

# A comparison of timber quality of blackwood grown in young swamp forest, fenced regeneration, and a plantation

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## Abstract

*This study compared the timber properties of blackwood (*Acacia melanoxylon* R.Br.) grown under three different silvicultural systems: swamp forest regeneration, fenced regeneration mixed with eucalypts, and plantation. The plantation material was sourced from seed taken from a single tree at the same location as the swamp forest regeneration. Trees sampled were from 14 to 22 years old.*

*Timber attributes, including basic density, green moisture content, percentage heartwood and heartwood colour, were measured, as were tree and bole height. Wood samples from the two native forest treatments (swamp forest regeneration, and fenced regeneration) had similar properties. Wood samples from the plantation were similar in most respects to those from the native forests but had significantly higher green moisture content. Increased diameter increment did not adversely affect basic density or heartwood colour of the timber at the tree ages studied.*

## Introduction

Blackwood (*Acacia melanoxylon* R.Br.) produces one of the world's best furniture timbers (Boland *et al.* 1984). The wood has been recognised as a quality cabinet timber for over a century (Jennings 1998) and prized for the patterns and colour of its heartwood (Searle 2000), which varies from light brown to dark brown, with occasional

red tints and black streaks. The sapwood is white (Boland *et al.* 1984). The timber is a medium-density hardwood that dries easily, has low shrinkage, stains easily and takes a fine, even polish (Searle 2000). It glues satisfactorily with most common adhesives and is a very good bending timber (TTPB 2001). In addition, logs are moderately easy to peel for veneer, although veneers may split and buckle during drying (Searle 2000).

The species has a wide ecological tolerance, occurring over an extensive range of soils and climatic conditions. It extends along the east coast of Australia, from southern Tasmania to northern Queensland. It is primarily restricted to the coastal belt but extends further inland at higher altitudes (Playford *et al.* 1993).

### *Source of blackwood timber*

The main source of blackwood timber in Australia is from the native forests of Tasmania, where the best timber for high value cabinet woods and veneers is obtained from the north-west (Jennings 1998). Sawlog production in Tasmania has averaged 13 000 m<sup>3</sup>/yr over the last five years (Forestry Tasmania, unpublished data). This volume is derived from blackwood arising from forest operations in eucalypt-dominated forests, and from harvesting operations in blackwood swamp forests (Forestry Tasmania 1999). Australia's other main source of blackwood timber is Victoria, where

sawlog production has averaged 1900 m<sup>3</sup>/yr over the last 12 years (Lambert 2004).

### *Quality of blackwood timber*

Blackwood timber can display wide variations in its properties. Published basic density data for blackwood range from 312 to 681 kg/m<sup>3</sup>. Harris and Young (1988) noted that lower density blackwood causes problems due to its lower hardness and strength characteristics. Extreme variation in density is noted (e.g. Gleason 1986; Nicholas *et al.* 1994) as causing problems in manufacturing 'where uniform raw material is preferred to avoid changes in knife angle, sanding speed, etc.' (Nicholas *et al.* 1994).

Heartwood colour and colour variability are also of some concern to the timber industry (e.g. Grubner *et al.* 1982; Clifton 1990; Lambert 2004; Nicholas and Brown 2002). Colour variation can cause difficulties in matching timber where colour consistency is important (Nicholas and Brown 2002). Barry *et al.* (2003) investigated the nature and genesis of a possible oxidative chemical stain that develops in blackwood timber following harvesting. This is a particular problem in the production of veneer, where its presence results in the downgrading of veneers in the market.

Figure in the grain (e.g. fiddleback, birdseye, raindrop) is highly sought after (Lambert 2004) and is seen as having enormous commercial potential if it can be cultivated and managed. Figure in timber is believed to be genetically influenced (Nicholas and Brown 2002).

The aim of the present study was to determine whether differences in growing conditions and silvicultural regimes affect the timber quality of blackwood.

### **Methods**

Timber from three silvicultural systems, swamp regeneration, fenced regeneration

(referred to as fenced-intensive-blackwood, FIB) and plantation, was included in the study. Samples were selected to be of equivalent ages (14–22 years old). This is considerably younger than commercial maturity, which is expected to be achieved at 70, 60 and 30 years for swamp blackwood, FIB and blackwood plantations respectively.

### *Study sites and treatments*

Details of the three study sites and seven treatments are summarised in Table 1.

**Swamp blackwood.**—Blackwood swamp forest is a naturally occurring forest type that is found predominantly on the low lying, poorly drained flats in north-western Tasmania, west of Smithton. It has been utilised as a rich source of blackwood timber for over a century (Forestry Commission 1991). A detailed study of its floristics and ecology are given in Pannell (1992).

Plots for this study were located in the Plains Creek area in coupes CH044A, CH044B and CH044C (Figure 1, Table 1), and were selected to match the age of the FIB plots.

**Fenced-intensive-blackwood.**— Forestry Tasmania began establishing a new

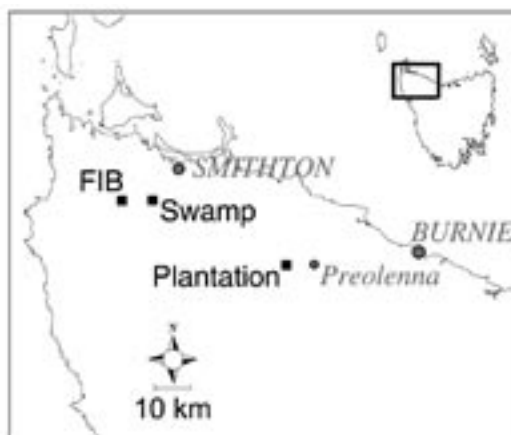


Figure 1. Location of the three treatments (FIB, swamp, plantation) in north-western Tasmania. Local weather stations are at Smithton and Preolenna.

