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G.K. Brennan, B.R. Glossop and M.E. Rayner

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W.U.R.C. Technical Report No. 29

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SAWMILLING REGROWTH KARRI OF DIFFERENT AGES FROM DIFFERENT SITE TYPES AND DOMINANCE CLASSES

G.K. Brennan, B.R. Glossop and M.E. Rayner

SUMMARY

Logs of regrowth karri (*Eucalyptus diversicolor* F. Muell.) representing a range of age classes (49-70 years) and dominance classes (dominant-suppressed) were sampled from trees from six stands representing the range in site productivity in the older regrowth estate. The logs were sawn into structural timber (40 mm and 50 mm thick) and appearance boards (30 mm thick). Log yields, board recoveries (volume and grade), log size and the presence and severity of defects were related to recovery and sawing characteristics. Wood properties were also examined. Potential problems associated with brownwood and other fungal rots are discussed.

Mean recovery across all stands was 26.6 per cent, of which 23.5 per cent met Structural Grades 1, 2 or 3 specification and 3.1 per cent met Appearance Grade specification. Recovery percentage was best correlated with log size and tree dominance class, followed by fungal decay and insect damage. Mean board recoveries were significantly different ($P<0.05$) between log position (butt, mid or crown), dominance class and site quality classes. The assessment of defects within logs from the different sites indicated that under-sized boards were the most frequent defects causing downgrade, followed by knots, gum veins and pockets, surface checks and then borer holes. Some decayed boards were discarded in sawmilling and consequently the amount of decay recorded during grading was reduced.

Air drying 30 mm boards indicated that regrowth karri can be successfully dried if protected in the early stages of drying and not exposed to harsh drying conditions.

INTRODUCTION

Karri (*Eucalyptus diversicolor* F. Muell.) occurs naturally in areas of the south-west of Western Australia, from Wheatley on the Donnelly River in the north to Walpole in the south. Outlier populations occur around Margaret River and Karridale to the west and the Porongurup Range to the east of the main forest area. Water catchment protection, conservation and recreation, as well as timber production, are important in the karri forest.

In 1989/90 the timber industry in W.A. used approximately 40 000 m^3 of karri sawlogs supplied from regrowth forests (CALM 1990). Average dimensions of the logs from the regrowth estate are generally smaller than the logs obtained from the traditional old-growth stands, necessitating different sawing and seasoning techniques. Within such even-aged regrowth stands the growth rate of individual trees correlates significantly with their relative position (dominance) in the stand (White 1971), but few data are available on possible correlations to sawn recovery. Indeed, few studies of the utilisation and seasoning characteristics of the logs from such stands, or of the extent and severity of internal defects caused by pathogens and insects have been undertaken. Such information is essential for the efficient planning of harvesting and processing of this valuable resource.

As part of a wider investigation of the growth and site productivity of regrowth karri stands (Rayner 1991a), trees representing varying age and dominance class at each of six sites were felled and sectioned. The primary objective of the present study was to examine the sawn-wood recovery and degrade associated with the range of tree size, age and dominance classes occurring within these stands. This paper reports the sawn recovery and wood properties of logs sampled from six regrowth karri stands growing in areas of high, medium and low site quality and aged between 49 and 70 years. Sawn recovery and defects (including bow and spring) of the sawn timber were related to growth rate (diameter and height increment), age, tree dominance and site quality.

MATERIALS AND METHODS

Stand sampling and study design

On the basis of past silvicultural practice, four broad categories of karri forest are recognised viz. virgin karri forest, selectively cut-over forest, and regrowth forests regenerated either prior to 1939 or after 1966. Logs sawn in this study came from regrowth forests regenerated from clearfelling forest up to the late 1930s and are considered representative of these stands, in which first-thinning operations have commenced.

The stands from which the trees were felled and logs removed were subjectively selected to ensure that the range in site quality and tree size was representative of the regrowth estate older than approximately 50 years. High, medium and low site qualities were sampled. Rayner (1991a) detailed the complete sample framework of which the stands reported here comprise a part.

At each site six trees were selected (one dominant, two codominant, two subdominant and one suppressed stem) following complete enumeration of all trees within a fully-stocked 0.1 ha plot. Trees were classified into dominant, codominant, subdominant and suppressed categories based on tree height and form. The trees selected for felling represented the mean d.b.h.o.b. for trees within each of the crown categories.

Stand, tree and site description

Table 1 summarises the site history, tree classification and site quality for each of the six stands.

With the exception of plot number 4, each stand regenerated as an even-aged stand following burning of logging debris or wildfire. They had not been subjected to any prior silvicultural treatment and variation in tree vigour between the dominance classes is evident in the number of growth rings observed at stump height for each tree. As is common for eucalypts of this growth habit, suppressed and subdominant trees may persist in the stand without producing discernible late wood rings for many consecutive seasons (Rayner 1991b). This is supported by growth plot data which showed that some subdominant stems had no increment over periods of up to ten years. The age of the trees within each plot was therefore taken as the age of the dominant trees.

Each of the stands had been subjected to control burns at varying frequency, while three stands had also been subjected to wildfires on specific occasions. While the map records upon which these data are based are of limited precision and contain information no earlier than 1935 (CALM Fire Protection Branch), it was apparent that these stands would provide a useful indication of the possible extent and frequency of fire-induced defects within logs sampled from these forests.

The site quality of each stand is represented by a number of measures. Stand site index provides a quantitative measure of site quality and has been shown to correlate well with timber volume productivity in such forests (Rayner 1991b). The vegetation community-types identified by Inions *et al.* (1990) also provide a broad indication of site floristics and soil/climate characteristics, while the subjective site quality class has been provided simply to facilitate later comparison and discussions within this report.

Measurements of stand basal area and stocking density (Table 2) indicate that the sample stands represent fully-stocked stands on each site, and could be expected to produce increment at rates directly related to their stand site index (Rayner 1991b).

Log specifications and preparation

Within each tree logs were cut at intervals of 4 m from the butt to a top diameter limit of 15 cm s.e.d.u.b. The total number of logs in each crown category varied due to the smaller size of the subdominant and suppressed trees. A disc for assessment of sapwood width and moisture content was taken at this position (4 m intervals).

Table 1
Site history, tree classification and site quality for six sample stands

Plot no.	Forest block	Tree no.	Dominance class [1]	Number of growth rings [2]	Stand age (yrs)	Site index (m)[3]	Site quality class	Vegetation community type [4]	Stand History	Fire history [5]
1	Murtin	1	Dom	70	70	36.2	Very low	7 (Stewart)	Seed tree regeneration	Wildfire 1961/62 C/B 1967/68 [2] C/B 1973/74 C/B 1979/80
		2	Codom	59						
		3	Codom	70						
		4	Subdom	51						
		5	Subdom	49						
		6	Supp	31						
2	Sutton	1	Dom	58	58	39.3	Low	9 (McNamara)	Seed tree regeneration	No wildfires C/B 1952/53
		2	Codom	53						
		3	Codom	56						
		4	Subdom	44						
		5	Subdom	50						
		6	Supp	26						
3	Channybearup	1	Dom	55	55	42.7	Medium	10 (Shea)	Seed tree regeneration	C/B 1972/73 C/B 1980/81
		2	Codom	53						
		3	Codom	53						
		4	Subdom	41						
		5	Subdom	44						
		6	Supp	42						
4	Channybearup	1	Dom	49	49	46.2	Medium	10 (Shea)	Regenerated from wildings	Wildfire 1949/50 C/B 1956/57 C/B 1962/63 C/B 1969/70
		2	Codom	49						
		3	Codom	47						
		4	Subdom	34						
		5	Subdom	36						
		6	Supp	27						
5	Court	1	Dom	53	53	50.8	High	12 (White)	Seed tree regeneration	Wildfire 1949/50
		2	Codom	49						
		3	Codom	45						
		4	Subdom	52						
		5	Subdom	43						
		6	Supp	43						
6	Yanmah	1	Dom	50	51	44.4	Medium	10 (Shea)	Seed tree regeneration	C/B 1937/38 C/B 1954/55 C/B 1971/72 C/B 1977/78
		2	Codom	42						
		3	Codom	51						
		4	Subdom	43						
		5	Subdom	35						
		6	Supp	39						

[1] Dom = Dominant, Codom = Codominant, Subdom = Subdominant, Supp = Suppressed

[2] Growth rings were measured at stump height (0.3 m)

[3] Stand dominant height at a base age of 50 years (Rayner 1991a)

[4] Categories described in detail in Inions *et al.* (1990)

[5] C/B = control burnt in stated year

Table 2
Stand description of regrowth karri trees for the six sites

Plot No.	Forest Block	Basal area (m²/ha)	Stocking (stems/ha)
1	Murtin	30.4	304
2	Sutton	39.0	288
3	Channybearup	30.3	460
4	Channybearup	43.7	631
5	Court	23.8	364
6	Yanmah	36.8	519

The following specifications were used for logs harvested from the six plots.

Diameter	Minimum s.e.d.u.b. 150 mm. Maximum s.e.d.u.b. 350 mm.
Length	4 m.
Form Sweep:	in log up to 250 mm s.e.d.u.b. - Nil in logs larger than 250 mm s.e.d.u.b. - 35 mm in any 2.4 m length.
Faults	Logs up to 250 mm s.e.d.u.b. - free of severe decay, dry limbs, dry sides and double heart. Logs larger than 250 mm s.e.d.u.b. - double heart or decay in the heart centre were allowed, provided that there was a minimum of 100 mm diameter of clear wood around the circumference of the log. Logs were supplied with ends sawn generally square with a maximum sloven of 250 mm. Ends were free of falling shakes and shatter.

