 years old), juvenile (9 to 25), immature (26 to 120), mature (121 to 250), senescent (250 plus). The characteristic structure of each of these stages is described in detail in Appendix 1. These stages differ from Jacobs' (1955) growth stage descriptions of Juvenile, Sapling, Pole and Mature in that they describe stand rather than tree characteristics. In terms of development stage mapping for old growth purposes, recognition and mapping of the mature and senescent stages are of most interest.

Fire disturbance plays several roles in stand development and condition. It provides conditions for germination of karri, it burns and regenerates the understorey, and if severe enough, may kill the overstorey trees (Breidahl and Hewett 1995). If large patches of trees are killed, an even-aged stand of karri is initiated, while less severe fire may result in a new patch of regeneration and the development of an uneven-aged stand. The progression through development stages will follow in the absence of further disturbance to the overstorey. New disturbances may truncate the development process wholly or partly and create new cohorts of regeneration (Bradshaw and Rayner 1997a). While some uneven-aged stands result from regeneration processes following a progression to senescence, the majority of uneven-aged stands are the result of fire disturbance to the overstorey at much younger ages (see Bradshaw and Rayner 1997b, figure 3). The relatively high proportion of such stands suggests that fire disturbance to the overstorey should be considered a natural part of the dynamics of the karri forest and the presence of uneven-aged stands and regrowth *per se* should not be used as an indicator of disturbance that would preclude it from old growth. Nevertheless, a point of delineation is required to assign the dominant development stage to uneven-aged stands.

Mapping development stages

A methodology for mapping development stages in the karri dominant forest had already been developed by the Department of Conservation and Land Management (Bradshaw and Rayner 1997a) and mapping had been completed for those types within the main karri belt. The method utilized the descriptions in Appendix 1 to assign development stages to even-aged stands. For unevenaged stands, the development stage of the stand was assigned on the basis of the 'dominant' cohort. Dominance in this context is based on 'biological' dominance rather than 'statistical' dominance. A dominant cohort is defined as the oldest cohort with a crown cover exceeding 25% - this is the level beyond which older cohorts are known to cause suppression of the remaining younger cohorts (Rotheram 1983). Figures 1A-D illustrate some of the variations in structure and their assigned development stages. The procedures are summarized below:

- Karri dominant forest in the main karri belt was identified within CALM's GIS database of forest types. The data was based on earlier air photo interpretation maps (Bradshaw et al 1997).

- Even-aged stands of known age (Armstrong 1984) were obtained from the up-to-date records in CALM's GIS database. This identified all stands in the Establishment and the Juvenile stages and some of the Immature stands.

- Areas of karri dominant forest not identified as even-aged regrowth were interpreted using 1:25 000 colour aerial photography to categorize stands as immature, mature or senescent on the basis of the dominant cohort. Crown cover of the dominant cohort was also recorded. The minimum area recognized as a stand was nominally 2 ha but in practice was more commonly 10 ha.

Immature stands were distinguished from mature on the basis of crown size and character.

Initial attempts to differentiate mature from senescent stands based on the proportion of mature or senescent crowns apparent on air photo interpretation were unsuccessful and resulted in an underestimate of senescence. Trees that were clearly senescent when viewed from the ground were not always detectable as such on aerial photos at 1:25,000 scale. (An independent consultant engaged by the Commonwealth to review interpretation methods came to a similar conclusion. A similar observation was made in the old growth mapping in Victoria.) Senescent stands were therefore identified on the basis of the structural characteristics described in Appendix 1 i.e. where there were indications of senescent crowns in the upper canopy associated with gaps in the canopy sufficient to allow for the initiation and persistence of regeneration (Figure 1D)

Photo interpretation was unable to separate early mature from late mature forest.

- Age was estimated at 121 randomly selected sites within these categories using a sample of dominant tree diameters and a previously derived regression of age versus diameter of large dominant trees. These age data were within the expected range for the development stage. Approximately 50% of the mature forest was aged as 'late mature' (see Bradshaw and Rayner 1997a, Figure 2).

- Continuous field checking of the interpreted area was carried out. On the basis of field information, interpretation was re-evaluated where necessary. Some changes to forest type were also made as a consequence of this validation process.

Figure 1A. An example of a stand with 15% crown cover of mature trees, and 55% canopy of immature trees. Classified as *Immature*. The mature cohort is less than 25% and is therefore not considered a 'significant' cohort.