Table 1. Details of study area and treatments.

Coupe	Swamp blackwood			Fenced-intensive-blackwood			Plantation
	CH044A	CH044B	CH044C	TG007A	TG0021A	TG0021B	RP266/1/2
Age (years)	22	17	16	19	15	14	15
Area (ha)	5	7	12	29	37	40	2.9 <sup>1</sup>
Latitude (°E)	40° 55'	40° 55'	40° 55'	40° 53'	40° 55'	40° 55'	41° 05'
Longitude (°S)	145° 02'	145° 02'	145° 02'	144° 57'	144° 56'	144° 56'	145° 28'
Altitude (m asl)	30	30	30	60–75	40–80	40–80	250–300
Soil type	Grey sandy loam over Quaternary sand and clay deposits <sup>2</sup>			Yellow-brown gradational clay-loams over Cambrian greywacke turbidite sequences <sup>2</sup>			Krasnozom over Tertiary basalt <sup>3</sup>
Average annual rainfall (mm) <sup>4</sup>	1100			1100			1590
Average annual raindays <sup>4</sup>	194			194			188
Mean maximum temperature (°C) <sup>4</sup>	16.9			16.9			14.9
Mean minimum temperature (°C) <sup>4</sup>	7.8			7.8			7.5
Silvicultural treatment	Clear-felled, not burnt or fenced	Clearfelled, burnt and fenced		Clearfelled, burnt, sown with eucalypt seed and fenced			Scalped, ripped, mounded and planted

<sup>1</sup> Total area of provenance trial.

<sup>2</sup> Richley (1978)

<sup>3</sup> Allen (1992)

<sup>4</sup> Australian Bureau of Meteorology data for Smithton (swamp and FIB) and Preolenna (plantation). Smithton is located approximately 10 km north-east of the swamp site and 15 km east of the fenced-intensive-blackwood site. Preolenna is located approximately 5 km east of the plantation site (also see Figure 1).

blackwood resource known as fenced-intensive-blackwood (FIB) in 1989 (Jennings and Dawson 1998) in order to increase the future supply of blackwood. The silviculture comprises the clearfelling of blackwood-rich wet eucalypt forest, which is then burnt, sown with eucalypt seed, and fenced to exclude native mammals (Jennings 1998). The blackwood regenerates freely from ground-stored seed and, in the absence of native mammal browsing, establishes at high stocking densities as an understorey to the eucalypt regeneration (Jennings and Dawson 1998). The intention is to thin the eucalypt component in order to maximise the production of blackwood.

For this study, the three oldest FIB coupes in Tasmania (TG007, TG021A, TG021B) were selected for sampling. They are located 6 km to the west of the swamp blackwood coupes (Figure 1).

**Plantations.**—The plantation material used in this study was part of a blackwood provenance trial, Research Project (RP) 266/1/2. The trial was established in 1988 on a former pasture site at Meunna (5 km west of Preolenna, Figure 1), and was designed to test the performance of 23 blackwood provenances in pure plantings without a nurse crop. The trial consisted of row plantings of pure blackwood. There were

five replicates of 22 provenances, with one provenance having four replicates due to stock shortage. The replicates were blocked, with provenances randomly allocated one row per replicate. Plots were single rows of 20 trees. Blackwood was planted at 800 stems/ha at 3.8 m spacing (Allen 1992). The trial was neither thinned nor pruned.

In this study, only the Plains Creek provenance was used. Seed for this provenance had been collected from a single tree of superior phenotype from the same location as the swamp regeneration examined in the present study.

### *Sampling*

For each of the swamp and FIB coupes, 50 circular plots of 10 m radius were randomly located and numbered using GIS-based, plot-location software. Plots numbered from one to 30 in each coupe formed the basis of the sample. Plots numbered from 31 to 50 in each coupe formed a pool of reserve plots. The largest diameter blackwood on each plot was measured. Where a plot was blank (no blackwoods present) or contained only small trees (< 10 cm diameter at breast height over bark, DBHOB), the nearest of the reserve plots in that coupe was measured instead.

In the plantation, trees within each of the five replicate plots of the Plains Creek provenance were numbered, each plot being a single row of 20 trees. Fifty trees were randomly selected. Trees numbered one to 30 formed the sample, with the remainder being reserved in case of missing, dead or small trees (< 10 cm DBHOB), in which case the closest reserve tree in either the same plot or the nearest plot was selected instead.

**Tree measurements.**—For each selected tree, the DBHOB, total height, and green crown height (height to lowest green branch) were measured, and the number of green branches with a diameter at their base



*Photo 1. Oven-dry blackwood cores.*

of greater than 2 cm, in the lower 6 m of the stem, was counted.

**Wood measurement.**—All sample trees were stem-cored using a 12 mm Treecor™ increment borer (Downes *et al.* 1997). One core sample was taken from each tree at breast height (1.3 m) in a north-south direction through the central pith.