Storage

Logs were stockpiled under water spray for up to two months before sawing.

Evaluation of log degradation

Prior to milling, end splits were rated from one to five using a photographic key. Codes 1 and 2 were minor splits (fissures not extending to the log perimeter), 3 moderate (one or two fissures extending to the log perimeter) and 4 and 5 severe splits (most fissures extending to the log perimeter with splits occurring along the log).

Log characteristics assessed

Clarke (1989) provided a detailed description of the following characteristics:

Sweep

Sweep is a curvature of large radius, or a gradual curve in a log over an extended distance. This was recorded for each log and if sweep exceeded the limit given in the log specification, the log was docked.

Sapwood width

Sapwood width was measured at four positions around the log at predetermined heights above ground level and the average width calculated. Sapwood width and percentage were related to dominance, height and site quality using regression analysis.

Knots and holes

Knot type and size on the log, centre flitch during sawing, and appearance boards were recorded. Knots were assessed as green intergrown or live knots (i.e. a knot completely integrated with the surrounding wood of the supporting stem or branch) or as dry encased knots (i.e. a dry or dead knot partially or wholly surrounded by bark tissue). Holes are created by knots that have fallen out of the timber thus leaving a void. Each of these knots was classified into one of four size classes: 10-25 mm, 25-50 mm, 50-75 mm, and greater than 75 mm.

Gum veins and pockets

Gum or kino is a natural exudation produced in or exuded from hardwood trees as a result of fire, mechanical damage, insect attack or other causes. Gum, whether in pockets, rings or veins, occurs in all hardwood species.

Gum veins and pockets on the worst face of the centre flitch and in the butt, middle and crown sections and full length sections, were recorded. Length of gum veins was measured. During docking and grading, gum veins and pockets were recorded when they were docked out or resulted in a downgraded board.

Brownwood, rots and stains

Brownwood describes karri heartwood which is darker than normal. It appears to be a wound response by regrowth karri to fungal invasion. The brown colour is caused by the accumulation of tannin within rays and axial parenchyma in the heartwood. Some of these fungi have the ability to degrade lignin and cause either straw rot in sapwood or white pocket rot in heartwood within a year (Davison 1989).

Pocket rot is a rot in which the decay processes have been limited to small areas or pockets, usually lens-shaped and surrounded by apparently sound wood. There are no external symptoms to indicate the presence of pocket rot. White rot is a type of decay caused by fungi that utilise a large amount of the lignin, leaving a white or light coloured residue of cellulosic material.

Straw rot is a straw-coloured heart rot occurring in the living tree before felling. It can be diagnosed from rough swellings on the bole of a tree. In sawn timber the wood is bleached, very soft and stringy.

Brown rot is a type of decay caused by fungi which utilise mainly the cellulose fraction of the wood, leaving a brown friable residue containing a high percentage of lignin.

Decay and stain (brownwood) were assessed on the centre flitch and the area affected on each face. During docking and grading, decay (pocket rot, straw rot or brown rot) and brownwood were recorded if they were docked from a board or resulted in a board being downgraded.

Sawmilling

Logs with a s.e.d.u.b. of 350 mm or less were broken down by a twin edger saw with overhead beam feed, using the Waugh (1980) cutting pattern. This pattern is described in more detail in Brennan *et al.* (1990a). Some logs were supplied which were larger than the 350 mm s.e.d.u.b. specified, and these were broken down on a horizontal bandsaw by cutting a 30 mm or 40 mm slab from one side of the log, turning the log over and repeating the procedure, to leave a 200 mm centre flitch. All slabs were resawn on a 'Jonsered' band resaw and the centre flitch cut on the twin edger and band resaw using the Waugh pattern.

Boards were produced by taper sawing wings and flitches into 20 mm, 30 mm, 40 mm or 50 mm thicknesses. In all cases the strategy was to achieve maximum length.

Defects unacceptable in AS2082-1979 (Standards Association of Australia 1979) for Structural Grades 1, 2 and 3, and in the W.U.R.C. grading rules for appearance grades e.g. brittle heart, rot, excessive knots, gum and wane (Brennan *et al*.1990b) were removed in the docking process. The percentage of defects docked from structural and appearance boards, and occurrence in comparison with board length and log volume were recorded.

Grading

Appearance boards were graded into Clear, Feature, Processing or Merchantable grades using the W.U.R.C. grading rules given in Brennan *et al.* (1990b) and 40 mm and 50 mm boards into Structural Grades 1, 2 or 3 using AS2082-1979. Boards below Structural Grade 3 were recorded as below grade. Faults resulting in downgrading of appearance boards were recorded.

Insect damage (bullseye borer)

The larva of the bullseye borer (*Tryphocaria acanthocera* Macleay) eats into the bark in a spiral fashion and gradually works into the sapwood. It then bores upwards on an erratic course for a distance of 3 to 4 m. Bullseye borer galleries are usually about 5 to 10 mm diameter and are a major cause of gum rings or pockets in marri and karri regrowth stems.

In this study the damage from the bullseye borer was recorded on the worst face of the centre flitch. Hole classes (1 to 5 holes, 5 to 20 holes, and greater than 20 holes), average hole size, and whether the hole was surrounded by clean, decayed or stained wood, were recorded. During docking and grading, insect damage was recorded if it was docked out or if it downgraded a board.

Epicormics (birds eyes)

The number of epicormics were assessed on the worst face of the centre flitch. In the grading exercise the percentage of boards downgraded was recorded.

Length of splits

The longest lateral split at each end was measured.

Moisture contents of normal wood and brownwood

Moisture contents of clear wood and brownwood were taken at the butt ends of six logs. Matched adjacent specimens were cut from the same growth ring, and moisture contents were determined by the oven dry method (Standards Association of Australia 1972).

Seasoning

The appearance boards were strip-stacked for air drying in an enclosed shed. Conditions in the shed were estimated as:

equilibrium moisture content (emc) - 11.5 to 12.5 per cent
dry bulb temperature (dbt) - ranged between 18°C and 25°C
air velocity - minimal (approx. 0.2 m/s).

After six months the timber was moved to an open shed where it was stored for a further three months until the timber dried to 15 to 20 per cent moisture content. Final drying to between 6 and 8 per cent was done in a commercial high temperature kiln, using the following schedule:

dry bulb temperature (dbt) - 90°C
wet bulb depression (wbd) - 50°C
relative humidity (rh) - 15 per cent
air velocity - 1 m/s.

Weight restraint was used in the initial and final stages of drying.

Analysis

Principal component analysis was used to determine which 'external' and 'internal' variables were important in predicting total recovery. The external variables used in the analysis were dominance, mean annual increment (M.A.I.), s.e.d.u.b., site quality, plot location, log position (butt or crown) and sweep. The internal variables were amount of brownwood, decay and insect damage, length of gum veins, sapwood area, length of end splits and number of knots and epicormic buds.

RESULTS AND DISCUSSION

Log yield

The distribution of log sizes (s.e.d.u.b.), total recovery, and structural and appearance recoveries based on log volume for each plot are given in Table 3. As expected, recovery was related to log size i.e. the large logs had higher recoveries. Hence, butt logs had higher recoveries than mid and crown logs and dominant/codominant trees need higher recoveries than subdominant/suppressed trees. The relationship of site quality to recovery also relates to log size. The trees in Plot 1 (site quality 4) were between 12 and 21 years older than trees in the other plots, producing logs similar in size to those from the higher quality sites.

The largest logs (mean s.e.d.u.b. of 358 mm), came from Plot 5, which had higher site quality and a lower basal area and stocking compared with the other plots (Table 2), resulting in larger trees per unit area. The smallest logs (mean s.e.d.u.b. of 219 mm) came from Plot 3. Plot 1 provided the greatest number of logs because the original sample had a small number of subdominant/suppressed trees, and additional subdominant logs were harvested to balance the log distribution.

The overall distributions of numbers of logs and log volume by s.e.d.u.b. class are shown in Figures 1 and 2. Forty-eight per cent of the logs were in the 150 - 190 mm and 200 - 240 mm classes and 4 per cent in the 500 - 540 mm and > 550 mm classes. However, logs between 300 mm and 500 mm contained 58 per cent of the total volume, with the 450 - 490 mm class containing 17 per cent of the volume, more than any other class. Twenty-seven per cent of logs (equivalent to 58 per cent of the volume) were larger than the maximum specification size of 350 mm s.e.d.u.b., and had to be broken down on the horizontal bandsaw.

The distribution of numbers of logs and volume for the dominant/codominant and subdominant/suppressed classes of trees are shown (Figs 3, 4). Logs from dominant/codominant trees were mainly greater than 250 mm (84 per cent), whereas logs from subdominant/suppressed trees were mostly less than 250 mm (89 per cent), which is directly related to tree and log size. Log volume distribution showed the majority of the volume greater than 250 mm (94 per cent) was contributed to by the dominant/ codominant trees, whereas the subdominant/suppressed trees were 73 per cent of the volume below 250 mm s.e.d.u.b. Eighty per cent of the total log volume was from dominant/codominant trees, and the balance from subdominant and suppressed stems.