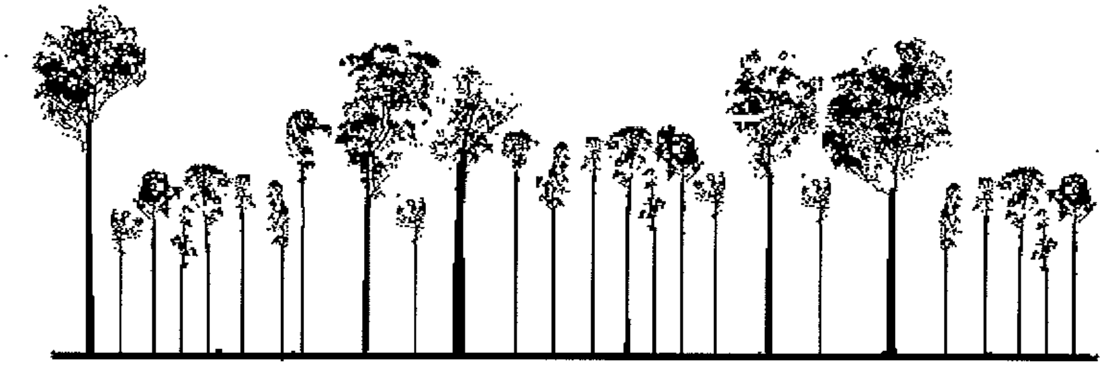

Figure 1B. A stand with 30% mature canopy cover and 50% immature crown cover is classified as *Mature* (multiple cohorts)

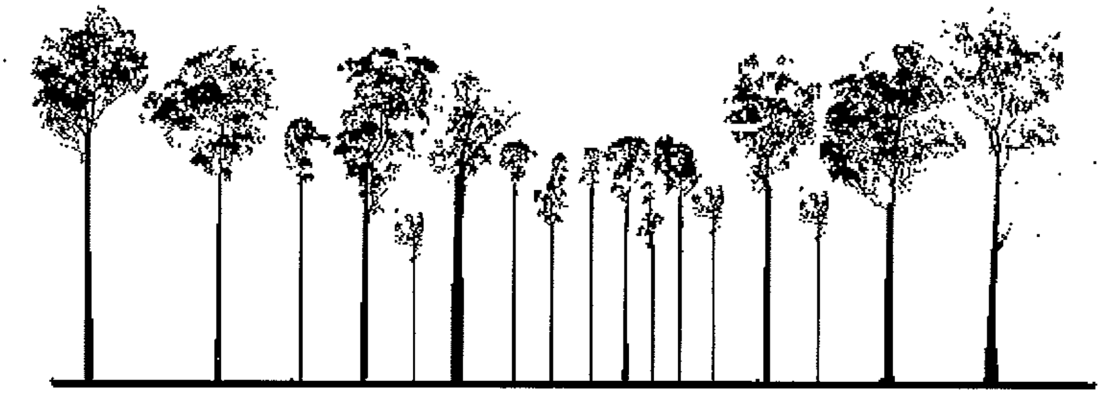

Figure 1C. A stand with 55% mature canopy cover and 15% immature crown cover is classified as *Mature*. The immature cohort is less than 25% and is therefore not considered a 'significant' cohort

Figure 1D. An example of a senescent stand showing evidence of senescence in the dominant mature canopy and with gaps developing and providing the opportunity for regeneration to become established. Age sampling of the karri dominant forest showed that all stands over 300 years of age were of this structure (Bradshaw and Rayner 1997a).

To complete the development stage mapping for the old growth project, this methodology (with the exception of further age sampling) was extended to the remaining karri forest mixtures i.e. mixtures with marri (*Corymbia calophylla*) and the tingles (*E. jacksonii, E. guilfoylei* and *E. brevistylis*), to all the karri forest outside the main karri belt and to private property. Private property was interpreted but not field checked.

Dry sclerophyll forest

Structural dynamics

Jarrah (*E. marginata*) forest dynamics differ substantially from those of the karri forest. Jarrah seedlings may become established under a canopy following even mild disturbance. Seedlings that survive the initial establishment period develop into lignotubers (van Noort 1960, Abbott and Loneragan 1986). This process is repeated to some extent every time the area is burnt. As a consequence the majority of jarrah forest contains a substantial lignotuber pool. The lignotuber develops over a period of time (perhaps 20 years) to the stage where it is capable of rapid development into a sapling if overstorey competition is removed.

