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PLANTATION-GROWN NEW ZEALAND KAURI: A PRELIMINARY STUDY OF WOOD PROPERTIES

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ABSTRACT

For a preliminary investigation into the solid wood properties of plantation-grown New Zealand kauri (*Agathis australis* (D.Don) Lindl.), 20 stems were sampled from a 68-year-old planted stand in New Plymouth in the North Island of New Zealand. The stems sampled represented the largest diameters and therefore fastest growing stems (mean diameter 39.4 cm, mean height 20.5 m). Sapwood comprised 80% of the stem at ground level, increasing to 99% at 10 m above ground. Basic density decreased with increasing stem height from ground level to 10 m (469 kg/m^3 to 435 kg/m^3). Density was uniform across the width of the stem at the butt, and was consistent across the sapwood zones at higher points on the stem. Tangential and radial shrinkage across the width of the stem averaged 4.1% and 2.9% respectively. Modulus of elasticity (stiffness) averaged 13.6 GPa and was as high as 15.0 GPa, and was uniform across the width of the logs. This study identified homogeneous wood property traits in plantation-grown kauri logs composed mainly of sapwood. The sapwood properties tested were at least similar to those of logs from natural second-growth stands and some were superior to old-growth heartwood. Kauri sapwood logs from plantations have the potential to be a legitimate and valuable resource.

Keywords: wood properties; sapwood; heartwood; *Agathis australis*.

INTRODUCTION

Mature, or "old growth", New Zealand kauri has been recognised as a superb multi-purpose tree since the first migration of Polynesian peoples to New Zealand. Kauri wood was found to be easy to dry and work, stable, moderately durable, and strong (Kirk 1889). It has an ability almost unique among conifers to naturally shed its branches as the lower crown becomes suppressed. From large-diameter stems, wide planks of unblemished (heart)wood of considerable length could be produced

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(Hutchins 1919). Hinds & Reid (1957) described old-growth kauri as the "criterion of excellence" for its inherent wood properties.

However, Hinds & Reid (1957) also described slightly different qualities in timber produced from regenerating forests. They reported that younger trees of smaller diameter still produced good-grade narrows, mainly sapwood, with many of the properties of virgin stock but lacking its durability and dimensional stability.

Kauri's reputation as an excellent general-purpose timber species is related to the heartwood that constituted a significant proportion of the often-large diameter (>2 m) stems of natural old-growth stands. The perception of loss of value in sapwood and in young trees through absence of heartwood has strongly influenced thinking about growing kauri in plantations as the very long rotations required to achieve usable quantities of heartwood make growing kauri on a large scale unattractive economically (Herbert *et al*. 1997), although the "kauri" name may confer some advantage.

Wood property and utilisation studies on kauri from natural second-growth stands have been completed (C.M.Colbert & D.L.McConchie unpubl. data; Gibson 1983). Findings from these studies, of stems 10–60 cm diameter and (estimated) 120–150 years of age, generally show a high proportion of sapwood and provide an insight into these sapwood properties. The extensive utilisation study by Gibson (1983) of thinnings from a regenerating stand near Russell in Northland showed:

(1) Clean sap timber was suitable for boatbuilding purposes and could also be used for other specialist uses, although with more limitations than mature kauri.

(2) Sap timber had lower density than the original resource material but similar shrinkage.

(3) Timber suffered brown staining during kiln-drying.

(4) Stiffness (MoE) was approximately 20% lower than in mature kauri at 10.8 GPa and strength (MOR) was similar at 97 MPa.

(5) There were several problems with veneer peeling, which included gum bleeding stain, brown staining, and splitting of sheets possibly due to heartwood and sapwood combinations.

(6) Appearance and softness limited furniture and art-type wood turnery options; however, the wood was suitable for production run type turnery.

(7) For several products, comparison of prices with alternative species would play a role, despite the kauri name.

Although it was not specifically tested, Gibson (1983) commented on stability and durability of second-crop kauri based on the known qualities of old-growth heartwood. These comments reflected the perception/expectation that young or fast-grown kauri sapwood would be less stable. Durability was expected to be same as or similar to that of sapwood from old-growth stems, i.e., non-durable. A principal aim of our paper is to present data on young, plantation-grown trees that challenge Gibson's assumptions.