The effect of high, medium and low site qualities on log distribution and volumes is shown in Figures 5 and 6. The high quality sites contributed 35 per cent of the log number, the medium 43 per cent and low 22 per cent, and log volumes were 47 per cent, 36 per cent, and 17 per cent respectively. Seven logs greater than 50 cm s.e.d.u.b. in the high quality site contributed 14 per cent of the total volume. If they were excluded, little difference would have occurred in log distribution between high and medium site qualities.

Analysis of variance for board recovery

Mean recoveries of boards by site quality, log position and dominance are given in Table 4. Analysis of variance showed that log position (butt, mid or crown), dominance class, and site quality, and the interaction of log position and dominance had a significant effect on recovery ($p<0.05$).

A Duncan's multiple range test showed that there was no significant difference for recoveries from butt and mid logs, but both were significantly different from crown logs. Recoveries of dominant/codominant logs were significantly different to those from subdominant/suppressed logs. The volumes from the high site quality (Plots 4 and 5) were significantly different from the medium site quality (Plots 2, 3 and 6) and the low site quality (Plot 1). Similarly, there was no significant difference for board recovery between the low and medium site qualities. The results showed that log size was the overriding factor in determining recovery.

The analysis was also used to assess the effect of decay in the logs on recovery. For logs without decay, the mean recovery was 28.1 per cent , and for logs with decay the recovery was 21.7 per cent, but they were not significantly different. A large proportion of each log (particularly the centre with brittle heart and a knotty core) contained a large amount of decay and was chipped without recording the amount of decayed wood. In future trials the volume of waste chipped will be recorded to give a better estimation of the amount of decay and other defects in regrowth karri logs.

Table 3
Log diameter (s.e.d.u.b.) distribution and sawn recovery from site areas

Plot No.	Site Qual	No. logs	s.e.d.u.b. (cm)		No. logs	Total recovery		Based on log volume		Based on board volume	
			mean	s.d.		mean	s.d.	Structural recovery (%)	Appearance recovery (%)	Structural recovery (%)	Appearance recovery (%)
1	4	41	24.6	10.1	41	25.0	15.0	22.6	2.4	90.6	9.4
2	3	27	28.6	8.3	27	15.7	11.2	14.7	1.0	93.5	6.5
3	3	23	21.9	7.5	23	22.8	12.8	15.5	7.3	68.2	31.8
4	2	32	28.4	13.5	31	30.4	15.2	27.8	2.6	91.1	8.9
5	2	31	35.8	11.9	31	36.6	11.9	34.8	1.8	95.2	4.8
6	3	28	27.2	9.6	28	29.0	13.2	25.4	3.6	87.5	12.5
Total			27.8			26.6		23.5	3.1	98.9	9.1

Figure 1: Distribution of regrowth karri logs by s.e.d.u.b. (cm).

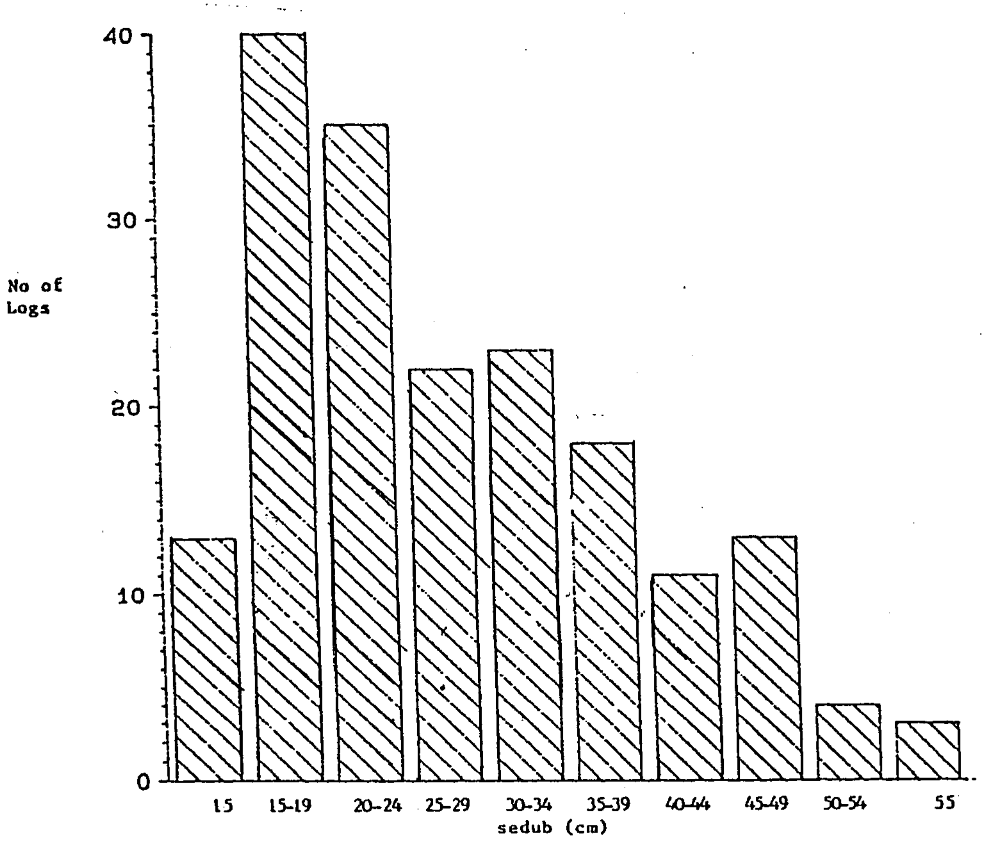


Figure 2: Distribution of the volume of regrowth karri log by s.e.d.u.b. (cm).

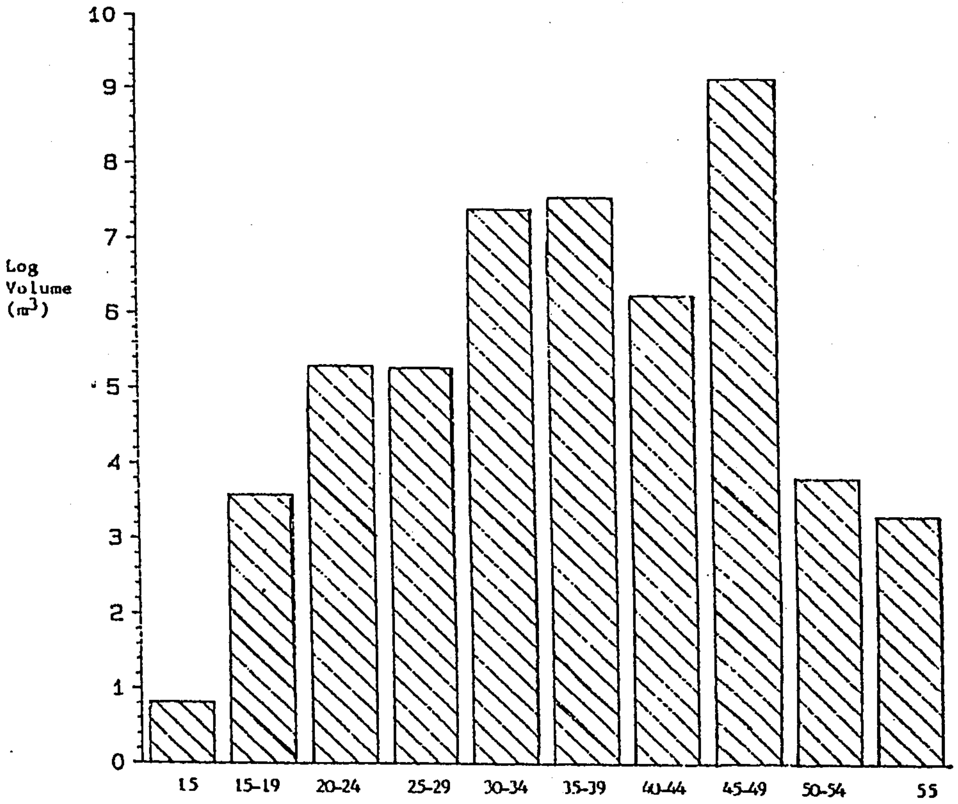


Figure 3: Distribution of dominant/co dominant and sub-dominant/suppressed logs by s.e.d.u.b. (cm).