Jarrah has other characteristics that affect its dynamics. It is relatively resistant to fire, it has a very strong capacity to recover from defoliation, and it is persistent, i.e. it can survive under extreme competition.

Disturbance (typically fire in natural forests) which removes the overstorey competition will allow for the release and rapid development of the established lignotubers. If the overstorey removal is temporary (e.g. defoliation) the development of the saplings will be arrested when the overstorey crowns recover. The released regeneration will then be subjected to varying degrees of suppression. Development will proceed again at the next temporary setback of the overstorey crowns. If the reduced competition is permanent (as a result of mortality of the overstorey) then the saplings will continue to develop if the gap in the overstorey is large enough. Release under these circumstances is not necessarily associated with fire e.g. mortality may be due to old age or windthrow.

This pattern of more or less continuous recruitment is reflected in the multi-aged structure of much of the jarrah forest. Cohorts of different age (or more precisely time since release) occur at fine scale and are often difficult to differentiate because of the overlap between dominant individuals of one cohort and suppressed individuals of another. This is exacerbated over the long term by the impact of fire damage in the crowns. All of the jarrah forest shows indications of previous fire disturbance of varying intensity.

More or less single storey stands do occur where mature trees dominate the site and inhibit lignotuber establishment or development. Such stands also occur as woodlands where understorey competition, infertile soils or low rainfall inhibit lignotuber establishment and development.

While the differences in the mature and the immature strata are often readily apparent in cutover forests when examined on aerial photos, such distinction is much less evident in virgin forests. Because development stages could not be reliably and consistently interpreted from aerial photographs in the same way as for karri forest, the qualification for old growth jarrah is based on the time and severity of disturbance (other than that caused by fire).

Wandoo (*E. wandoo*) occurs as a forest and as an open woodland formation. Its dynamics are also characterized by continual recruitment of regeneration following fire. In the woodlands in particular, regeneration occurs in patches that are closely associated with ashbed. The characteristic structure of these woodlands is one of single age cohorts occurring in distinct groups with a range of ages at the stand level. No attempt was therefore made to map stand development stages in the wandoo and old growth determination is based on disturbance history described below.

Disturbance history

Because of the fundamental role that fire plays in the normal stand dynamics of karri, jarrah and wandoo forests and the fact that all mature forests have been subject to many fires in the past, fire has not been included as a form of overstorey disturbance in the mapping of old growth. Fire induced regrowth cohorts that do not dominate the stands are therefore not considered indicators of disturbance that would preclude a stand from being old growth. To do otherwise would be to restrict old growth to even-aged mature or senescent stands. In the case of the wet sclerophyll karri forest, stands with any proportion of fire induced regrowth may qualify as old growth provided that the mature or senescent canopy cover is more than 25 percent. This is unlike the definition that applies in the Victorian and Tasmanian assessments (Anon 1996a, Anon 1996b) where fire induced regeneration of more than 10% canopy cover usually precludes the stand from classification as old growth.

In considering disturbance in the context of old growth, attention is therefore confined to what might be described as unnatural disturbance i.e. clearing (mainly for agriculture and mining), logging, exotic disease and grazing. The effects of disturbance are considered more than negligible where changes to the structure of the overstorey caused by these disturbances are still evident or where changes to the overstorey or the understorey are irreversible e.g. alterations to species composition caused by *Phytophthora cinnamomi.*

Clearing

Records of past agricultural clearing in what is now forest are generally good. In Western Australia, the maximum age of forest that could result from abandoned farm clearing would be 170 years. In practice most areas of forest that were once cleared for agriculture date from the 1920's or later, too recent for any regeneration to be mature and therefore qualify as old growth. Open cut mining areas are even more recent. Areas subjected to these forms of disturbance in the past therefore have been excluded from old growth.

Logging

Records of past logging have been maintained since the 1920's, recording harvesting which began in the forest areas in about the 1870's. A substantial proportion of areas harvested before 1940 were given intensive silvicultural treatment in the preceding two decades and detailed records of this work are available. Logging records are now maintained in the CALM GIS system, recording logging activities by decade of harvest. They are generally reliable for state forest areas with less reliability in those reserved areas not previously managed by the then Forests Department. However as part of the RFA process, these records underwent substantial checking. Archived records were digitised and more recent harvesting was re-mapped from orthophotos to ensure consistency of map data. Particular emphasis was given to field checking to confirm that areas recorded as virgin were indeed unlogged and for checking areas recorded as logged where there was a possibility that they may have been unlogged (e.g. steep areas). The data is primarily records based and priority for field checking was given to larger areas that were in question. While small areas of forest may be incorrectly recorded, the percentage affected in this way is considered to be very small.