Green core samples were stored in a cool room at 4–5°C in plastic tubes, and green volume and mass measured. Volume measurements were made using the buoyancy force method. Cores were then placed in a drying oven at 102°C and dried to constant weight. Average sapwood and heartwood widths were measured on the oven-dry cores (Photo 1). Percentage heartwood was based on cross-sectional area from the one measurement of sapwood and heartwood. Mean annual diameter increment was derived for each core using core length and regeneration age of the sample. Any evidence of timber figure was noted.



Photo 2. *Pinus radiata* boards (35 mm thick), drilled and ready for the cores to be glued.

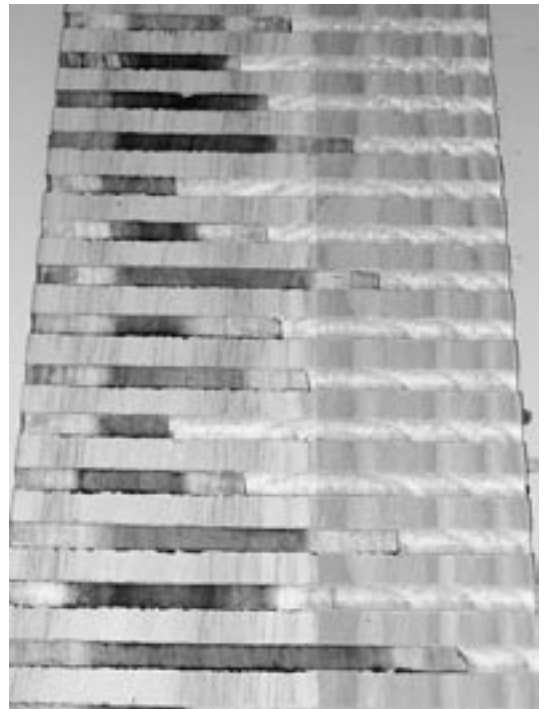


Photo 3. An example of a dressed board with the cores ready for colour measurement.

Heartwood colour was measured using a variation of the technique described by Janin and Mazet (1987). Oven-dry cores were set within blocks of dressed radiata pine (Photo 2) using PVA glue. The blocks were then dressed in a planer-thicknesser, so that half of each core remained in the block and presented a dressed radial surface suitable for colour measurement (Photo 3).

All colour measurements were taken two days after the wood blocks were dressed, to minimise possible colour change resulting from exposure to air and sunlight. Heartwood colour was measured on either side of the central pith, half-way between the pith and the sapwood, with a Lorentzen and Wettre Elrepho spectrophotometer, using a 9 mm aperture. Colour measurements used the CIELAB colour space (CIE 1986) that allows the specification of colour perceptions in terms of a three-dimensional space. The  $L^*$ -axis is known as the lightness, and extends from 0 (black) to 100 (white). The other two co-ordinates,  $a^*$  and  $b^*$ , represent

redness-greenness and yellowness-blueness respectively, and are unbounded.

To provide a context for the sample core colour measurements within the broader blackwood colour spectrum, four colour measurements were also taken from a selection of blackwood veneer samples. These veneer samples represented examples of blackwood colour at the light (one sample), medium (two) and dark (one) range of blackwood colours and were selected for sampling by eye.

Analysis of variance (ANOVA) with Tukey's HSD (Honest Significant Difference) multiple comparison test was used to determine differences between the seven treatments for each of the tree form and timber attributes. Correlation coefficients were calculated across the total sample of 210 trees. Correlations were considered to be strong where  $R$  was  $\geq 0.8$  or  $\leq -0.8$ , moderate where  $0.5 \leq R < 0.8$  or  $-0.8 < R \leq -0.5$ , and weak where  $-0.5 < R < 0.5$  (adapted from Devore and Peck 1993).

Table 2. Blackwood tree attributes for swamp forest coupes, fenced-intensive-blackwood (FIB) coupes and the plantation. (Sample size = 30 trees per coupe). Values in a row followed by the same letter do not differ significantly ( $P > 0.05$ ).

Coupe		Swamp			FIB			Plantation
		CH044A	CH044B	CH044C	TG007A	TG021A	TG021B	RP266/1/2
DBHOB (cm)	Mean	21.4 <sup>a</sup>	16.3 <sup>c</sup>	17.0 <sup>bc</sup>	13.8 <sup>c</sup>	15.2 <sup>c</sup>	13.8 <sup>c</sup>	20.1 <sup>ab</sup>
	SE	1.1	0.7	0.7	0.6	0.6	0.6	0.8
Tree height (m)	Mean	16.1 <sup>a</sup>	12.3 <sup>bc</sup>	12.0 <sup>cd</sup>	11.5 <sup>cd</sup>	13.5 <sup>b</sup>	11.6 <sup>cd</sup>	10.7 <sup>d</sup>
	SE	0.5	0.2	0.2	0.4	0.3	0.3	0.2
Height of lowest green branch (m)	Mean	6.9 <sup>a</sup>	6.0 <sup>ab</sup>	5.1 <sup>b</sup>	5.4 <sup>b</sup>	6.0 <sup>ab</sup>	5.6 <sup>b</sup>	2.3 <sup>c</sup>
	SE	0.5	0.3	0.3	0.3	0.3	0.3	0.2
Count of green branches in lowest 6 m of stem	Mean	0.6 <sup>b</sup>	0.6 <sup>b</sup>	1.5 <sup>b</sup>	1.2 <sup>b</sup>	0.9 <sup>b</sup>	0.8 <sup>b</sup>	6.2 <sup>a</sup>
	SE	0.25	0.15	0.43	0.24	0.26	0.17	0.43

## Results

### Tree form

Tree-form attributes are summarised in Table 2. There were significant differences in DBHOB and tree height across the seven treatments. In general, DBHOB and height values reflected tree age, with the FIB trees of younger average age having generally smaller DBHOB and height. Tree heights for CH044A were significantly taller than those from the other coupes, reflecting both the coupe's greater age and the retention of some regrowth elements from before the last harvest.