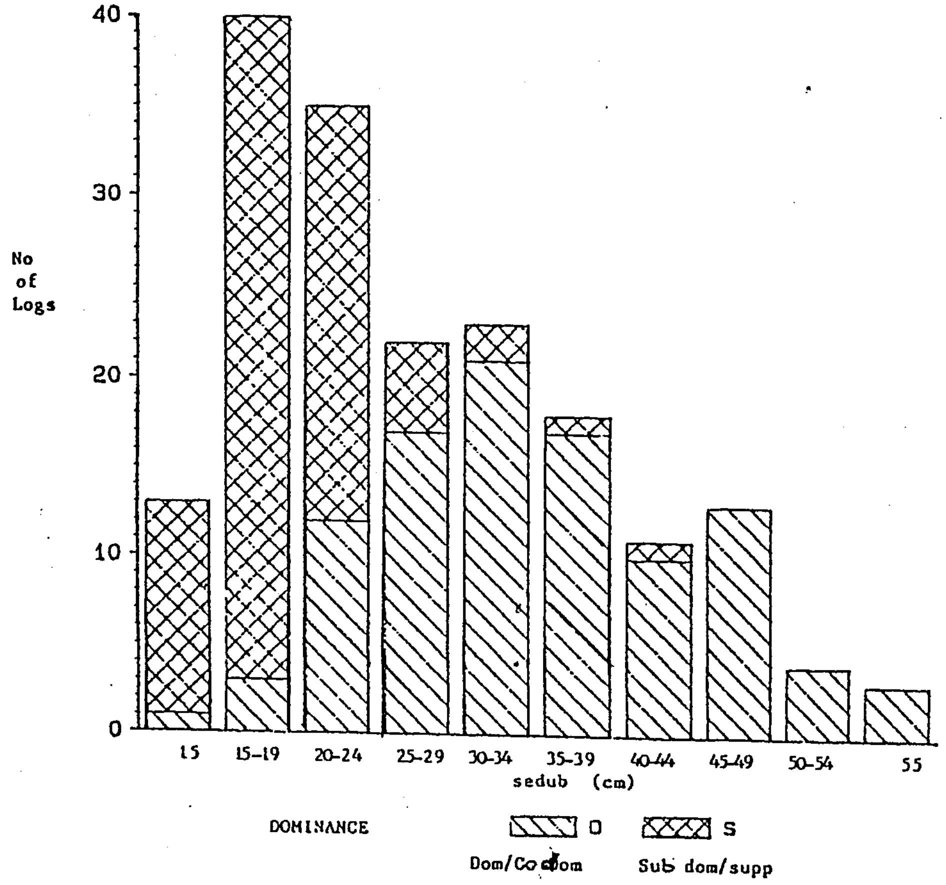


Figure 4: Distribution of volume for dominant/co dominant and sub dominant/suppressed logs by s.e.d.u.b. (cm).

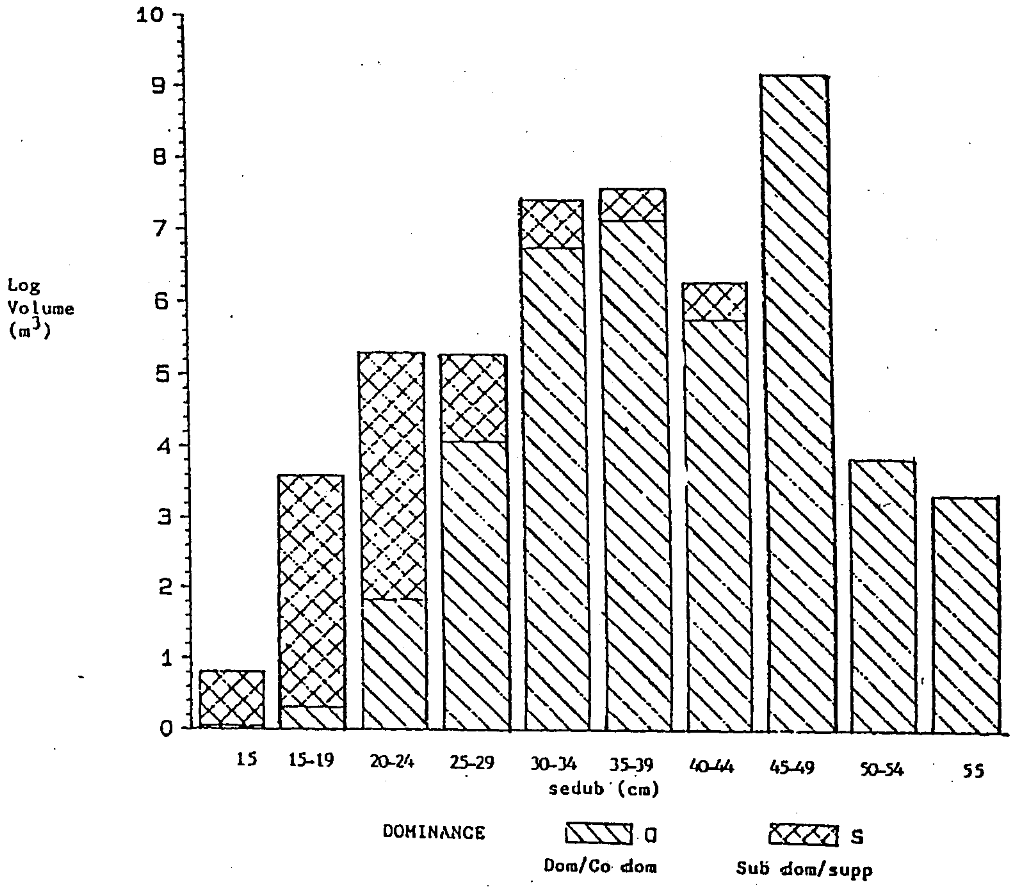


Figure 5: Distribution of logs from high, medium and low site qualities by s.e.d.u.b. (cm).

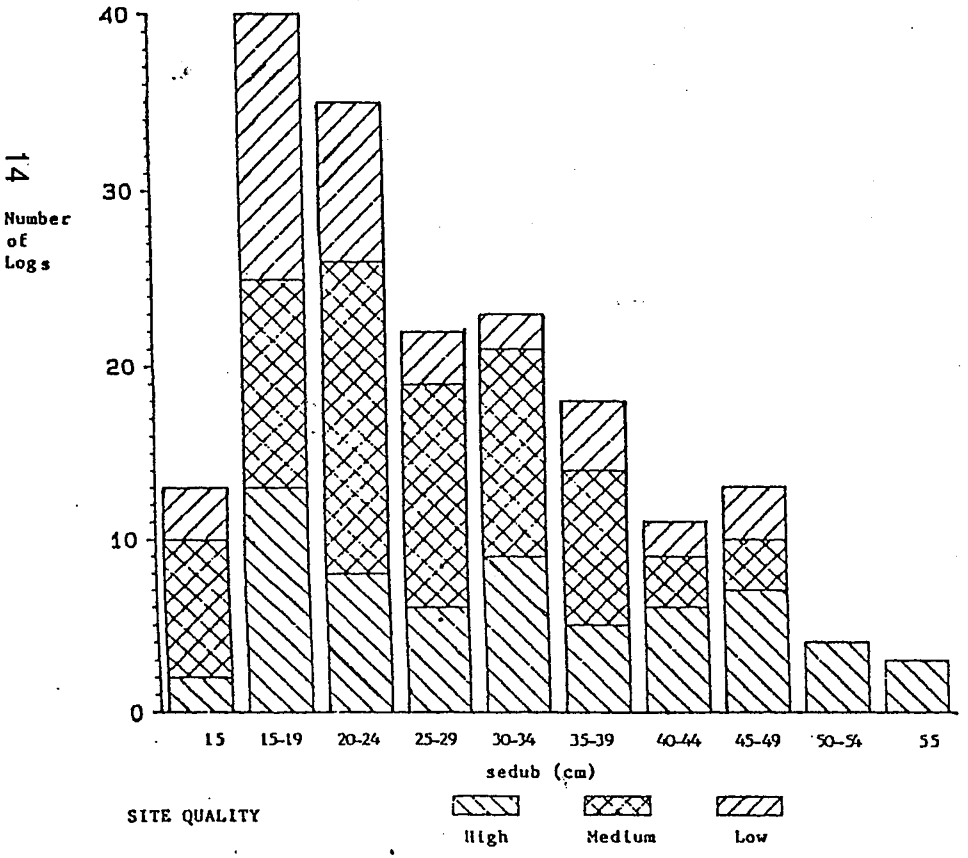


Figure 6: Distribution of log volume from high, medium and low site qualities by s.e.d.u.b. (cm).

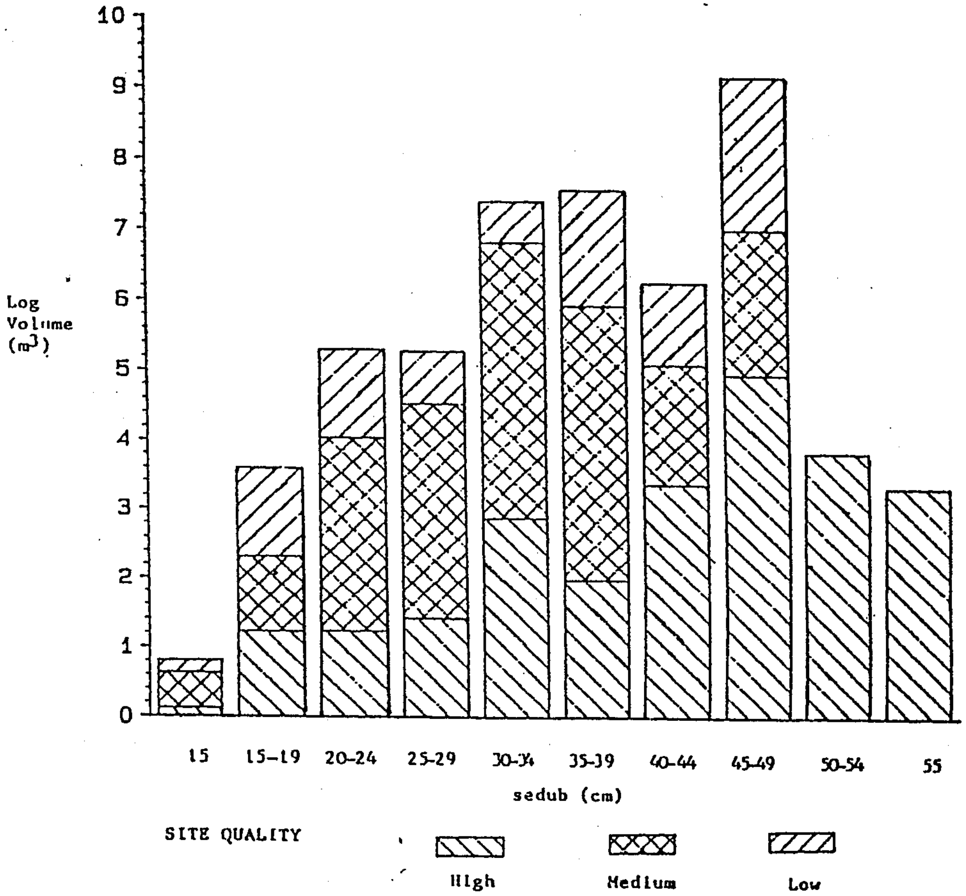


Table 4
Mean recoveries of boards milled from regrowth karri logs by site quality, log position and dominance class (Standard deviations in brackets)