To address the question of whether the effects of logging disturbance is now negligible, the intensity of past harvesting, the time since harvest and the number of times harvested have been considered.

The earliest harvesting of karri forest on the west coast resulted in even-aged regeneration that is only now approaching the early mature stage and is therefore too young to qualify as old growth. Selection harvesting from 1940 to 1967 generally removed in the order of 50% of the canopy and resulted in patches of regeneration throughout the harvested areas. The structural change to the forest that has occurred is an obvious consequence of the harvesting and cannot be considered negligible in the context of old growth. Most areas harvested between 1930 and 1940 and since 1967 have been clearfelled (Bradshaw and Lush 1981). Therefore all karri areas that have been previously harvested are excluded from old growth on the grounds that the effects of disturbance to the overstorey structure are still apparent and more than negligible.

The jarrah forest has undergone a variety of harvesting intensities (Stoneman et al 1989). Intensive harvesting was characteristic of jarrah forest harvested up to about 1940 and the high component of regrowth which resulted from that logging and the subsequent silvicultural treatment remains an obvious structural change in these forests. Harvesting since 1970 was also relatively intense and the evidence of harvesting is both too recent and too intensive for the disturbance to qualify as negligible. Many of these areas have also been cut more than once. Harvesting in the 1960's is considered too recent to have allowed any of these disturbances to have become negligible. All of the above areas are excluded from consideration as old growth.

Harvesting of jarrah forest between 1940 and 1960 was more variable in intensity and there was a possibility that some would qualify as having negligible disturbance in the context of old growth. The following criteria were used to select areas for possible field inspection: areas of forest which had been harvested once only between 1940 and 1960; that had not previously mapped as pole or sapling stands (Bradshaw et al 1997); that had not been subject to intensive silvicultural treatment (Stoneman et al 1989); and that had not been mapped as having symptoms of infection with *Phytophthora cinnamomi.* These areas were identified and a sample of these areas (25,000 ha) was jointly inspected in the field by Commonwealth and State officers. Areas were excluded from old growth (i.e. disturbance still more than negligible) if they showed evidence of harvesting that was sufficiently intense to have resulted in persistent regrowth as a result of that harvesting. Areas that showed evidence of harvesting (stumps etc) but with no evident structural change to the overstorey were described as 'minimally disturbed'. Areas containing patches of regrowth that were not a consequence of harvesting were included as old growth. In most cases the decision to include or exclude was obvious. Areas found to be virgin or 'minimally disturbed' in this process were included as old growth. 2787 hectares of additional old growth (11% of the area inspected) were included as a result of this inspection.

The wandoo forest and woodland were not studied in detail and all virgin areas were included as old growth.

All areas of private forest were assumed to have been disturbed by logging in the past. On most private land the Crown retained the right to the timber until 1965. The sawlog resource was actively sought until that time in the expectation that it would eventually be cleared for agriculture. In addition, most areas of private forest have been harvested to varying degrees by the owners.

Disease

Areas known to be affected by *Phytophthora cinnamomi* are considered to be more than negligibly disturbed and are excluded from old growth. In some cases symptoms will have advanced to the point of major disturbance to the overstorey while in others it will be confined to impacts on species composition of the understorey which may or may not develop into overstorey impact. In either event the impacts are not reversible. The source of the information is the existing maps of known infection, the data originating from the broadscale mapping of the 1970s to the detailed mapping of the present (Batini 1973, Brandis 1983). It is estimated that 17,000 ha of forest (1.3% of the non-old growth jarrah forest) were excluded from old growth on the basis of *Phytophthora cinnamomi* alone.

Grazing

While substantial areas of the forest have been grazed in the past, most leases in the forest areas were cancelled by the 1960's. There were no areas of publicly owned forest in the RFA area where it is considered that grazing impact would be sufficient to exclude candidate areas of old growth.

Most areas of private forest are still grazed to some degree and in many areas the original understorey has been replaced by exotic grasses. All areas of private forest have been excluded from old growth on the basis of either logging or grazing.