The mean height of the lowest green branch and the mean number of green branches in the lower 6 m of the main stem were significantly different in the plantation, compared with the other treatments. The plantation trees had more branches lower on the main stem than the swamp and FIB trees.

### Timber quality

There were significant differences in timber attributes between some of the seven treatments (Table 3). Percentage heartwood was significantly higher for both CH044A

and TG007A than for the other coupes. These coupes represent the oldest of the swamp and FIB treatments respectively.

There was a significantly higher mean green moisture content (GMC) in the plantation material (148%) than in the other six treatments, as well as higher green density and lower basic density. Sapwood width in TG007A (mean 43 mm) was significantly lower than in the other coupes. Mean annual diameter increment also showed significant differences across the seven treatments, being lower in TG007A (0.73 cm/yr) and higher in the plantation (1.26 cm/yr). The remaining coupes were not significantly different, with mean annual diameter increments between 0.96 and 1.06 cm/yr. No evidence of figure in the grain was observed in any of the samples.

### Timber colour

The heartwood colour measurements (Table 4) show that tree cores from the seven coupes had the same range of colours. Cores from one swamp coupe, one FIB coupe and the plantation had mean CIELAB b\* (blue/yellow) values significantly higher (more yellow) than cores from the other coupes. Figure 2 shows the blackwood heartwood

Table 3. Timber attributes for swamp coupes, fenced-intensive-blackwood (FIB) coupes and the plantation. (MAI = mean annual increment; sample size = 30 trees for each coupe; values in a row followed by the same letter do not differ significantly,  $P > 0.05$ ).

Coupe		Swamp			FIB			Plantation
		CH044A	CH044B	CH044C	TG007A	TG021A	TG021B	RP266/1/2
Heartwood (% area)	Mean	40 <sup>a</sup>	26 <sup>b</sup>	28 <sup>b</sup>	41 <sup>a</sup>	29 <sup>b</sup>	25 <sup>b</sup>	29 <sup>b</sup>
	SE	2.1	2.7	2.1	1.9	2.1	1.7	1.7
Basic density (kg/m <sup>3</sup> )	Mean	434 <sup>bcd</sup>	447 <sup>bc</sup>	466 <sup>b</sup>	480 <sup>a</sup>	423 <sup>cd</sup>	443 <sup>bcd</sup>	411 <sup>d</sup>
	SE	9	7	7	10	8	9	8
Green density (kg/m <sup>3</sup> )	Mean	933 <sup>ab</sup>	888 <sup>bc</sup>	990 <sup>a</sup>	996 <sup>a</sup>	836 <sup>c</sup>	877 <sup>bc</sup>	1010 <sup>a</sup>
	SE	26	20	15	16	23	22	13
Green moisture content (%)	Mean	114 <sup>b</sup>	99 <sup>cd</sup>	113 <sup>bc</sup>	109 <sup>bcd</sup>	97 <sup>d</sup>	98 <sup>d</sup>	148 <sup>a</sup>
	SE	3.6	3.7	3.4	3.4	3.1	2.8	3.8
Sapwood width (mm x2)	Mean	69 <sup>b</sup>	70 <sup>ab</sup>	71 <sup>ab</sup>	43 <sup>c</sup>	62 <sup>b</sup>	61 <sup>b</sup>	82 <sup>a</sup>
	SE	4	3	4	2	2	2	3
MAI (diameter) (cm)	Mean	0.97 <sup>b</sup>	0.96 <sup>b</sup>	1.06 <sup>b</sup>	0.73 <sup>c</sup>	1.01 <sup>b</sup>	0.99 <sup>b</sup>	1.26 <sup>a</sup>
	SE	0.05	0.04	0.05	0.03	0.04	0.04	0.05

Table 4. Heartwood colour attributes for swamp coupes, fenced-intensive-blackwood (FIB) coupes and the plantation. (Sample size = 30 trees per coupe; values in a row followed by the same letter do not differ significantly,  $P > 0.05$ )

