GROWTH AND UTILISATION OF YOUNG *CUPRESSUS MACROCARPA*

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ABSTRACT

An intensively pruned and thinned stand of *Cupressus macrocarpa* Hartweg provided a unique research opportunity for examining aspects of cypress tree growth and utilisation. At 27 years of age, the stand was harvestable in terms of stand volume, log size, and sawlog quality, identifying *C. macrocarpa* as a species with potential for short rotations. A heavy thinning at age 21 years resulted in minimal stem diameter response but caused a large increase in the number of large branches which in turn reduced the unpruned log quality. Based on a current growth model, a simulated *Pinus radiata* D.Don stand grown under the same regime and site conditions would have produced a similar total stand volume.

Sawing conversion from roundwood for a 39-log sample ranged from 52% in butt logs to 43% in third logs. Butt logs had low recovery of Clears grades owing to large knotty cores, but the inclusion of a weatherboard/exterior finish grade improved the total "high value" grade recovery to 73% of sawn timber. Corresponding recoveries for second and third logs were 13% and 8% respectively, reflecting the presence of large branches and sapwood.

The yield of kraft pulp from top logs and slabwood was poor in comparison to *P. radiata*, but the chemical consumption was normal. Paper from these pulps had very low bulk owing to collapse of the short low-coarseness fibres and had low tear strength but reasonable light-scattering properties. *Cupressus macrocarpa* could be used to produce kraft pulp if mixed in a low proportion with other more-favoured species.

Thermomechanical pulp made from slabwood chips was within the accepted range of commercial properties but, compared with *P. radiata*, energy consumption was high and refiner motor loadings were very unstable. The resulting paper had low brightness and strength. Attempts to make chemithermomechanical pulp within the accepted normal commercial range of properties were unsuccessful.

Keywords: growth; yield; sawing; pulping; wood properties; *Cupressus macrocarpa.*

INTRODUCTION

Plantings of *C. macrocarpa* in Cpt 9 of Lismore Forest in 1964–65 have provided a unique opportunity to examine aspects of tree growth and utilisation. An investigation undertaken in late 1991 and 1992 included an inventory, an assessment of stem and branch growth rings to determine past growth patterns, a sawing study, and a pulping study using three pulping processes.

An 8-ha stand (Macrocarpa A—*see* Table 1) was planted at wide spacing with a mixture of *Larix kaempferi* (Lamb.) Carr. (larch), pruned in four lifts, and thinned to low final-crop stocking. As there were no signs of the original *L. kaempferi* at the time of the inventory, it was assumed to have been suppressed at an early age and not to have influenced the *C. macrocarpa* growth. The stand was generally of good form regarding stem straightness and roundness. At 27 years of age the stems were over 90% sawlog (to a 250-mm s.e.d.—small-end diameter under bark) and were suitable for harvest. The soil type was yellow brown/yellow grey earth over mudstone. Contour was generally steep, aspect south-east, altitude 200 m a.s.l., and annual rainfall 910–1140 mm.

Adjacent to this stand were three others that afforded interesting comparisons of growth and yield. A small *C. macrocarpa* stand (Macrocarpa B) planted in 1965 at 1428 stems/ha had remained unthinned. The remaining two (Radiata A and Radiata B) were *P. radiata* which had been butt log pruned and thinned to different final stockings. Site productivity for all stands was rated as medium, site index for *P. radiata* being about 30 m. Stand histories are summarised in Table 1.

TABLE 1–Silviculture records with stocking (stems/ha) in parentheses.