Planted kauri can grow well in specific areas beyond its natural southern limit (Hutchins 1919). Pardy *et al.* (1992) reported on the performance of a range of kauri plantations throughout New Zealand. They found that kauri growth rates on good-quality sites (lowland: moist, fertile, and free-draining soils) were almost twice those in natural stands, even in plantations outside the accepted species natural range. Currently there is enthusiastic support for planting kauri and other native trees for cultural, environmental, and heritage reasons, as well as for potential timber production (Herbert *et al.* 1996). In a workshop on planting and managing native trees for future production, McConchie (1999) suggested that timber properties (of native species) would be largely age-dependent and would be compromised by a push for (excessively) short rotations. As with studies in natural second-growth stands, comparatively young (<70 years) planted stands indicated small amounts of heartwood in fast-growing stands. A recent study on heartwood development in natural second-growth and planted kauri stands has shown heartwood content to be strongly correlated with diameter, and secondly with age (Steward & Kimberley 2002). Typically, useable quantities will not appear until the trees are 70–80 cm in diameter when heartwood widths of 50 cm may be recovered. To achieve these sorts of diameters is likely to take between 90 and 133 years, depending on diameter increment. Such rotation lengths are often cited as a reason for not planting kauri for production.

Opportunities to study the wood quality of younger kauri material from planted stands will add to the limited data-set, and assist growers to decide on suitable specialty or niche market species. Such studies also test the theory that long rotations (>100 years) are required to achieve the desired wood outcome. A number of growers are looking to more specialty niche products, which offer potentially greater returns, and if managed on a sustainable basis will also fulfil certain environmental/cultural factors (Herbert *et al*. 1997). This preliminary study of wood properties is the first of plantation-grown kauri, aiming at identifying traits of importance for selection, breeding, and utilisation of kauri sapwood.

MATERIALS AND METHODS

Study Site

Material for this study came from the Brooklands Kauri Grove in Pukekura Park, New Plymouth. New Plymouth is approximately 120 km south of the area described by Sando (1936) as the natural range of kauri. The site is 40–60 m above sea level, within 2 km of the coast, and the kauri are growing on fine, soft, non-cohesive, New Plymouth yellow brown loam (New Zealand Soil Bureau 1954).

Mean annual rainfall is 1540 mm and mean annual temperature is 13.5°C (New Zealand Meteorological Service 1983). An average of 6.6 ground frosts occur per year.

The 1.5-ha Brooklands Kauri Grove was planted in 1935 at *ca* 1600 stems/ha. In 2001 the 67-year-old kauri stand retained a high stand density (1120 stems/ha); mean diameter at 1.4 m was 31.1 cm and mean height 19.3 m (Steward & Kimberley 2002). In 2001 management options for the stand were developed due to the high incidence of multi-leadering and the reduction in diameter increment. In October 2002 the kauri stand was thinned "with almost half the trees felled" (Gould 2003).

Standing-tree measurements

From each of 20 of the larger-diameter trees selected for thinning, diameter at breast height over bark (dbhob) was measured and a 5-mm pith-to-bark increment core was taken at breast height. Increment cores were divided from the bark end to provide, first of all, a 50-mm outerwood section for the assessment of outerwood density. The remainder of the core was cut into a series of 30-mm segments to provide regular measurement points for characterising the breast-height radial density pattern. Core segments were analysed for basic density using the maximum moisture content method (Smith 1954).

Disc and billet sampling

Total tree height was recorded and, after felling, cross-sectional discs were cut at the butt and at approximate 5-m and 10-m heights, for whole-disc wood property analysis. Some variation in disc collection height was permitted to avoid forking and branches. All discs were measured to provide diameters over bark (dob) and inside bark (dib), heartwood percentage, and ring counts, prior to sectioning to yield samples for the measurement of basic density. Two diametrically opposed sectors were cut from each disc. Butt and 10-m disc sectors were cut to provide basic density for heartwood and sapwood components. Sectors from the 5-m disc were machined into rectangular blocks representing 10 growth rings counting from the pith for pith-to-bark assessments of basic density and shrinkage to air-dry (12% emc) (Treloar & Lausberg 1995).

From each of four trees, representing the larger (i.e., faster-grown) end of the diameter range, a 2-m billet for assessment of solid wood characteristics was removed from height 1–3 m, i.e., the bottom of the butt log. The four billets were cant sawn (Walker 1993) to produce boards either 25 or 50 mm thick, and of varying widths, whose sawing pattern was recorded to allow identification of the ring position of each board within the log. Boards were stacked and air-dried under cover over the summer months, from mid November 2002 to mid April 2003.