		Swamp			FIB			Plantation
		CH044A	CH044B	CH044C	TG007A	TG021A	TG021B	RP266/1/2
CIELAB L* (black/white)	Mean	58.5 <sup>bcd</sup>	57.2 <sup>cd</sup>	55.9 <sup>d</sup>	55.8 <sup>d</sup>	62.0 <sup>a</sup>	60.4 <sup>ab</sup>	59.6 <sup>abc</sup>
	SE	0.7	0.8	0.8	0.8	0.9	0.8	0.5
CIELAB a* (green/red)	Mean	10.0 <sup>c</sup>	10.8 <sup>bc</sup>	10.7 <sup>bc</sup>	11.8 <sup>a</sup>	10.7 <sup>bc</sup>	11.1 <sup>ab</sup>	10.8 <sup>b</sup>
	SE	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CIELAB b* (blue/yellow)	Mean	20.7 <sup>b</sup>	19.7 <sup>a</sup>	19.4 <sup>a</sup>	19.6 <sup>a</sup>	19.8 <sup>a</sup>	21.5 <sup>b</sup>	21.4 <sup>b</sup>
	SE	0.2	0.2	0.3	0.3	0.2	0.2	0.1

colour measurements for all cores plotted in the CIELAB a\*/b\* plane. The swamp and FIB cores occupy almost identical a\*/b\* ranges while the plantation cores are clustered towards the yellow half of this range. Direct comparison of the veneer reference samples and the cores can only be illustrative as the veneer samples have a different origin and history, but showed that the heartwood cores fall within the light to medium-dark range of blackwood colours (Figure 2).

#### Correlation analysis

Strong correlations were observed between DBHOB and mean annual diameter increment, and oven-dry density and basic density. Moderately strong correlations were observed between green density and oven-dry density, basic density and green moisture content, between sapwood width and DBHOB and mean annual diameter increment, between CIELAB L\* and green and basic density, and between CIELAB L\*

Table 5. Correlation coefficients between variables across all trees. Only significant correlations ( $P < 0.01$ ) are shown. Moderate to strong correlations are shown in bold. (GMC = green moisture content)

	DBHOB	Sapwood width	Heartwood (%)	Diameter increment	Green density	Oven-dry density	Basic density	GMC	CIELAB L*	CIELAB a*	CIELAB b*
Sapwood width	<b>0.50</b>										
Heartwood (%)	0.46	-0.47									
Diameter increment	<b>0.87</b>	<b>0.56</b>	0.29								
Green density	0.2	-0.19	0.43								
Oven-dry density		-0.25	0.27		<b>0.61</b>						
Basic density		-0.31	0.29		<b>0.60</b>	<b>0.96</b>					
GMC	0.24		0.21	0.21	<b>0.60</b>	-0.22	-0.26				
CIELAB L*		0.24	-0.18		<b>-0.50</b>	-0.46	<b>-0.51</b>				
CIELAB a*					0.25	0.26	0.27		-0.23		
CIELAB b*	0.23	0.24		0.26		-0.25	-0.32		<b>0.72</b>		

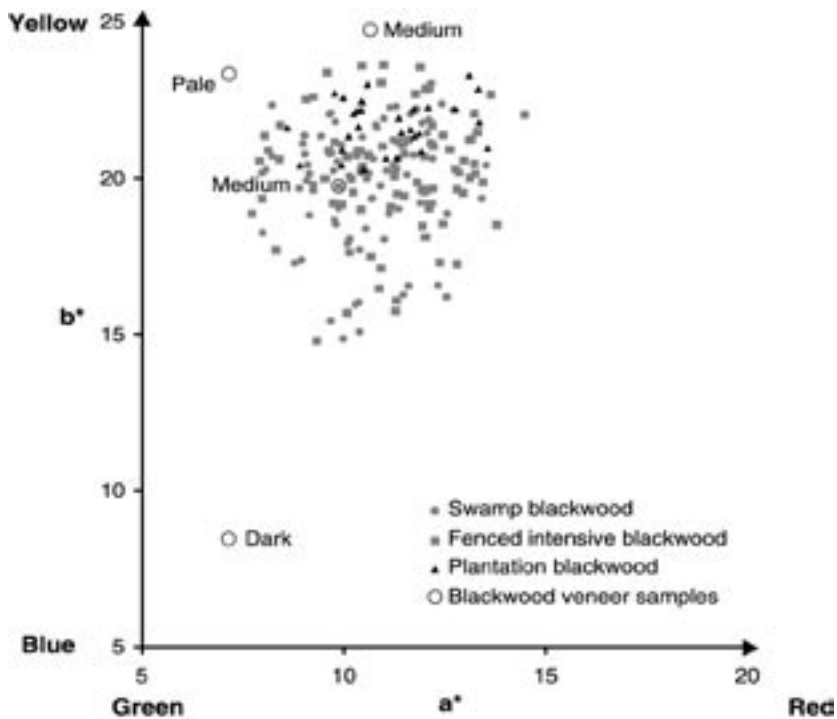


Figure 2. Blackwood heartwood colour measurements plotted in the CIELAB  $a^*$  (green–red)/ $b^*$  (blue–yellow) plane.

and CIELAB  $b^*$ . Of particular importance was the lack of strong and significant correlations between mean annual diameter increment and the three major blackwood timber quality attributes of basic density (no significant correlation), percentage heartwood (significant but weak correlation,  $R = 0.29$ ) and heartwood colour (significant correlation only with CIELAB  $b^*$ , but the correlation was weak,  $R = 0.26$ ) (Table 5).

## Discussion

### *Tree form*

Blackwood trees from the swamp regeneration and FIB treatments had very similar form. Jennings *et al.* (2003) recorded a mean green height (stem height of lowest living branch) of 5.7 m, and a mean number of green branches in the lowest 6 m of the stem of 1.8, for the trees in the FIB coupe TG021A at age 11 years. Trees in this coupe at age 15 had a mean green height of 6.0 m and mean number of green branches in the lower 6 m of the main stem of 0.9. Growth and the branch-suppressing influence of the competing vegetation appear to be continuing to improve the tree form in the FIB treatments.