Combining development stage and disturbance to determine old growth

Old growth forest was determined by the intersection of the development stage and disturbance data layers. In summary the ruleset for old growth was:

- Karri, karri/marri and karri/tingle forest—virgin (unlogged) forest that is mature or senescent.
- Jarrah, jarrah/marri and jarrah/tingle forest—virgin (unlogged) forest or forest subject to minimal disturbance as defined above and which is not known to be affected by *Phytophthora cinnamomi.*
- Wandoo forest and woodland—virgin (unlogged) forest or woodland.

There are two points of qualification required.

Karri forest: For the reasons described earlier, it was not possible to map separately early mature and late mature forest as would be necessary to meet the strict definition of the NFPS i.e. late mature and overmature forest. Age sampling of mature karri dominant forest (Bradshaw and Rayner 1997a, 1997b) suggest that 50% of the present virgin mature forest is late mature. If this proportion holds true for the mixtures and the tingles as well then some 53% of the virgin mature and senescent stands would then qualify as old growth. The old growth component of the mature and senescent forest can only be determined by detailed ground mapping and age sampling. This is impractical and is not required to determine the proportion of old growth reserved. The situation in Victoria is similar in that early and late mature could not be differentiated and both categories are included as old growth (Woodgate et al 1994). For mapping purposes all virgin mature and senescent forest are included as old growth.

Jarrah forest: The impact of *Phytophthora cinnamomi* as a source of disturbance is only recognized at the time of mapping. Much of this is based on mapping from the 1970's and it can be expected that there are now new or extended infections which have not yet been mapped. Old growth jarrah will be overstated to that degree but this will not change the situation in terms of percentage of area to be reserved.

RESULTS

Table 1 . The area of old growth and its reservation status within each forest ecosystem at December 1996.

Forest Ecosystem	Extant area of old growth (ha)	Percentage of extant old growth reserved				Area reserved (ha)	Area on public land outside reserves (ha)	Area on private land outside reserves (ha)
		Gazetted formal	Proposed formal *	Informal	Total reserved			
Jarrah Blackwood	48496	10%	13%	10%	33%	15830	32666	0
Jarrah Leeuwin	477	75%	0%	1%	76%	364	113	0
Jarrah Mt Lindesay	14003	5%	42%	3%	50%	6953	7050	0
Jarrah north-east	11561	17%	20%	8%	45%	5241	6320	0
Jarrah north-west	7923	69%	11%	5%	85%	6700	1222	0
Jarrah Rate's tingle	1021	88%	3%	0%	91%	927	94	0
Jarrah red tingle	214	48%	48%	0%	96%	205	8	0
Jarrah sandy	2171	97%	2%	0%	99%	2149	23	0
Jarrah south	160667	23%	26%	7%	56%	90308	70360	0
Jarrah Unicup	4464	23%	61%	2%	86%	3839	625	275
Jarrah woodland	13220	32%	14%	51%	98%	12932	288	0
Jarrah yellow tingle	7249	21%	1%	19%	41%	2951	4298	0
Karri main belt	53576	47%	4%	21%	72%	38712	14864	0
Karri Rate's tingle	674	100%	0%	0%	100%	674	0	0
Karri red tingle	3283	71%	26%	0%	98%	3206	77	0
Karri south coast	#							
Karri west coast	492	90%	10%	0%	100%	491	1	0
Karri yellow tingle	6969	28%	1%	20%	48%	3367	3602	0
Western wandoo forest	7856	20%	54%	6%	80%	6275	1581	0
Western wandoo woodland	2987	27%	22%	12%	61%	1818	1169	0

Notes:
* proposed in Forest Management Plan 1994-2003
\# not analysed - more than 90% outside RFA region

The areas mapped are shown in Map 14 of the Comprehensive Regional Assessment Volume 2 1998.

APPENDIX 1

Description of Stand Development Stages for Even-aged Karri Forest.

(From Bradshaw and Rayner 1997)

Stands of karri develop through several distinct stages from establishment to senescence.

In order to describe the stages in their simplest form we will discuss the development of distinctly even-aged stands and avoid the complexities of site and species mixtures. These descriptions are expanded versions of those previously described by Butcher [2] in CALM (1992). Figures A1-3 provides a diagrammatic illustration of the structure and key features of these stages.