Board measurements

Once moisture content was <20% the boards were machined to regular sizes. Twenty-seven boards from the four trees were tested for sound velocity by Hitman, and 42 boards for sound velocity by IML hammer. Twenty-one 50-mm boards were planed to a uniform size (150 × 50 mm) and tested by static bending to measure stiffness or modulus of elasticity (MoE) in accordance with AS/NZS4063: 1992 "Timber Stress-graded In-grade strength and stiffness evaluation".

Boards were tracked according to position and distance from the pith in each billet and the average MoE for those four tree billets was calculated for distances of zero, 50, 100, 150, and 200 mm from the pith.

RESULTS

Standing Tree Properties

For the 20 trees, dbhob averaged 39.4 cm (range 31 to 48 cm) and tree height averaged 20.5 m (range 18.5 to 23.4 m) (Table 1). Outerwood basic density ranged from 391 kg/m^3 to 497 kg/m^3 and averaged 451 kg/m^3.

TABLE 1–Diameter at breast height over bark, height, and outerwood density measurements for the 20 trees assessed

	Mean	Min.	Max.	SD
Diameter at breast height (cm)	39.4	31.0	48.1	4.4
Total height (m)	20.5	18.5	23.4	1.7
Outerwood density (kg/m^3)	451	391	497	31

Breast height increment cores were sectioned to provide an outerwood portion (outermost 50 mm) and subsequent 30-mm increments to the pith end of the core. Most cores consisted of 80 to 110 mm of sapwood, i.e., heartwood/sapwood boundary was located within the second 30-mm segment from the outerwood segment. The mean density profile from pith-to-bark for all 20 trees showed a relatively flat gradient, increasing approximately 10 kg/m^3 from pith to bark (Fig. 1).

Disc, Log, and Tree Properties

Between 0 and 5 m, average bark thickness showed little variation from 15 mm, decreasing to 12 mm for the top 10-m disc (Table 2). Diameter-inside-bark averaged 379 mm at 0 m, tapering down to 317 mm at 5 m, and averaging 195 mm by 10 m height.

No difference was apparent between heartwood and sapwood density in the butt disc (Table 2), averaging 465kg/m^3. The flat pith-to-bark density gradient shown for the breast-height increment cores (Fig. 1) also confirmed the homogeneous

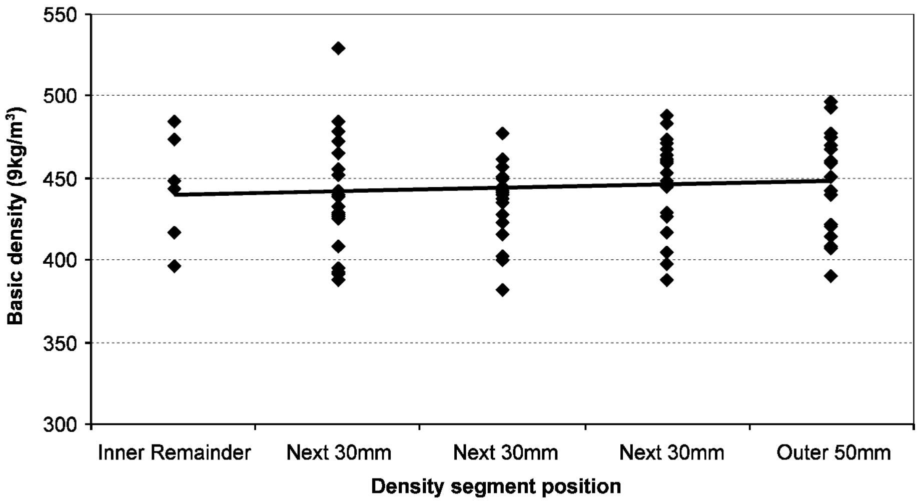

FIG. 1–Radial density pattern at breast height

TABLE 2–Average disc properties by sampling height (standard deviations in parentheses)