The plantation-grown blackwood had a lower green branch height and higher count of green branches, which results from the absence of competing vegetation and consequent absence of form-pruning to control branching. Blackwood is a difficult species to cultivate in plantations due to its poor apical dominance and tendency to heavy branching under these conditions (Neilsen and Brown 1997). Nicholas and Brown (2002) note that blackwood in its juvenile (bipinnate) leaf stage retains strong apical growth that is continuous rather than periodic. However, when blackwood changes to the adult (phyllodenous) stage, apical growth becomes periodic, the periods of growth become shorter over time, and the tree develops a strong and persistent branching habit. This periodic growth pattern

has also been considered to be the result of insect damage to the apical tip, causing loss of apical dominance and uncontrolled branch growth (Appleton *et al.* 1997). The transition from juvenile foliage to phyllodes is delayed in provenances from areas of high rainfall, and in trees growing in shaded conditions (Nicholas and Brown 2002).

Growing blackwood in plantation conditions encourages a rapid change from juvenile foliage to adult foliage and is associated with an early change to a periodic growth pattern and loss of apical dominance. Without form-pruning to counter the heavy branching habit, poor commercial form quickly develops.

### *Diameter increment*

Mean annual diameter increments for swamp and FIB trees were similar and reflect untended native regrowth conditions. Mean annual diameter increment for the plantation trees was significantly greater than for the other treatments and reflects more open growing conditions and better soils. The significantly lower diameter increment for TG007A reflected a generally poorer site, which is also reflected in the lower tree height, given the age of the trees. Only a weak positive correlation ( $R = 0.29$ ) was observed between diameter increment and the percentage of heartwood. This supports the results of Nicholas *et al.* (1994) who also observed a weak positive correlation ( $R = 0.38$ ) between DBHOB and the percentage of heartwood in 10-year-old blackwood (DBHOB at a known age is the equivalent of diameter increment).

Mean annual diameter increment was only weakly correlated with CIELAB  $b^*$  ( $R = 0.26$ ) and was not correlated with the other colour variables. Nicholas *et al.* (1994) also observed weak correlations between DBHOB, and visual colour grading and colour instrument measurements in 10-year-old blackwood. Mean annual diameter increment was not correlated to basic density, a result also supported by Nicholas

*et al.* (1994). This indicates that increasing blackwood growth rates through intensive silvicultural management or through selection and breeding should not negatively affect percentage heartwood, heartwood colour or basic density.

#### *Sapwood width and percentage heartwood*

DBHOB showed significant correlations with mean annual diameter increment, percentage heartwood and sapwood width, and percentage heartwood and sapwood width were also significantly correlated, reflecting the fact that in general the sapwood was confined to the outer 4–6 annual growth rings. Increasing growth rate therefore increases sapwood width but also increases percentage heartwood for a given tree age, due to the apparent upper limit on sapwood width, at least in the trees sampled here. In contrast, Nicholas *et al.* (1994) recorded percentage heartwood values as low as 0% for 10-year-old plantation-grown blackwood, indicating that sapwood width and heartwood development in blackwood are quite variable. Haslett (1986) states that sapwood is usually only 20–50 mm wide, presumably for samples grown in New Zealand. The significant but weak correlation between DBHOB and percentage heartwood ( $R = 0.46$ ) indicates that heartwood development is controlled by diameter and other factors. With the value of a blackwood log largely determined by the colour and volume of heartwood within the log, factors that affect heartwood development need to be better understood and managed. Currently, sapwood width and heartwood development represent significant uncontrolled variables in the development of a plantation blackwood resource.

Percentage heartwood values were remarkably consistent across all seven treatments. The two oldest coupes (CH044A, TG007A) contained trees with percentage heartwood values at or above 40%, while the remainder ranged between 25% and 29%. In a study of 21 trees of 70-year-old plantation-grown blackwood

in New Zealand, Haslett (1986) observed a mean percentage heartwood of 79%. Nicholas and Brown (2002) give a figure of 61% for 21-year-old plantation-grown material. Haslett (1986) noted a figure of over 50% sapwood by volume for 15-year-old New Zealand blackwood. No tree or stem diameter information is given for these studies. Nicholas *et al.* (1994) recorded percentage heartwood of 0–74% for 10-year-old plantation-grown blackwood, with mean tree DBHOB values of between 16.6 and 20.5 cm. The four seedlots in their study had mean values ranging between 42% and 52%. The authors noted that the rate of heartwood formation changes with time and tree size, but 50% heartwood at age 10 years appeared quite acceptable (Nicholas *et al.* 1994). Only 10% of the 210 trees sampled in the current study had percentage heartwood of greater than 50%. Occurrences of unusually low percentage heartwood trees, such as the 0% observation by Nicholas *et al.* (1994), are a cause for concern for blackwood growers.