Establishment

In a natural forest the establishment stage begins with the death of a tree or a group of trees in the original overstorey of such a size that the space that is vacated is not 're-occupied' by the surrounding trees (Breidahl and Hewett 1995)

If the conditions for establishment are suitable (primarily an exposed mineral soil seed bed and a source of seed) then the 'unoccupied' space will become occupied by seedlings. These seedbed conditions are most commonly created by fire of varying intensity and as a result the early phases of establishment are characterized by strong inter-specific competition from the understorey species that regenerate at the same time. Rapid growth of the seedlings ensures dominance over the understorey and the establishment stage ends with canopy closure of the saplings at about eight years of age. By this age competition has reduced numbers from perhaps 1,000,000 germinants to 5,000 saplings per hectare and the saplings are about 6 - 10 meters tall.

Net nutrient demand is highest during this period (O'Connell and Menage 1982).

Juvenile

The juvenile stage begins with crown closure and is characterized by a period of intense intra-specific competition which results in the emergence at the end of this stage of about 400-500 dominant and co-dominant trees from an original 5000 individuals at the start of the period. Current annual volume increment peaks towards the end of this period.

The juvenile stage ends when the stand is about 25-30 years old and the crown shape of the dominant and co-dominant trees has begun to alter from the previous conical form to a more rounded shape. This is due to the retention of branches at the base of the crown as

[2] G. Butcher, Department of Conservation and Land Management, Hayman Road, Como, WA

they become too large to be shed cleanly from the bole. The appearance of the stand changes at the end of the period due to the shedding of the lower dead branches causing the stand to take on the more open appearance of the 'pole' stand.

By the end of the juvenile stage and without further fire disturbance the understorey also changes in character. Much of the short lived 'fire weed' species have died and together with the leaf litter and coarser debris, form a partially suspended, well aerated dead litter layer which is still accumulating. There is a sparse mid-layer of green understorey canopy at about 4 meters. Changes in understorey composition over time have been illustrated by Christensen (1972).

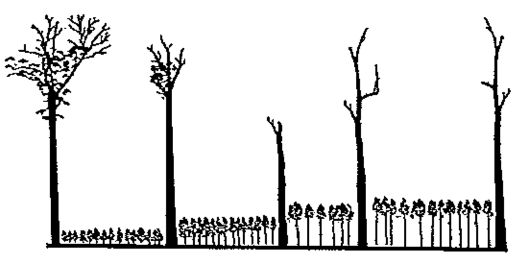

Figure A1. **Establishment** **Juvenile**

Immature

Competition continues throughout the immature stage though at a less rapid rate than in the juvenile stage. Dominants and co-dominants reduce from about 300 to 150 stems per hectare. Small gaps in the canopy resulting from the death of individual trees are quickly re-occupied by the vigorously growing adjacent trees. Net basal area increases till about 50 years of age from which time it fluctuates about a plateau according to the limitations of the site and periodic mortality events (Rayner 1992a).

Height growth continues at a slower rate but the dominants achieve 90% of their final height by the time they are 60-70 years old (Rayner 1992b).

Although bole length continues to increase, the lower dead branches are no longer shed cleanly. The dead branches are now shed by first breaking off several centimeters from the bole and then either rotting away or being overgrown as the bole diameter increases (Jacobs 1955). There is opportunity for the development of hollows to be initiated at this stage where larger branches are involved. The 'shaping' branches become larger and more persistent towards the end of the stage.

This stage ends when individual tree crowns have reached the size above which they are no longer capable of expansion, regardless of the space available. This occurs at about 120 years of age.

In the absence of further fire disturbance the understorey becomes more open. The highly suspended litter of the juvenile stage has broken down, a few long lived individuals of shrub species (such as *Chorilaena quercifolia)* remain, and dry matter (<25 mm) accumulation has stabilised at levels in excess of 50 tonnes per hectare (McCaw unpublished). The situation beyond 65 years is a matter of speculation since this is the longest (documented) unburnt site known to the authors.

Mature

The rapid growth stage ends as the physical limitations of each individual are reached. They can neither occupy more of the site nor increase their crown dimensions; only tree diameter will steadily increase. Intra-specific competition is much reduced and the stand enters a period of relative stability.

The crown has reached its maximum size (about 20-25 meters diameter) and permanent or shaping branches form the outline of the crown. As the extremities of the primary crown become less efficient, epicormic shoots develop within the crown (Jacobs 1955). The branches will periodically break, resulting in replacement through epicormic development without changing crown dimensions (Mackowski 1984). Individuals will slowly decline in vigour, although the growth rate of a dominant tree is largely maintained (Rayner 1992a). Where an individual tree dies, the remaining trees are unable to take up the available growing space, leaving a break in the canopy and allowing regeneration to occur. In many other non-eucalypt forest types this equates to the time when the regeneration of tolerant species will be released and begin to develop (Oliver and Larsen 1990).