Disc height (m)		Bark thickness (mm)	Diameter inside bark (mm)	Heartwood (mm)	Heartwood (%)	Comp. wood (%)	Heartwood density (kg/m³)	Sapwood density (kg/m³)	Basic density (kg/m³)	Heartwood rings	Total rings
0	Mean	15	379	175	20	2	464	469	468	21	63
		(4)	(42)	(31)	(6)	(4)	(26)	(27)	(25)	(4)	(3)
5	Mean	14	317	124	16	6	–	–	444	11	50
		(2)	(46)	(32)	(6)	(6)			(28)	(3)	(5)
10	Mean	12	195	6	1	4		435	435	1	37
		(4)	(40)	(24)	(3)	(3)		(29)	(29)	(2)	(5)

nature of heartwood and sapwood in this study. Disc basic density averaged 468 kg/m^3, 444 kg/m^3, and 435 kg/m^3 for the 0, 5-, and 10-m discs respectively and indicated a gradual decrease in density with stem height.

Outerwood density from a 5-mm increment core at 1.4 m above ground correlated strongly with whole-disc density at 0 m above ground (correlation 0.93), 5 m (correlation 0.84), and 10 m (correlation 0.70). Mean whole-disc density at 0 m above ground varied from mean outerwood density at 1.4 m by +4% (outerwood density ÷ whole disc density), at 5 m by +2%, and at 10 m by –4%.

An average count of 63 rings was measured for the butt discs, ranging from 56 to 68 rings with an average of 21 heartwood rings (range 15 to 28). Heartwood was present in 10% of the 20 stems at 10 m above ground and averaged only 6 mm in diameter.

Smalian's formula was used for calculation of volume. Although not as accurate as other methods (e.g., 3-D formula of Ellis 1986) it provides a reasonable guide to actual volumes and is more suited to applying weighted wood property values to establish log and tree estimates. By age 68 these kauri had produced approximately 0.7 m^3 of log volume, with heartwood constituting 16% (Table 3) and individual trees ranging from 7% to 23% heartwood. Compression wood levels were generally low and averaged 4% for tree weighted value. Whole-tree basic density averaged 452 kg/m^3 and ranged from 407 kg/m^3 to 493 kg/m^3.

TABLE 3–Average log and tree properties (standard deviations in parentheses)

Log height class		Length (m)	L.e.d. (mm)	S.e.d. (mm)	Volume (m^3)	Bark thick-ness (mm)	Heart-wood (%)	Comp. wood (%)	Basic density (kg/m^3)
Butt	Mean	4.4	379	317	0.444	15	19	3	459
		(0.5)	(42)	(46)	(0.096)	(3)	(6)	(4)	(26)
Second	Mean	5.1	317	195	0.285	14	12	5	442
		(0.9)	(46)	(40)	(0.089)	(2)	(5)	(5)	(28)
Tree	Mean				0.729	14	16	4	452
					(0.158)	(3)	(5)	(4)	(26)

Note. The log and tree property values were calculated from the disc values in Table 2.

5-m Disc Radial Properties

Both air-dry density and basic density showed no more than 3.5% variation from pith-to-bark (Table 4) which coincides with the flat density gradients shown for breast-height increment cores and butt discs described earlier, and is the feature that

TABLE 4–Variations in air-dry and basic density along with shrinkage from pith-to-bark at 5 m stem height

Property	Ring group					Disc
	1 to 10	11 to 20	21 to 30	31 to 40	41+	
Density (kg/m^3)						
Air-dry	541	531	540	537	537	538
Basic	453	439	444	440	437	444
Air-dry* shrinkage (%)						
Longitudinal	0.02	–0.01	–0.03	–0.02	–0.04	–0.02
Radial	2.2	2.6	3.2	3.2	3.4	2.9
Tangential	3.8	4.2	4.3	4.2	4.0	4.1
Volumetric	6.0	7.1	7.6	8.0	8.7	7.5

* Adjusted to 12% moisture content

gives stability to the wood. Disc values at 5 m averaged 538 kg/m^3 for air-dry density and 444 kg/m^3 for basic density.

Air-dry shrinkage was negligible for longitudinal shrinkage from pith to bark. For radial shrinkage an increase from 2.2% near the pith to 3.4% in the outermost growth rings was recorded with a disc weighted value of 2.9%. Tangential shrinkage was relatively constant across all ring groups and averaged 4.1%. Volumetric shrinkage was approximately equivalent to the sum of radial and tangential shrinkages and averaged 7.5% for the disc weighted average (Table 4).