Harrison (1974) undertook a major study (75 trees across eight districts) of heartwood percentage because the value of a blackwood log in South Africa is more closely related to its mean heartwood diameter than to its mean under-bark diameter. A curvilinear relationship was found between under-bark diameter and percentage heartwood width. Harrison included heartwood analyses at stump height and at 4 m intervals up the tree, and recorded percentage heartwood widths of 14–90% (2–81% by area) for stem under-bark diameters of 10–30 cm. This corresponds closely with the range of values recorded here. For stems with diameters above 20 cm, the minimum percentage heartwood recorded by Harrison was 55% (30% by area), showing that the proportion of heartwood increases rapidly with increasing diameter. Very similar results were observed here, with only five trees of diameter greater than 20 cm having heartwood contents of less than 25% by area.

The plantation had higher average annual rainfall than the FIB and swamp sites but

Table 6. Published data on basic density of blackwood timber. (n/a = not available)

Reference	Age (yr)	Basic density (kg/m <sup>3</sup> )	
		Mean	Range
Current study	14–22	443	305–571
Nicholas <i>et al.</i> (1994) <sup>1</sup>	10	n/a	312–577
Nicholas and Brown (2002) <sup>2</sup>	21	480	382–566
Harris and Young (1988) <sup>3</sup>	46	475	390–576
Haslett (1986) <sup>4</sup>	70	581	465–670
Kingston and Risdon (1961) <sup>5</sup>	n/a	546	396–673
Greenhill and Dadswell (1940) <sup>6</sup>	n/a	540	399–681

<sup>1</sup> A total of 59 trees from four seedlots of 10-year-old New Zealand plantation-grown blackwood were sampled with mean seedlot values ranging from 424 to 498 kg/m<sup>3</sup>.

<sup>2</sup> A total of 45 trees of 21-year-old New Zealand plantation-grown blackwood.

<sup>3</sup> A total of 15 trees of 46-year-old New Zealand plantation-grown blackwood.

<sup>4</sup> A total of 245 samples from 21 trees of 72-year-old New Zealand plantation-grown blackwood of unknown provenance.

<sup>5</sup> A total of 45 trees assumed to be from native forest from South Australia, Victoria and Tasmania.

<sup>6</sup> A total of 28 trees of Australian samples assumed to be from native forest.

a similar number of rain days per year. However, there was no significant difference in percentage heartwood across these three sites when results for treatments at a site were pooled (data not shown). These results do not support Harrison (1974) who hypothesised that environment was the main control over heartwood content, with wetter sites having higher heartwood content. A weak correlation ( $R = 0.43$ ) was observed here between percentage heartwood and green density, as also observed by Nicholas *et al.* (1994). A weak correlation ( $R = 0.21$ ) was also observed here between percentage heartwood and green moisture content. However, Nicholas *et al.* (1994) observed a moderate correlation, which they attributed to higher moisture content in blackwood heartwood than sapwood, as demonstrated earlier by Haslett (1986).

#### Basic density

The basic density values recorded in this study (305–571 kg/m<sup>3</sup>) cover the lower half of basic density values recorded in the available literature (Table 6). However, the basic density range observed corresponds

to ranges recorded in other studies with material of similar ages.

Basic density, along with green and oven-dry densities, was significantly negatively correlated with CIELAB L\*, indicating a possible relationship between low density and light colour. Britton Bros, Sawmillers (pers. comm., 2003) have noted a similar relationship in the milling and sale of blackwood.

In a study of within-tree variation in basic density for blackwood, Ananias (1989) found that basic density increased from 460 to 540 kg/m<sup>3</sup> from the pith to a radius of 12 cm. Haslett (1986) measured increases in basic density from 520 to 600 kg/m<sup>3</sup> to a radius of 15 cm. Both studies showed basic density then dropped with increasing radius before levelling off (at 510 and 580 kg/m<sup>3</sup> respectively). These studies demonstrate the impact of juvenile wood upon the wood characteristics of young blackwood. The young age of the material sampled for this project suggests that basic density is comparatively low due to the predominance of juvenile wood. Table 6

shows a general trend of increasing average basic density with increasing age of the material, as reported by Ananias (1989) and Haslett (1986). This generally reflects the increasing proportion of mature wood with increasing age.

Harris and Young (1988) noted that the pattern of wood density variation in blackwood makes conventional mean density values of limited value. There is remarkable variation from tree to tree. Another source of variation is more apparent at the textural level: streaks of tension wood are common in blackwood, and these tend to become very gummy in heartwood, giving rise to dark coloured, dense, hard wood that responds very differently to tools compared with the surrounding normal wood. However, tension wood causes few problems in drying, and its colour adds greatly to the character of the timber.

Wood at the lower end of the density range (400 kg/m<sup>3</sup> or less) tends to be rather soft for uses such as joinery and furniture. The elimination of this low density material may well be possible by careful seed and site selection in planted stands (Harris and Young 1988). Britton Bros, Sawmillers (pers. comm., 2003) have noted the difficulty of marketing lower density blackwood material. Forty-three per cent of the samples from the plantation treatment have a basic density below 400 kg/m<sup>3</sup>. This may indicate that the particular provenance used (Plains Creek) is less suitable commercially, although the density will increase as the stand ages and the proportion of juvenile wood decreases.

#### *Green density and green moisture content*

Small but significant differences in green density were found between the seven treatments, as in the closely related green moisture content (GMC). The plantation trees had a significantly higher GMC than all other treatments, possibly due to differences in annual rainfall, recent rainfall or drought, genetic differences, or a combination of factors. Nicholas *et al.* (1994)

noted no significant difference between four seedlots in green density, while recording significant differences in basic density and GMC. Green density was significantly and moderately correlated with oven-dry and basic densities, and GMC. Nicholas *et al.* (1994) found green density strongly correlated with basic density and only poorly correlated with moisture content.