Age (years)	Stand			
	Macrocarpa A	Macrocarpa B	Radiata A	Radiata B
0	Established 1964 (714*)	Established 1965 (1428)	Established 1964 (2300)	Established 1964 (2300)
5	Pruned 2.1 m (378)		Pruned 2.4 m (500)	Pruned 2.4 m (500)
6	Pruned 3 m (378)		Pruned 4 m (287)	Pruned 4 m (287)
7			Pruned 6 m (287)	Pruned 6m (287)
7			Thinned to waste (500)	Thinned to waste (500)
8	Pruned 4.3 m (385)			
11	Pruned 6 m (385)			Thinned with yield (250)
11	Thinned to waste (385)			
21	Thinned with yield (200)			
27	Sampled		Harvested	Harvested

*As a mixture with *L. kaempferi* at 714 stems/ha which was suppressed and any remnants removed at first thinning.

METHODS

MARVL inventories (Deadman & Goulding 1979) carried out in the two *P. radiata* stands in January 1991 and the two *C. macrocarpa* stands in September 1991 were used to compare the growth performance of the two species. Using the regime shown for the Macrocarpa A stand in Table 1 and the PPM88 Growth Model (García 1990), stand parameters were obtained for a simulated stand of *P. radiata*. As a confidence building exercise, the model was firstly calibrated against the Radiata B stand, and dbh, mean height of the 100 largest-diameter trees/ha (MTH), basal area, and total standing volume (Table 2) were predicted to within 6% of the inventory data. Two permanent sample plots (PSP) set up in the Macrocarpa A stand at the time of production thinning in 1985 provided some record of past growth.

In the Macrocarpa A stand, 15 sample trees were selected so that both dbh frequency and ratio of log types by volume (*see* Table 2) approximated those of the stand. Butt logs were visually assessed for fluting depth, either as (a) lightly fluted, or (b) moderately fluted with any flute >10 cm in depth and flutes or out-of-roundness extending over halfway along the log. All branches on second and third logs (to approx. 15 m above ground) were measured for size and recorded as live or dead by position along the stem and by quartile.

Sample trees were felled and crosscut into logs—butt logs at the top of the pruning, and second and third logs at approximately 5-m intervals to a minimum 250-mm s.e.d. Altogether 15 pruned butt, 15 unpruned second, and 9 unpruned third logs were obtained.

A small sample of large branches (one large branch with diameter over 7 cm from each of 15 logs) from the unpruned sawlog zone was crosscut at the base, dried, and sanded. Growth ring configuration was examined in order to determine diameter development.

At the small end of each log, under-bark diameter growth by year was determined by measuring and summing two representative radii from pith to each respective growth ring and correcting for measured log s.e.d.

Sample logs were sectionally measured and the sawn outturn was assessed using methods described by Park & Leman (1983). Sawing was carried out at the Carter Holt Harvey Mill at Bulls. The half-taper sawing pattern removed boards from two opposing sides of the log, retaining a 150- or 200-mm cant. The cant was then sawn into boards with sawcuts at right angles to the cant sides. Sawing was generally to 25-mm boards with average overcuts of 1.9 mm in thickness and 4.8 mm in width. Timber was tallied and graded green off the saw according to NZS3631:1988 (SANZ 1988).

Much of the timber in heart dressing grade was suitable for potentially high value weatherboard and exterior finish end-uses as described in NZS3602:1990 (SANZ 1990). An additional grade was extracted from heart dressing grade using the criteria specified in these standards plus the following modifications:

- Any number of tight knots up to 15 mm allowed
- Pith allowed
- Occlusion scars and bark pockets up to 15 mm wide allowed
- Up to 2% sap on either face allowed.

Upper parts of the stem, in s.e.d. range 150–250 mm, were crosscut and tallied as pulp logs. Discs, 10–15 cm in thickness, were cut from pulp log ends and retained for a kraft pulping study. Five tonnes of slabwood were recovered from the sawmill, debarked and chipped, and used for preparing kraft pulp, thermomechanical pulp (TMP), and chemithermomechanical pulp (CTMP).

TABLE 2–Stand parameters for four adjacent 26- and 27-year-old *C. macrocarpa* and *P. radiata* stands and a simulated *P. radiata* stand grown under the Macrocarpa A stand regime.