Solid Wood Assessment

A single billet was recovered from the butt log of four trees after thinning. The billets ranged between 2.0 and 2.19 m in length, 31.0 and 39.3 cm small-end diameter, and 34.5 and 42.5 cm large-end diameter. Billets were cant sawn, using a Woodmiser band saw, within 1 month of felling. Conversion into cut boards varied between 70 and 75% of total log volume, yielding between nine and 12 boards of either 25 or 50 mm thickness per billet.

Five months after milling, boards were assessed for stiffness (modulus of elasticity, MoE) using the IML Electronic Hammer, and then after 10 months using the CHH Director HM200 tool. These devices measure the sound velocity from acoustic resonance (m/sec) (Bucur 1995), which is converted to modulus of elasticity. The mean modulus of elasticity was 7.8 GPa for the 42 boards tested by the IML Hammer and 10.2 GPa for the 27 boards tested by the CHH Director HM200 tool (Table 5). A comparison of the results for individual boards tested by both tools identified no similarity in values (correlation –0.25). This result is discussed later.

Twenty-one boards from four trees were planed to 150 × 50 mm and tested for stiffness using the static bending method. Modulus of elasticity ranged from 11.5 to 15.0 GPa (Table 5) for individual boards, with an average of 13.6 GPa. A comparison of 21 boards tested by the static bending method and with the two acoustic tools gave correlations of –0.45 for IML Electronic Hammer and 0.16 for the CHH Director HM200 tool. The boards from the four trees sawn were classified

TABLE 5–Comparison of modulus of elasticity measured using sound wave velocity and static bending

Method	N	Mean velocity (m/sec)	Mean MoE* (GPa)	Min. MoE (GPa)	Max. MoE (GPa)
IML Hammer	42	4228.2	7.8	6.5	9.6
Hitman	27	4.85	10.2	7.9	13.0
Static bending	21	–	13.6	11.5	15.0

* Converted from mean velocity for IML Hammer and Hitman tools.

by the distance of each board from the pith, irrespective of tree number (Table 6), which showed that there was no difference in mean values of modulus of elasticity for each class of distance from the pith. The number of boards in each class was too few for a robust indication, but the stiffness close to the pith seemed to be the same as near the bark. This might also indicate (knowing that density is almost constant from pith to bark) that microfibril angle may be uniform radially.

TABLE 6–Modulus of elasticity across the width of the log measured by static bending.

	Distance from pith (mm)				
	0	50	100	150	200
N	4	8	5	3	1
Mean MoE (GPa)	13.3	13.9	13.6	13.2	13.0

DISCUSSION

Earlier work by Colbert & McConchie (unpubl. data) and Gibson (1983) recorded distinct differences between heartwood and sapwood densities, averaging approximately 460 kg/m^3 and 425 kg/m^3 respectively for both studies for similar-aged material. The current study indicated relatively uniform density across the width of the log (including sapwood and heartwood). The more southern locality of the New Plymouth site, and possible genetic differences (e.g., seed from a few parents), may have contributed to this result. Butt discs from second-growth kauri at Russell Forest and the two disc heights labelled L.E. and S.E. from kauri received from the New Zealand Forest Service Office in Kaikohe, and assumed to be from Russell Forest (all from Colbert & McConchie unpubl. data), averaged 505 kg/m^3, 458 kg/m^3, and 413 kg/m^3 respectively, indicating parity with current study values. In this instance the labels L.E. and S.E. are presumed to indicate large-end and small-end sections of the log. Large-end sections are assumed to be from a point just above the stump, while small-end sections are presumed to be either from a point just below the crown or from a point of minimum small-end diameter. The lack of, or reduced percentage of, heartwood in the assumed small-end section tends to confirm this assumption. The results for whole tree density from this study of the Brooklands kauri also compare favourably with Colbert & McConchie's earlier study in which stem values from kauri from the Kaikohe Office averaged 441 kg/m^3. The random sample for mechanical testing in the Gibson (1983) utilisation study averaged 434 kg/m^3, which was slightly down on current study values. For comparative purposes Hinds & Reid (1957) quoted a value of 480 kg/m^3 for mature kauri. Colbert & McConchie (unpubl. data) reported values of 605 kg/m^3 and 504 kg/m^3 for butt discs, which would be expected to be higher than current study values at 5 m. Air-dry density (12% m.c.) for old-growth kauri was reported at 520 kg/m^3 by Hinds & Reid (1957) and somewhat higher at 560 kg/m^3 by Clifton (1990). However, more importantly it indicates that on the basis of this study, timber from plantation-grown kauri at age 68 years has similar properties to 120- to 150-year-old kauri from natural second-growth stands (Table 7).