Published GMC values for blackwood range from 44% to 176% (Table 7). These values were obtained using a range of different measurement techniques and are therefore difficult to compare directly. The GMC values in this study are within the published range cited, with the exception of one sample from the plantation treatment with a very high GMC of 194% and a very low basic density of 360 kg/m<sup>3</sup>. Green moisture content was moderately correlated with green density ( $R = 0.60$ ). For the plantation treatment alone, GMC was moderately negatively correlated with basic density ( $R = -0.73$ , data not shown). Nicholas *et al.* (1994) only observed a weak negative correlation between GMC and basic density for their four plantation-grown seedlots.

Moisture content is important when drying timber and its variability impedes the development of effective drying schedules (Nicholas *et al.* 1994). However, while blackwood GMC is very variable, the timber can be dried without any major problems (Haslett 1986).

#### *Heartwood colour*

Nicholas *et al.* (1994) provide the only other published data on blackwood heartwood colour measurement using the CIELAB colour space. Differences in colour measurement techniques between that study (measured on the undressed cross-sections of green samples) and the present investigation (measured on the dressed radial face of dried stem cores) prevent a direct comparison of results. CIELAB L\* (lightness) and CIELAB b\* (yellow-blueness) were found to be moderately correlated in this study ( $R = 0.72$ ),

Table 7. Published data on green moisture content (GMC) of blackwood timber. (n/a = not available)

Reference	Age (yr)	GMC (%)	
		Mean	Range
Current study	14–22	111	63–194
Eckbo and Scott (1925) <sup>1</sup>	n/a	60	n/a
Greenhill (1937) <sup>2</sup>	n/a	117	66–167
Haslett (1986) <sup>3</sup>	70	105	54–155
Nicholas, Young and Gifford (1994) <sup>4</sup>	10	n/a	69–176
Nicholas and Brown (2002) <sup>5</sup>	21	118	n/a
Shukla, Verma and Aswal (1987) <sup>6</sup>	n/a	44	n/a
Vuuren, Banks and Stohr (1978) <sup>7</sup>	n/a	68	n/a

<sup>1</sup> A total of 15 'pieces tested' from South African plantation-grown material.

<sup>2</sup> Australian samples assumed to be from native forest. Number and origins not stated.

<sup>3</sup> A total of 245 samples from 21 trees of 72-year-old New Zealand plantation-grown blackwood of unknown provenance.

<sup>4</sup> A total of 59 trees from four seedlots of 10-year-old New Zealand plantation-grown blackwood were sampled, with mean seedlot values from 99% to 120%.

<sup>5</sup> A total of 45 trees of 21-year-old New Zealand plantation-grown blackwood.

<sup>6</sup> A total of nine logs of Indian plantation-grown blackwood of unknown provenance.

<sup>7</sup> South African plantation-grown material; no details given.

meaning that lighter wood was more yellow. Nicholas *et al.* (1994) also observed strong correlations between CIELAB L\* and b\* values and also between CIELAB b\* and CIELAB a\* values. The plantation trees, derived from a single mother tree, showed less variation in core colour than trees from the swamp and FIB treatments (Table 4, Figure 2). Timber from the youngest FIB coupe (TG021B), the oldest swamp coupe (CH044A) and the plantation had significantly higher CIELAB b\* values (more yellow) than that of the remaining coupes.

Some workers within the blackwood timber industry (Britton Bros, Sawmillers, pers. comm.; Maton Guitars, pers. comm.) have experience that suggests that heartwood colour and basic density are negatively correlated. However, in this study, only a moderate (negative) correlation ( $R = -0.51$ ) was observed between CIELAB L\* and basic density. A larger correlation may have been found if the cores had contained a greater range of colours within the blackwood colour spectrum, as did the veneer samples (Figure 2). For example, the darkest of the core samples had a CIELAB L\* value of

44.2 and a CIELAB b\* value of 15.1, whereas the dark veneer sample had a CIELAB L\* value of 32.2 and a CIELAB b\* value of 8.4. It is possible that sample cores that include a greater range of colours may give a clearer correlation between heartwood colour and basic density.

## Conclusion

Timber attributes for young blackwood (14–22 years old) were similar for the seven treatments studied across three silvicultural regimes. Silviculture may therefore not have a strong influence on these attributes, although the wide genetic variability in blackwood (e.g. Playford *et al.* 1993) makes any definitive understanding difficult until silvicultural trials using clonal material are carried out. The results of this study predict that increasing blackwood annual diameter increment by intensive management (such as thinning of native stands or plantations) would have little impact on important blackwood timber attributes such as basic density, percentage heartwood and heartwood colour.

The new FIB resource has timber characteristics equivalent to the existing swamp blackwood resource at the tree ages studied, although it remains to be seen whether this equivalent quality persists until commercial maturity. Provided blackwood tree form continues to be adequately managed and good growth rates maintained, the FIB resource therefore has the potential to contribute significant future volumes of high quality blackwood sawlog.

Many questions remain to be answered regarding the silviculture of blackwood, including the impact of site, climate

and genetics on percentage heartwood, heartwood colour and basic density, before consistently high timber quality can be guaranteed, as required for a premium cabinet timber species such as blackwood.

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