Site Quality	Mean Recovery (%)	Log Position	Mean Recovery (%)	Dominance Class	Mean Recovery (%)
High (Plots 4,5)	33.5 (12.5)	Butt	30.7 (12.8)	Dominant/ Co-Dom	32.8 (11.4)
Medium (Plots 2,3,6)	22.6 (11.2)	Mid	28.8 (10.6)	Sub-Dom/ suppressed	19.6 (12.4)
Low (Plot 1)	25.1 (13.4)	Crown	16.4 (12.5)		

Grading

Structural boards were graded to AS2082-1979 (Standards Association of Australia 1979) into Structural Grades 1, 2, 3, and below grade, and appearance boards according to the W.U.R.C. grading rules (Brennan *et al.* 1990b). Combining all plots the mean recovery was 26.6 per cent, of which 23.5 per cent made Structural Grades 1, 2 or 3, and 3.1 per cent made appearance grade (Table 3). The structural recovery was greater than 87 per cent, except in Plot 3, which had 31.8 per cent of appearance boards and 68.2 per cent structural. Estimating the percentages in structural and appearance grades for each plot showed that 42.7 per cent of structural boards made Grade 3 or better, with high proportions in Grades 1 and 2, indicating that inherent defects (particularly knots) in regrowth karri were not a problem when grading to AS2082.

The trial produced 82 per cent of sawn production as Structural Grade 3 or better i.e. F11 stress grade or above. Appearance boards accounted for 12 per cent of sawn production, and 6 per cent was below grade for either structural or appearance material (Table 5). Resawing and then drying those boards below Structural Grade 3 was an option to increase the percentage of appearance boards. Total recovery of sawn material from all plots was 26.6 per cent. Based on structural timber volume, 23.3 per cent made Structural Grade 1, 16.4 per cent Structural Grade 2 and 42.7 per cent Structural Grade 3, and 5.5 per cent were below grade. For appearance boards 1.2 per cent made Clear Grade, 2.5 per cent Feature, 2.4 per cent Processing, and 6.1 per cent Merchantable (Table 5).

Table 5
Recovery of structural and appearance timber by plot
(based on board volume)

	Recovery of structural grade (%)				Recovery of appearance grade (%)			
Plot No.	1	2	3	Below Grade	Clear	Feature	Processing	Merchantable
1	21.7	21.9	46.9	-	0.6	2.3	1.6	4.8
2	8.9	13.6	63.9	7.5	0.1	1.1	1.1	4.2
3	6.1	12.2	37.6	12.5	3.7	5.1	6.2	16.7
4	49.1	17.5	21.6	3.2	0.6	2.7	2.4	2.9
5	29.0	24.3	39.8	1.9	0.7	1.5	0.9	1.7
6	24.9	9.0	46.3	8.0	1.5	2.5	2.1	6.3
Mean	23.3	16.4	42.7	5.5	1.2	2.5	2.4	6.1

In a previous sawmilling trial using regrowth karri, White (1989) found that more than 80 per cent of the sawn production was Structural Grade 3 or better i.e. F11 stress grade or above, and the recovery of structural timber was 30.2 per cent. For appearance grades little furniture grade material was produced, with a rejection rate in excess of 50 per cent owing to insect damage and associated brownwood.

Most appearance boards were Merchantable, rather than Feature, Processing or Clear Grades. The inherent features in regrowth karri e.g. knots, gum, insect damage, restricted the amount of timber in Clear Grades. On a plot basis, Plot 3 produced the highest proportion of appearance boards compared with structural material, and also the highest amount of Clear Grade.

Although Plots 1, 4 and 5 had been subjected to wildfires, no trend in the amount of insect damage, gum pockets or veins, or butt damage, could be related to effects of fire.

Summary of defects recorded in grading

The assessment of defects from the different plots indicated that under-sized boards (37 per cent) were the most frequent defect causing downgrade, followed by knots (24 per cent), gum veins and pockets (23 per cent), surface checks (16 per cent) and borer holes (14 per cent) (Table 6). The range of under-sized boards was consistent across all the plots, whereas borer damage was more common in Plots 1 and 2 (the low site qualities) and gum in Plots 1, 2 and 3. Surface checks occurred more frequently in Plots 1 and 5 (Table 7). Decayed boards had been discarded in sawmilling, and consequently the amount of decay recorded during grading was low (Table 8).

Table 6
Summary of defects downgrading appearance boards
(Percentage of boards with a defect)

	Plot No.						
Defects	1	2	3	4	5	6	Mean
Undersize	35.7	34.2	36.0	39.4	30.6	42.5	37
Skip	5.4	13.2	10.4	10.1	11.1	13.2	10
Surface checks	23.2	7.9	12.0	8.3	24.1	16.0	16
End split	2.7	7.9	12.0	4.6	5.6	0.9	6
Twist	2.7	0	1.6	2.8	0.9	2.8	2
Spring	8.0	18.4	9.6	8.3	8.3	14.2	10
Cup	5.4	10.5	8.0	4.6	8.3	6.6	7
Bow	16.1	10.5	8.8	12.8	5.6	11.3	11
Sapwood	2.7	5.0	6.4	15.6	16.7	7.5	9
Knots	26.8	15.8	8.0	23.9	18.5	26.4	24
Insect damage	25.0	36.8	12.0	6.4	5.6	16.0	14
Epicormics	1.8	2.6	4.8	0.9	0.9	0.9	2
Gum veins	23.2	18.4	25.6	9.2	13.0	16.0	18
Gum pockets	4.5	13.2	11.2	1.8	2.8	1.9	5
Decay	1.8	2.6	3.2	2.8	0	1.9	2
Knot holes	10.7	7.9	4.8	8.3	4.6	10.4	8

Relationship of recovery to site factors and defects.

Principal component analysis was used to examine the relationship between total recovery, 'external' variables (e.g. dominance class, M.A.I., s.e.d.u.b., site quality, plot location, log position, sweep) and 'internal' variables (e.g. amount of brownwood, insect damage, decay and length of gum veins, length of end splits). Three major groupings used in the analysis showed that the most important variables in predicting total recovery were:

Group A - dominance, M.A.I., s.e.d.u.b., length of end splits, and sapwood area;
Group B - site quality, straw rot, rot area, brownwood area; and
Group C - stain area and epicormics.

Variables in group A are more important than those in group B, which are more important than those in group C.

Table 7
Percentage of defects in structural or appearance grade boards and lengths affected

Plot	Under size		End splits		Shake		Cross grain		Brittle heart		Sap-wood		Wane		Gum veins		Gum pockets		Decay		Stain		Knots		Epi-cormics		Insect damage	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1	4.0	0.4	57	4	1.2	0.2	0.4	0	5.0	1	68	0.2	41	6	34	0.3	35	1	8.7	0.8	62	0	52	5	82	0	70	6
2	2.5	0	51	2	0	0	0	0	2.5	1	70	0	35	5	53	0.6	41	2	15.0	1.6	76	0	62	12	75	0	87	6
3	1.8	0	72	6	0	0	0	0	6.2	2	75	0.2	43	4	65	1.7	50	2	5.0	1.0	43	0.2	54	5	75	0	57	3
4	1.3	0.2	67	6	3	0.3	0	0	4.7	0.8	65	0	43	7	30	0	46	2	12.0	0.2	55	0	57	9	88	.01	34	2
5	1.3	0.1	56	3	3.5	0.9	0.2	0	5.3	1.1	64	0	40	5	34	0.2	37	1	6.0	0.7	48	0	58	7.6	82	0	49	1.9
6	2.5	0.3	75	8	4.0	1.0	0.5	0	4.0	0.9	70	0	41	4.9	41	0.4	43	3	4.6	0.2	43	0	67	7.5	71	.02	46	1.9

A = Percentage of boards affected.

B = Percentage length of boards affected.

Table 8
Percentage of defects docked during sawmilling (based on log volume)

Plot No	Under size	End splits	Shake	Brittle heart	Wane	Gum veins	Gum pockets	Decay	Stain	Knots	Insect damage
1	0.20	2.28	0.05	0.44	1.94	0.08	0.42	0.40	0	2.09	2.42
2	0	1.05	0	0.34	1.18	0.13	0.53	0.40	0	3.7	1.94
3	0	3.27	0	0.65	1.13	0.47	0.68	0.41	.06	2.33	1.05
4	0.15	3.88	0.20	0.25	2.40	0	0.92	0.10	0	4.59	0.69
5	0.10	2.10	0.24	0.55	2.14	0.08	0.77	0.37	0	4.25	1.10
6	0.12	4.75	0.42	0.37	1.67	0.09	1.16	0.05	0	3.03	0.72
Total	0.11	2.81	0.17	0.42	1.87	0.10	0.76	0.28	0	3.55	1.31

Note: Centre flitches and wings with excessive defects (particularly decay) were converted to woodchips.