TABLE 7–Comparison of density, stiffness, and shrinkage for old-growth, second-growth, and plantation-grown kauri

	Basic density (kg/m^3)	Stiffness (MoE) (GPa)	Shrinkage (%)	
			Radial	Tangential
Old-growth	520	13.0	2.3	4.1
Second-growth	472	10.8	2.6	3.9
Plantation	451	13.6	2.9	4.1

As density characteristics within individual stems are uniform pith to bark, and the relationship between outerwood and whole-disc density to 10 m above ground varies by 4% or less, it is suggested that whole-tree density can be determined by outerwood cores at 1.4 m alone.

Hinds & Reid (1957) quoted values of 2.3% and 4.1% for radial and tangential shrinkage respectively, for old-growth kauri that consisted mainly of heartwood (Table 7). The predominantly sapwood discs from 5 m tree height in the current study showed higher levels of radial shrinkage but the difference for tangential shrinkage was negligible. Colbert & McConchie (unpubl. data) recorded similar shrinkage values to those in the current study for their young natural second-growth kauri — radial 2.6% and tangential 3.9%.

The values for radial and tangential shrinkage in plantation-grown kauri compare favourably with that of *Pinus radiata* D.Don (radial 2.0%, tangential 4.0%) reported by Burdon & Miller (1992). Cown (1999) reported shrinkage patterns (pith to bark) of *P. radiata*, which were similar to those for most species. The figures for plantation-grown kauri in this study reflect the pattern that “shrinkage in the tangential direction is about twice that in the radial plane”, and longitudinal shrinkage is usually small (–0.02% in plantation-grown kauri). Radial shrinkage for plantation-grown kauri marginally increased from pith to bark, but the tangential shrinkage gradient was relatively flat pith to bark — these were consistent with established patterns. Volumetric shrinkage for plantation-grown kauri reflects the pattern identified in *P. radiata* where volumetric shrinkage is approximately equivalent to the sum of radial and tangential shrinkages. Longitudinal shrinkage also reflected established patterns with the greatest shrinkage at the pith (3% variation within samples) reducing to 1% variation at the bark.

Clifton (1990) reported stiffness of mature kauri (heartwood) as being 9.1 GPa (MoE). This figure is at odds with results of Colbert & McConchie (unpubl. data) who identified 10.8 GPa (MoE) for second-growth kauri (Table 7), and who described it as "approximately 20% lower than mature kauri". A recalculation of modulus of elasticity from the imperial values (1890 lb/sq.in.) used by Hinds & Reid (1957) suggests that the true value for mature kauri should be 13.0 GPa — a figure considerably closer in value to, albeit still lower than, that recorded for plantation-grown kauri in this study. The use of acoustic tools for an indication of modulus of elasticity gave contradictory and inconclusive results. Later discussion suggests that the method of using the tools, with boards remaining in stacks during testing, could be the cause of these inconsistent results (Grant Emms pers. comm.).

At 68 years of age heartwood levels were low, averaging 20% at butt level and decreasing to negligible amounts by 10 m. Heartwood has historically been the preferred recovered timber grade, and these values compare favourablywith an earlier study on six trees from a second-growth kauri stand in Northland (presumed to be Russell Forest) in which discs from two heights presumed to be 0 m and 5 m averaged 21% and 12% respectively (Colbert & McConchie unpubl. data). A recent study by Steward & Kimberley (2002) using breast-height increment cores showed a strong correlation between heartwood content and diameter at breast height. The heartwood content found in the New Plymouth kauri was within the predicted range based on mean diameter of the stand.

The significant reduction of diameter inside bark with increasing height of some stems suggested, at first appearance, a significant taper. This apparent taper, unusual for kauri, was explained by the multi-stem nature of most of the kauri selected for thinning. The 10-m disc (and occasionally the 5-m disc) was frequently obtained from above a multi-leadered stem; therefore there was a corresponding significant reduction between that and the diameter recorded at 0 m and 1.4 m above ground (Fig. 2).