Stand	Age	Stocking (stems/ha)	dbh (cm)	MTD* (cm)	BA* (m^2/ha)	MTH* (m)	TSV* (m^3/ha)	Merch. vol. (m^3/ha)	Log type†			
									Pruned (m^3/ha)	Unpruned, small-branched (m^3/ha)	Unpruned, large-branched (m^3/ha)	Pulp (m^3/ha)
Radiata A	26.7	412	41.0	50.1	54.5	35.4	624	570	102	253	92	123
Radiata B	26.7	298	47.0	55.9	51.9	37.2	629	592	200	202	106	84
Macrocarpa B	26	1354	25.6	40.0	69.6	19.1	481	331	0	117	10	205
Macrocarpa A	27	171	53.6	57.5	38.6	25.1	353	324	145	48	101	30
Simulated *P. radiata* stand	27	171	47.0		29.6	37.2	353					

* MTD = Mean dbh of 100 largest diameter trees per hectare
BA = Stand basal area
MTH = Mean height of 100 largest diameter trees per hectare
TSV = Total standing volume

† Small-branched log type for *P. radiata* = sawlogs with branches up to 6 cm in diameter (inventory carried out previously by forest management staff)
Small-branched log type for *C. macrocarpa* = sawlogs with branches up to 7 cm in diameter
Pruned sawlogs to 300 mm s.e.d.
Unpruned sawlogs to 250 mm s.e.d.
Pulp logs to 150 mm s.e.d.

Kraft pulping methods were similar to those described by Uprichard & Grey (1973). Chips were analysed to determine basic densities and chemical composition. Three pulps (H factors: 1000, 1500, and 2000) were prepared from top logs and one with a target kappa number of 30 was made from slabwood. Paper handsheets were made from kappa 30 pulps after beating for 1000, 2000, 4000, and 8000 revolutions in a PFI mill. Fibre properties were determined using the Kajaani fibre analyser and standard handsheet properties were evaluated.

The procedures used in evaluating *C. macrocarpa* slabwood for TMP and CTMP were similar to those described by Richardson *et al.* (1990). Chips were analysed to determine fibre and chemical properties. Refining was carried out in a "commercial" Jylha SD52/36 single-disc refiner. For the TMP process, chips were first pre-steamed at 80°C for 10 minutes and then pre-heated at 125°C and 1.5 bar pressure for 3 minutes. CTMP preparation differed in that prior to pre-heating the chips were impregnated with 25 g sodium sulphite/*l* at pH 7.5. For each process three replications of two-stage refining runs were attempted. The first stage produced a primary pulp from which secondary pulps were made using three different input energy levels. The pulps were analysed for freeness and fibre size distribution. Paper handsheets were prepared and standard strength and optical property tests were carried out.

RESULTS AND DISCUSSION

Stand Growth

Stand parameters and data for the simulated stand of *P. radiata* grown under the same regime as the Macrocarpa A stand are given in Table 2. Macrocarpa A stand was 10–12 m shorter than the adjacent *P. radiata* stands but 6 m taller than the highly stocked *C. macrocarpa* stand. Although the poor height development in Macrocarpa B stand may be partly attributable to both age and site, it is possible that height suppression was associated with high stocking. Piece size development in the Macrocarpa A stand was high with dbh in excess of the *P. radiata*. Compared with the *P. radiata* stands, the lower basal area of Macrocarpa A stand reflected the low final stocking while the low TSV also reflected tree height difference. The simulated *P. radiata* stand produced the same TSV as the Macrocarpa A stand.

The inventory found 68% of unpruned sawlogs in the large branched category and, as most branches were alive and actively growing, this proportion will increase with time.

Data from the two PSPs (Table 3) provide some indication of the possible basal area and TSV had the heavy thinning in 1985 not taken place. The two plots have been growing at a current annual increment (CAI) of around 30 m^3/ha. Had their stocking remained at 440 stems/ha, the CAI would probably have been larger giving a TSV in 1991 of about 550 m^3/ha.