Log size (dominance, M.A.I., s.e.d.u.b. and site quality and location) and health appear to have the largest effect on recovery, followed by decay and insect damage. The interaction of site factors with external (e.g. dominance, M.A.I. and s.e.d.u.b.) and internal (e.g. decay, insect damage and knots) variables showed that most had no relationship to total recovery and appearance or structural grade recovery.

Bow and spring

Mean bow was similar in boards from logs from all plots, with material from Plot 6 having the largest amount of bow (Table 9). However, these values of bow were less than those found by Brennan *et al*. (1990a) following milling of regrowth karri logs stockpiled under reduced watering schedules. The reduction is presumably owing to thicker boards (40 mm and 50 mm) cut in this trial having less bow and spring than the 28 mm thickness used in the stockpiling trials.

According to AS2796-1985 (Standards Association of Australia 1985), the amount of bow and spring measured in this trial would be acceptable in Select Grade dressed boards, and a large proportion would make Clear grade. Past seasoning experiments have indicated that drying 25 mm regrowth jarrah from green to below fibre saturation point in a tunnel kiln under mild winter conditions reduces the amount of bow (Brennan 1990). Regrowth karri should have a similar reduction in bow during drying.

Differences in spring were observed in boards cut from logs from different plots, and the means are similar to those recorded by Brennan *et al.* (1990a).

Table 9
Mean bow and spring in karri boards

Plot	Bow (mm/m)		Spring (mm/m)	
	Mean	S.D.	Mean	S.D.
1	2.2	1.7	0.9	1.0
2	2.4	2.0	0.7	0.8
3	2.4	3.7	1.1	1.4
4	2.2	1.8	0.9	6.4
5	1.9	1.7	0.8	0.9
6	3.4	2.4	1.1	1.4
Total	2.4		0.9	

Table 10
End splitting (per cent) of butt ends of regrowth karri logs by dominance class and site quality

End Splitting Code	Dominance class			Site Quality		
	All plots	Dom/ codom	Subdom/ supp	High	Medium	Low
0 (no splitting)	1	1	0	0	1	0
1 and 2 (minor)	72	31	40	24	28	20
3 (moderate)	23	19	5	9	12	2
4 and 5 (severe)	4	4	0	1	3	0
Total	100	55	45	34	44	22

End splitting

Data on end splits of regrowth karri at the butt and crown ends are given in Tables 10 and 11. For the butt end 72 per cent of logs had minor, 23 per cent moderate, 4 per cent severe end splitting and 1 per cent had no splitting. Similar results can be seen for the crown end, with 77 per cent having minor, 20 per cent moderate and 3 per cent severe splitting.

Logs from dominant/codominant trees accounted for 55 per cent of end splitting and from sub-dominant/suppressed trees 45 per cent. For all logs, those from dominant/ codominant trees had six times more moderate and severe splits than logs from subdominant/suppressed trees for the large end, and three times more for the crown end. Logs from high (34 per cent) and medium (43 per cent) site quality had more end splitting than those from low site quality (23 per cent). The logs from medium and high site quality sites had eight and five times respectively the amount of moderate and severe end splitting (butt end) than found in low quality sites, and three times more splits at the crown end.

In all cases the dominant/codominant trees and the logs from high and medium site qualities had greater end splitting. Growth rate and the amount of growth stresses would cause more splitting in the dominant and codominant logs. However, Brennan *et al.* (1990a) have found after storing regrowth karri that the stresses may be reduced by using appropriate watering schedules. The majority of the logs stored in the present study had end splitting codes 1, 2 or 3, with only 7 per cent having codes 4 or 5 (Table 10).

The lengths of splits for butt and crown ends of the logs, by dominance class and site quality, are given in Tables 12 and 13. The logs from dominant/codominant trees had a mean split length of 273 mm for the butt end and 231 mm for the crown end, which is approximately three times longer than the mean for subdominant/suppressed logs. Logs from high site quality had longer splits than those from medium and low site qualities, for both butt and crown ends. This relationship is similar for end splits, with logs from dominant/codominant trees and high and medium site qualities having the greatest amount of splitting.

The mean split length for dominant/codominant logs for butt and crown ends was 251.9 mm. If the splitting was extensive an average 500 mm of the 4 m log would need to be docked.

Table 11
End splitting (per cent) of crown ends of regrowth karri logs by dominance and site quality

End Splitting Code	Dominance			Site Quality		
	All plots	Dom/ codom	Subdom/ supp	High	Medium	Low
0 (no splitting)	0	0	0	0	0	0
1 and 2 (minor)	77	38	39	25	33	18
3 (moderate)	20	14	6	9	8	3
4 and 5 (severe)	3	3	0	1	3	0
Total	100	55	45	35	44	21

Table 12
Length of splits (mm) for butt and crown ends of dominant/codominant and subdominant/suppressed logs (Standard deviations in brackets)

	Dominant/ codominant	Subdominant/ suppressed
Butt end	273 (252)	89 (73)
Crown end	231 (191)	84 (87)

Borers

The high percentage of boards with insect damage indicated considerable differences between sites in the amount of attack (Table 7). The percentage of boards and the percentage length of boards affected showed similar trends.

Abbott *et al.* (1992) reported on the damage caused to even-aged regeneration of karri by the bullseye borer beetle, which was found on harvesting first thinnings. Damage was not found in fully stocked stands younger than 14 years, but tended to be associated with the proximity of this regrowth to old growth forest or non-clearfelled stands. Other factors involved are site effects and drought, but not fire damage.

According to Abbott *et al.* (1992), thinning may be an option to reduce infestation of regrowth stands by the bullseye borer, but further research on the effect of site factors on karri physiology and borer ecology is needed.

Brownwood

Brownwood in karri has been recognised for at least 35 years. It is particularly common in regrowth stands, its cause is generally unknown, but it has not been considered a defect. Brownwood appears to be a wound response by regrowth karri to fungal invasion, and the colour is caused by the accumulation of tannin within rays and axial parenchyma in the heartwood. However, recent research has shown that some of these fungi have the ability to degrade lignin and either straw rot in sapwood or white pocket rot in heartwood can develop within a year (Davison 1989).

Wood rotting fungi often infect the above-ground parts of a tree through wounds, and brownwood is frequently associated with insect damage, gum rings and branch stubs.

A preliminary survey of brownwood occurrence in regrowth karri sawlogs from a high quality site in Treen Brook Block (Pemberton District) showed that 73 per cent of logs contain some brownwood, and its severity ranges from scattered pockets to the whole log being affected (Davison 1989). In the survey 53 per cent had only brownwood, only 10 per cent brownwood and straw rot, 4 per cent brownwood and white pocket rot, 5.6 per cent brownwood and brown cubical rot, and 27.4 per cent brownwood or rots.

The assessment of defects in structural and appearance boards (Table 7) showed that the greatest percentage of decay-affected boards was in Plots 1, 2, and 4, suggesting that site quality was not correlated with decay. However, the greatest lengths of affected boards were in Plots 1, 2 and 3, with Plots 4 and 6 having least, with scattered pockets of decay occurring in logs from Plot 4. In all cases the lengths affected were small, and assessment of the percentage of decayed and brownwood-affected wood which would be processed by chipping is required in future trials. The appearance grading showed that logs from Plots 2, 3 and 4 had the highest percentage of boards affected by decay.

Samples from 36 trees from the six plots were used in a karri rot survey reported by Davison (1989). All trees had some symptoms of decay i.e. discoloured sapwood, brownwood, white pocket rot, straw rot, discoloured brittle heart, or discoloration associated with insect galleries. Although sample size varied, the number of sample disks with infections showed that Plot 5 had the least decay (31 per cent), then Plots 4 and 6 (61 per cent), Plot 3 (67 per cent), Plot 1 (74 per cent) and Plot 2 (80 per cent).

Brown rot, white pocket rot and straw rot are secondary and tertiary forms of decay. The small amount of these rots recorded could be owing to the young age of these trees as the fungi have not advanced to produce secondary and tertiary decay.

A large proportion of regrowth karri sawlogs are affected by brownwood and rots. Fungi were isolated from 48 per cent of brownwood, rots and other discoloration in fresh karri, while they were only isolated from 12 per cent of apparently unaffected heartwood. Similar fungi were isolated from both brownwood and white pocket and straw rots. As an example of the potential economic effects of brownwood, Davison (1989) estimated that if 20 per cent of regrowth sawlogs are rejected because of unacceptable incidence of brownwood and rots, the potential dollar loss could be as high as $1.5 million.

Measures to reduce the incidence of brownwood and rot in regrowth karri would be based on factors such as reducing the incidence of borer damage in regrowth stands, examining the relationship between branch size and infection, reducing the inoculum source in the vicinity of regrowth stands, and reducing root infection.

Moisture contents of normal wood and brownwood

All logs showed an increase in moisture content while stockpiled for eight months under water spray, with the brownwood samples showing a greater uptake of moisture than normal wood. Brownwood samples increased in moisture content by a mean of 31.1 per cent and normal wood samples by 19.4 per cent, indicating that brownwood has greater permeability than normal wood.