The amount of heartwood in the stems was expected to be negligible and so no attempt was made during cutting to create boards of different grades (i.e., sapwood *v*. heartwood). Typically, fresh rough-sawn boards were pale in colour with a small amount of feature from grain and rare branch traces. Once a machined surface was achieved, the timber had a natural lustre and a characteristic speckle was evident, even within boards that had no heartwood content. During drying some boards attained a degree of twist. This involved four of the 21 boards, and in the extreme case the twist was 2.5 cm. The reason for the appearance of twist in these boards was unknown; however, three of the four boards with twist contained the central pith, and a mixture of heartwood and sapwood. Their modulus of elasticity also tended to be lower than the mean. Some minor surface sap-staining occurred during the drying process; however, most of the sap-staining was removed when boards were planed (Fig. 3).

FIG. 2–Discs taken from 5 m (29.4 cm dbh) and 10 m (18.4 cm dbh) above ground from tree No. 12. Note: The significant difference in diameter between the two discs is because the disc from 10 m was taken from one side of a multi-leadered crown.

FIG. 3–Cut and planed sapwood boards (150 × 50 mm) from plantation-grown kauri.

Despite the small sample size, stiffness of sapwood boards was significantly higher than recorded for old-growth heartwood. Results of wood property tests in this study suggest a wider potential use for sapwood and sapwood logs than may earlier have been envisaged. Surface hardness tests will be conducted in future, as this characteristic will be important if the timber is to be used in furniture or other wearing areas. Further research is needed to investigate the brown-staining problem in kiln-dried timber and also problems with veneers, i.e., brown-staining, gum bleeding stain, and sheet splitting due to heartwood and sapwood combinations. Research is also required to correlate wood properties and green crown height.

Numerous authors have reported on the wood properties of selected old-growth *Agathis* spp. from Queensland, Fiji, and the Philippines (e.g., Orman 1949; Grenning 1957; Schmidt 1962; Bootle 1983; Nikles in press). They variously described basic density between 480 kg/m^3 and 550 kg/m^3, with no variation in density from pith to bark, and density reducing with height up the stem (Table 8). Radial shrinkage was between 1.5 and 3.0%, and tangential shrinkage between 3.0 and 4.5%. These, and the other, Pacific kauri species are all highly prized for their fine-grained uniform timber (Whitmore 1977). The patterns for consistent wood properties from pith to bark found in this study of plantation-grown *A. australis* are consistent with those found in other *Agathis* species. Individual comparisons of basic wood properties between the plantation-grown *A. australis* and plantation-grown or old-growth *A. robusta* (C. Moore ex F.Muell.) and *A. Palmerstonii* (F.Muell.) from Australia, *A. vitiensis* ((Seem.) Bentham & Hooker f.) from Fiji, and *A. dammara* ((A.B. Lamb.) L.C. Rich.) from south-east Asia are very favourable (Table 8).

TABLE 8–Comparison of density, stiffness, and shrinkage for plantation-grown *Agathis australis* and other *Agathis* sp.

Species	Type	Location	Basic density (kg/m^3)	Stiffness (MoE) (GPa)	Shrinkage (%)	
					Radial	Tangential
A. australis	Plantation	New Zealand	451	13.6	2.9	4.1
A. palmerstonii	Plantation	Queensland	400	7.8	3.6	4.6
A. robusta	Old growth	Queensland	481	7.8	2.0	3.5
A. vitiensis	Old growth	Fiji	550	10.7	3.0	4.5
A. dammara	Old growth	Philippines	550	9.3	1.5	3.0

This was a preliminary investigation of the wood properties of relatively fast-grown kauri from a single plantation. The findings support the comments of Hutchins (1919) who noted, when discussing housing construction, that "kauri sapwood was as good as heartwood indoors" and that "there is no great difference in the actual market value of sound heart and sound sapwood of kauri, provided it is free from borer". There may be an opportunity to confirm these results and to investigate further areas of interest when other stands are thinned in due course. The timber in this study behaved similarly to older second-growth kauri from natural stands, with a predominance of sapwood in the log. The majority of characteristics reported on in this study showed uniform radial wood properties, which is characteristic of this species even at this "relatively" young age.

This study looked at the basic wood properties of, in effect, plantation-grown kauri sapwood; future studies will focus on drying of this material and its performance through to manufactured final products.

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