Sample Tree Growth

With the exception of the two permanent sample plots established in 1985, there are no mensurational data for stand growth or response to thinning. Examination of growth rings has provided some additional information. Stem diameter growth at three positions up the stem is indicated in Fig. 1. It was not possible to analyse cross-sections at stump height because of their asymmetric under-bark profiles.

TABLE 3–Data from two Permanent Sample Plots (PSP) established in the Macrocarpa A stand in 1985 at the time of second thinning.

	PSP	Before thinning 1985	Residual 1985	Removed 1985	July 1991
Stocking (stems/ha)	Plot 1	470	180	290	180
	Plot 2	410	140	270	140
	Mean	440	160	280	160
dbh (cm)	Plot 1	34.9	36.3	33.9	50.1
	Plot 2	37.0	44.1	32.6	56.1
	Mean	36.0	40.2	33.2	53.1
BA (m^2/ha)	Plot 1	44.8	18.6	26.2	35.4
	Plot 2	44.0	21.4	22.6	34.6
	Mean	44.4	20.0	24.4	35.0
TSV (m^3/ha)	Plot 1	357.6	150.0	207.6	338.0
	Plot 2	349.2	165.7	183.5	332.5
	Mean	353.4	157.8	195.6	335.2

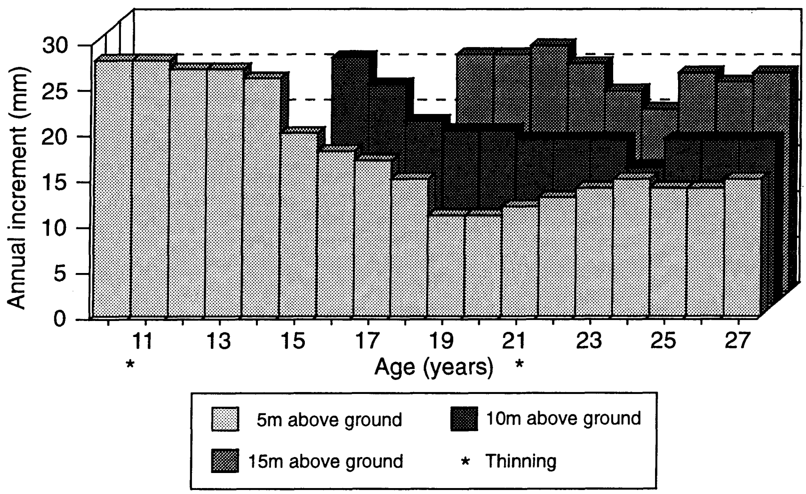

FIG. 1–Annual stem diameter increment in the Macrocarpa A stand.

Stem diameter increments (Fig. 1) show a surprisingly small response to thinning at age 21 years. At 5 m above ground (i.e., the base of the green crown) diameter increments increased by about 3 mm after thinning. At 10 and 15 m above ground, diameter growth was maintained at a fairly constant level. Diameter increment for an unthinned stand is unknown. To put this in perspective, if the 3-mm additional increment applies to dbh (which is likely—Jacobs 1938; Larson 1963) a gain of 0.28 m^2/ha and a loss of 24.4 m^2/ha in BA were made as a result of thinning.

Annual ring growth in the large-branched sample showed a very different response (Fig. 2). It is clear that after thinning at age 21 years, there was a large and sustained increase in branch diameter increment.