Drying

At the time of stripping, the sawn timber had initial moisture contents ranging from 73 per cent to 80 per cent which, after six months storage in a shed, reduced to 25 to 35 per cent. The air drying stage resulted in the timber having minimal surface checking which was mainly confined to ends and the top and bottom layers of the bundle. This indicated that regrowth karri can be successfully dried i.e. if protected in the early stages of drying and not exposed to harsh drying conditions.

Sapwood width and percentage

The sapwood width (recorded in log assessment) and percentage of logs, by site quality and dominance class, are given (Table 14). The mean percentage of sapwood of logs from all plots was 29.3 per cent, with little variation between plots. Mean sapwood width for all logs was 22 mm, and ranged from 18 mm for Plot 6 to 30 mm for Plot 5.

Regression analysis confirmed that sapwood width related to diameter under bark (d.u.b.) for all plots, and had a better correlation than sapwood percentage to height up the bole to the top crown log (r^2 of 0.52 and 0.44 respectively). That is, as the d.u.b. increased so did sapwood width and as the height increased so did the sapwood percentage. Sapwood width to height and sapwood percentage to d.u.b. had no relationships for all plots ,the individual plots and site qualities. Logs from the medium site quality had the best correlation ($r^2 = 0.51$) of sapwood width to d.u.b., whereas site qualities high and low had the best correlations of sapwood percentage to height.

Table 13

Length of splits (mm) for butt and crown ends of logs from high, medium and low site qualities (Standard deviations in brackets)

	Site Quality		
	High	Medium	Low
Butt end	231 (220)	181 (199)	156 (232)
Crown end	214 (173)	160 (181)	113 (131)

Table 14
Sapwood width and percentage by site and dominance class
(Standard deviations in brackets)

Plot No.	Forest block	Mean width (mm)	Percentage of sapwood (%)	Dominance	Mean width (%)	Percentage of sapwood (%)
1	Murtin	22.3 (9.9)	31.8 (15.0)	Dominant/ codom	25.5 (7.9)	31.6 (12.7)
2	Sutton	20.7 (7.6)	27.4 (12.4)	Subdom/ supp	13.1 (5.8)	25.5 (11.3)
3	Channybearup	18.6 (9.1)	28.4 (9.1)			
4	Channybearup	20.7 (13.3)	32.9 (15.7)			
5	Court	29.7 (9.7)	29.5 (11.1)			
6	Yanmah	17.7 (7.3)	27.0 (11.4)			

Note: Sapwood width was measured at four positions on sample discs cut at 4 m intervals along the log.

There are potential problems with using sapwood. Studies by the CSIRO Division of Forestry and Forest Products have shown that sapwood from regrowth karri from two sites and ages have been attacked by *Lyctus brunneus* Steph. under laboratory conditions (Creffield *et al.* 1987 and 1988). With an increasing portion of karri boards containing sapwood going into the market, the timber could need chemical treatment to prevent attack. This would be more efficient than discarding the sapwood during sawing, which would waste approximately 30 per cent of karri logs.

Product distribution

Distribution of board sizes milled in this trial are given in Figures 7, 8, 9, 10, 11 and 12. Distribution of thickness showed 67 per cent of the boards were 40 mm, 23 per cent 30 mm and only 8 per cent 20 mm and 2 per cent 50 mm. For volume, 79 per cent were 40 mm, 12 per cent 30 mm, 6 per cent 50 mm and 3 per cent 20 mm.

Figure 7: Distribution of board thickness by volume.

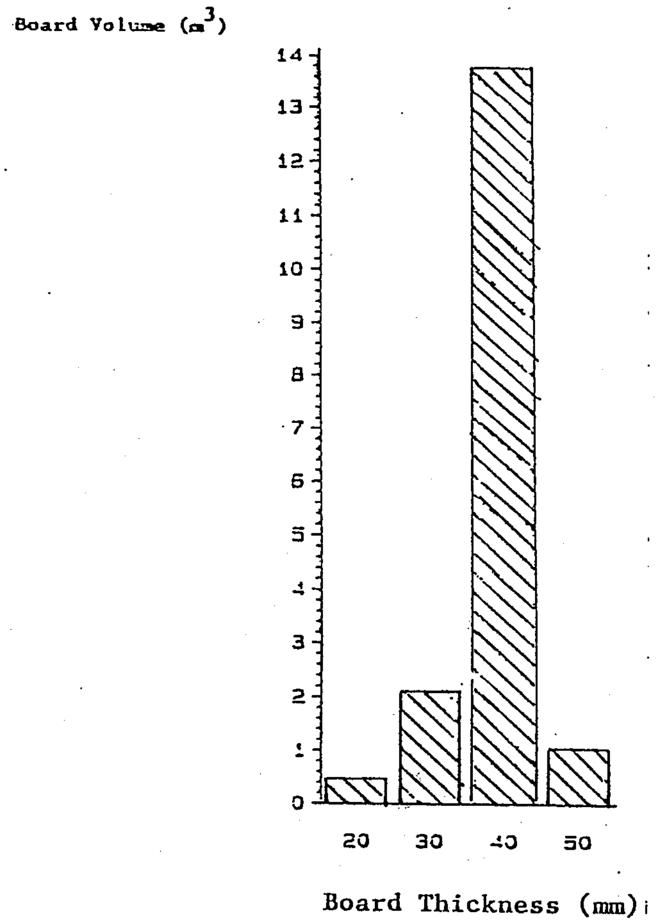


Figure 8: Distribution of board thickness by number of boards.

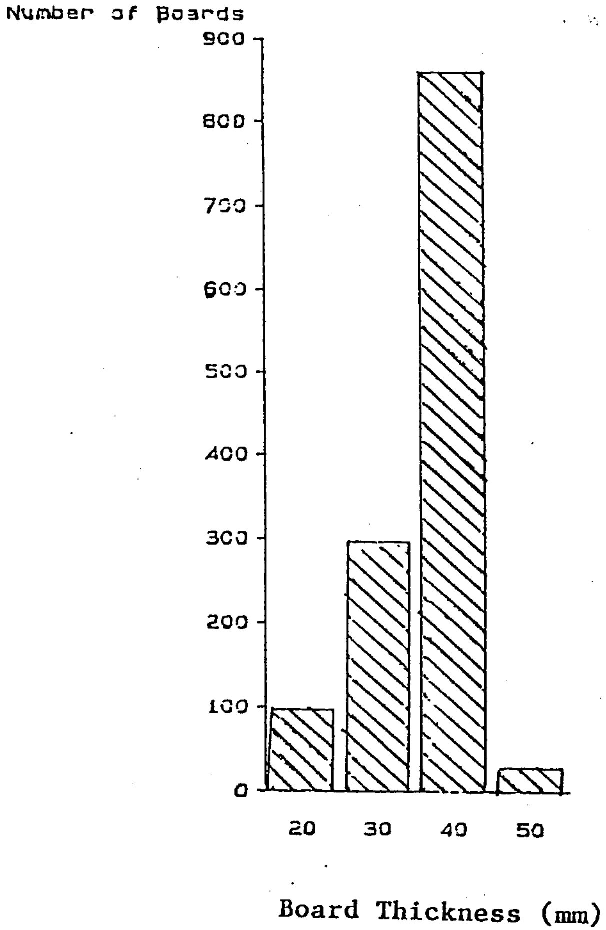


Figure 9: Distribution of board width by volume.

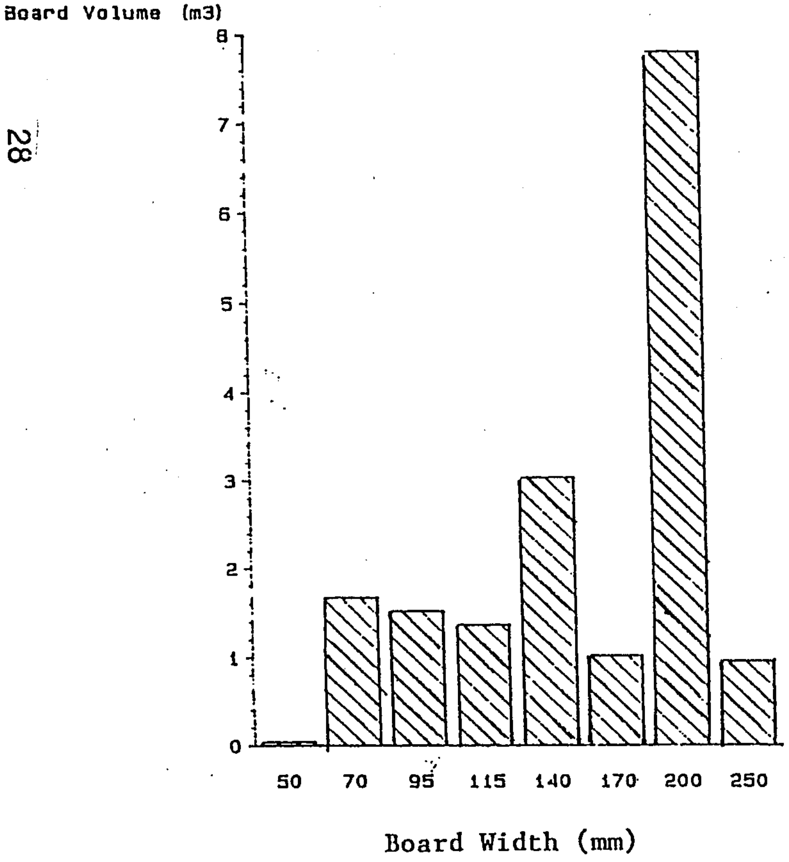


Figure 10: Distribution of board width by number of boards.