The majority of hollow development in crowns is probably initiated early in this stage as large shaping branches break and larger branch stubs overgrow. As with jarrah (Inions *et al.* 1989), their development will be accelerated by wildfire.

The end of this stage occurs when the stand is about 200-250 years old.

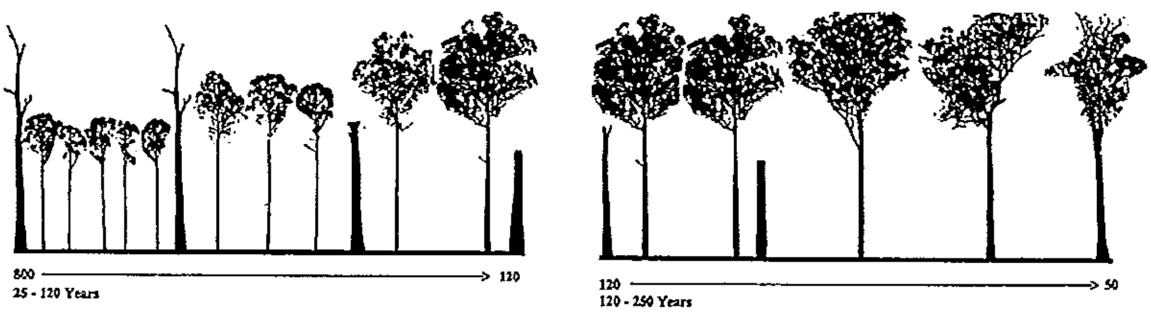

Figure A2 **Immature** **Mature**

Senescent

This is the stage of rapid decline in health, vigour and the number of original trees. The trees have a reduced control over the site. The process of crown renewal slows and, as major branch components are lost, they are replaced by epicormics lower on the branch or bole of the tree. This damage also provides entry points for fungi, which further weaken the tree's structure. In effect, the trees are in decline and will slowly break up. How much of this decline is due simply to the ravages of age and how much to the probability that trees of this age have been subjected to a greater number of damaging events is difficult to determine. However, even relatively young trees may become 'senescent' if severely injured and unable to support their existing structure following such an event.

Previous studies of tree ages (Rayner 1992a) have shown that few living individuals are known to exist beyond 350 years. The age distribution of large living individuals in the forest indicates a rapid decline in numbers between 200 and 280 years, followed by a more gradual reduction till there are only a few rare individuals recorded at 350 years.

Opportunities for regeneration increase as the control of the site by the overstorey diminishes with the increasing death rate of individuals in the stand. In the absence of severe 'stand replacing' disturbance this may result in small patches of regrowth becoming established in small gaps in the canopy if suitable regeneration conditions exist. This may then result in the development of a multi-layered forest. This is the beginning of a new establishment stage overlapping with the senescent stage.

In contrast with some forests, karri has no tolerant climax species waiting to eventually replace it in the absence of disturbance. Furthermore, life-long absence of disturbance from fire is inconceivable in this climate (Underwood 1978). This model is based on the presumption that fire at least of an intensity to create seed bed conditions will occur several times during the natural life span of karri. In the final phase of development there is therefore no late seral phase of alternate species but simply old karri forest which given even modest fire disturbance at that stage will be replaced by a new generation of karri forest.

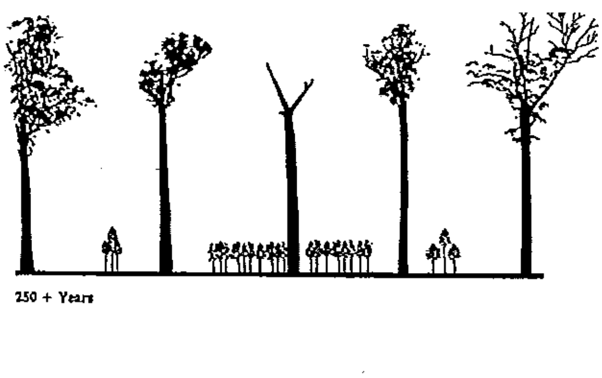

Figure A3 **Senescent**

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