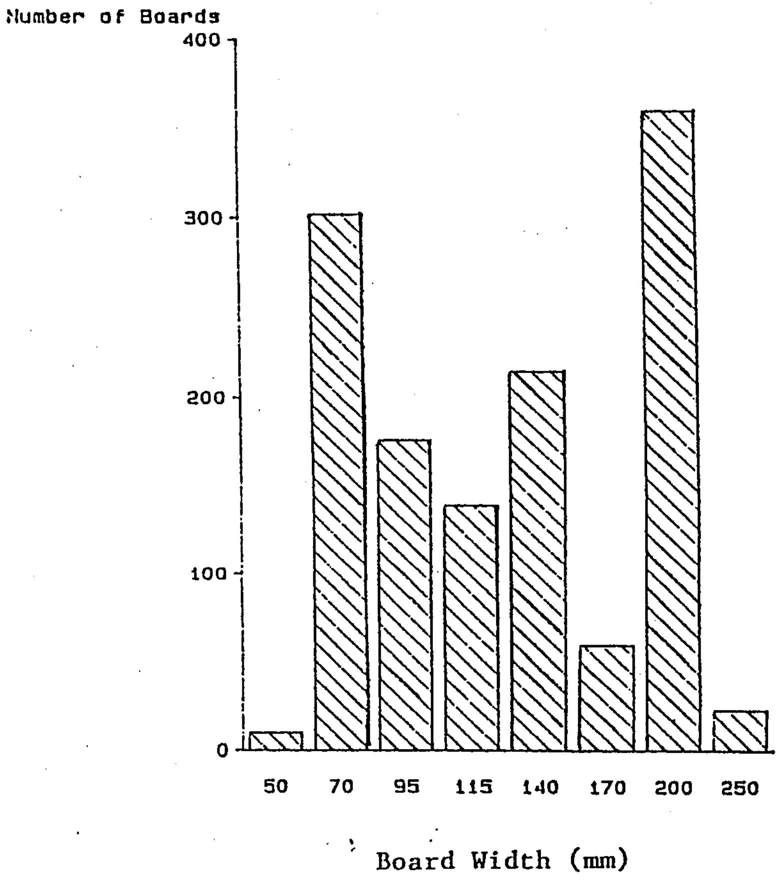


Figure 11: Distribution of board length by volume.

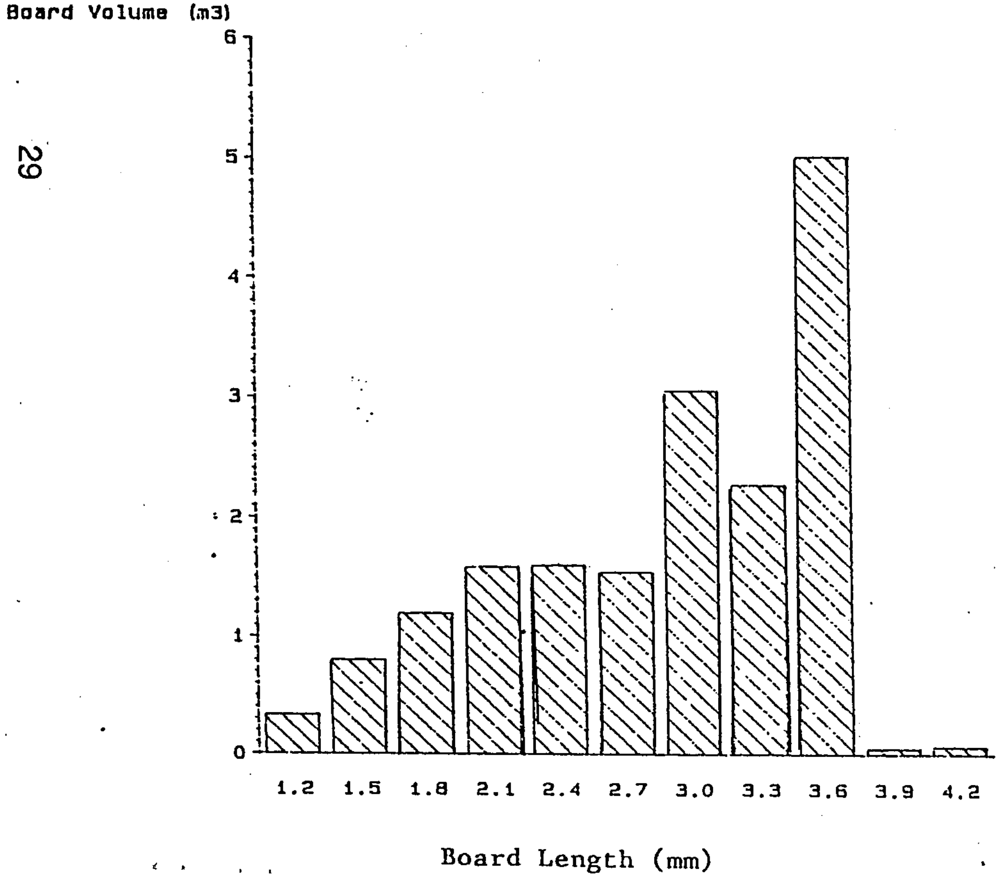
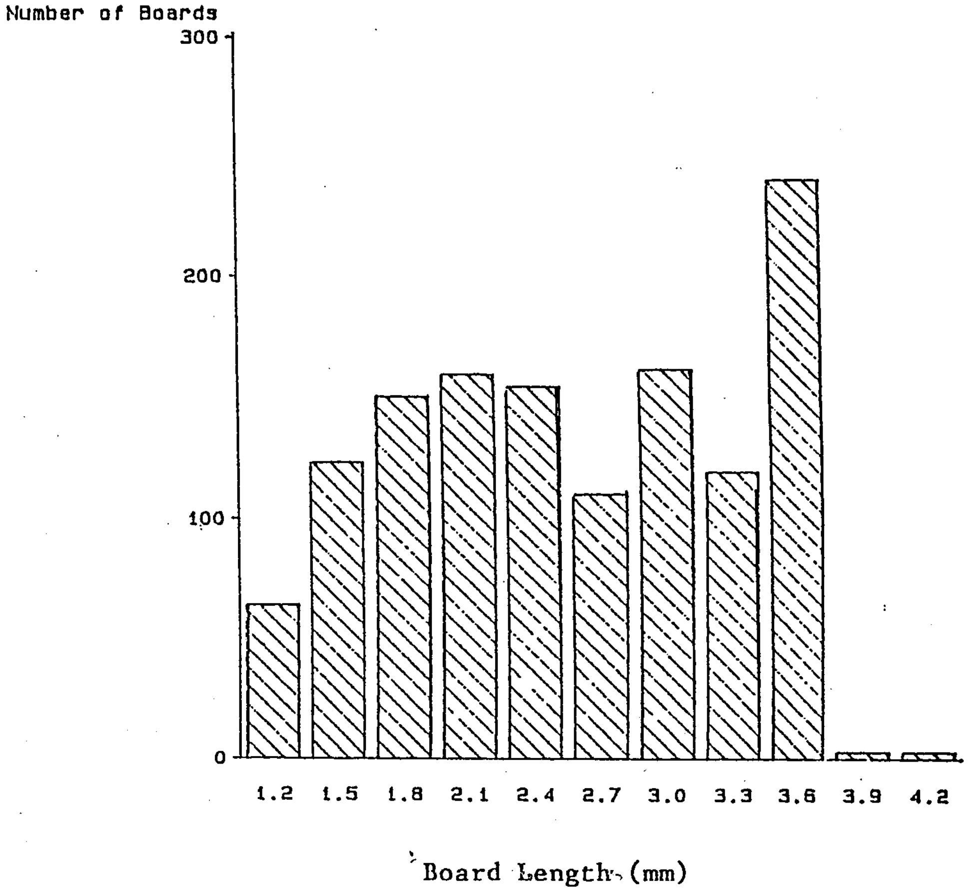


Figure 12: Distribution of board length by number of boards.



Width distribution showed 28 per cent of boards were 200 mm, 23 per cent 70 mm, 17 per cent 140 mm, 14 per cent 95 mm, with only 2 per cent 250 mm and 1 per cent 50 mm. Forty five per cent of the volume were 200 mm wide, 17 per cent 140 mm and 10 per cent were 70 mm, 95 mm, and 115 mm boards.

The most common length cut was 3.6 m (19 per cent) then 1.8 m, 2.1 m, 2.4 m and 3.0 m (12 per cent each). Most of the volume was 3.6 m long (28 per cent) then 3.0 m (17 per cent), 3.3 m (13 per cent) and 2.1 m, 2.4 m, and 2.7 m (all 9 per cent).

Product sizes and distribution obtained in any sawmilling operation are determined by the log dimension and quality, cutting pattern and market demand for finished products. Markets for sawn karri timber are predominantly structural grades, therefore this trial milled structural timber 40 mm and 50 mm thick, as the major products, with the remaining volume sawn into 30 mm thick appearance boards. Using the Waugh (1980) cutting pattern, the majority of logs could be cut into 40 mm and 50 mm thicknesses, however, the smaller logs produced less 40 mm and 50 mm and more 30 mm owing to size constraints.

In summary, this sawmilling trial of regrowth karri has provided basic data on the effect of age, site type and dominance class on sawn recovery. The detailed discussions on recoveries and associated defects will be of value to sawmillers.

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