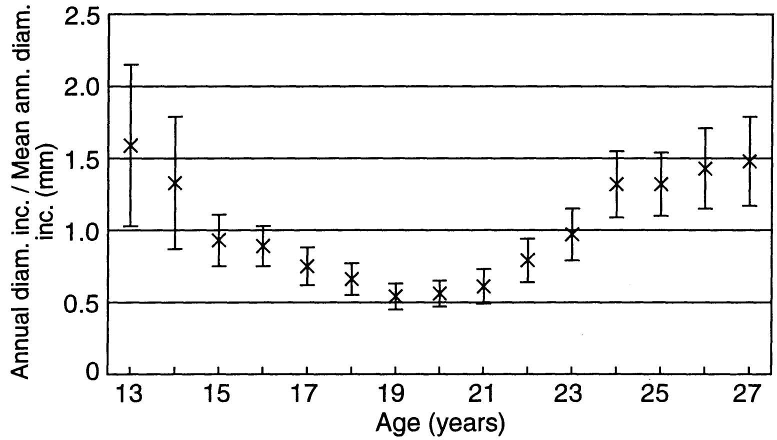

FIG. 2–Relative diameter growth of large branches in the Macrocarpa A stand.

Branch size development was affected by position on the stem (Tables 4 and 5). The total number of all branches per metre was approximately the same in second and third logs. It was also the same for uphill and downhill sides of the tree in third logs. The slightly greater number on the downhill side of second logs could reflect the loss of a few fine dead branches on the shadier uphill side or a misallocation of some branches to downhill quartiles. There were greater proportions of dead branches in the lower log and on the shadier uphill side of trees. Large branch numbers were greater in third logs and, in both log height classes, occurred mainly on the less-shaded downhill side of the stem.

TABLE 4–Total branch numbers (mean per metre of log) in the Macrocarpa A stand.

	Second logs			Third logs		
	Uphill	Downhill	Total	Uphill	Downhill	Total
Dead	4.9	3.8	8.7	2.8	1.3	4.1
Live	4.5	6.5	11.0	6.9	8.4	15.3
Total	9.4	10.3	19.7	9.7	9.7	19.4

TABLE 5–Large branches (mean No. of branches >7 cm in diameter per metre of log).

	Second logs	Third logs
Uphill side of stem	0.4	0.7
Downhill side of stem	1.2	1.3
Total	1.6	2.0

Heartwood is currently considered more valuable than wood containing sap as it is suited to exterior weatherboard and joinery use. Park & Smith (1987) reported very good heartwood development in a 52-year-old *C. macrocarpa* stand ("Hulls Stand") in the Wairarapa district, with 81% of under-bark volume in butt logs compared with 42–64% for age classes 26–34 years in other studies. In the Macrocarpa A stand, heartwood comprised 70.5% of butt logs, 64% of second logs, and 56% of third logs. Depth of sapwood was relatively constant at about 40 mm over the sawlog part of the stem (Table 6). Heartwood was forming, on average, after only 4–5 years.

TABLE 6–Sapwood thickness and number of rings of sapwood

	Height above ground (m)			
	0.2	4.9	10.4	15.4
Sapwood thickness (mm)	43	38	42	41
No. rings sapwood	4.1	4.7	4.9	5.2

Sawing Study

Mean log parameters for the sawlog sample are given in Table 7. There was generally little sweep in the study logs. Butt and third logs had high taper.

Stand records detailed four pruning lifts (Table 1). After reconstruction of the knotty core of the sawn butt logs, three pruning lifts were apparent where log length was under 4.3 m and four lifts for all longer logs. The overall defect core (DC) and the largest defect core associated with a single lift (maximum partial DC) are given in Table 7 as sample means. Maximum diameter over pruned branch stubs (DOS) is estimated here as the largest partial DC minus occlusion scar. Occlusion scars were measured from 50 partial DC zones providing a mean occlusion of 15.4 ±1.5 mm (95% confidence intervals). Subtracting the occlusion scar depth from the maximum partial DC resulted in an estimated mean maximum DOS for the 15 trees of 263 ±21 mm (95% confidence intervals). There was no apparent relationship between partial DC size and length of occlusion. Maximum partial DC for each tree varied between zones corresponding to second, third, and fourth lifts.

Mean sawing conversions by main grades (to actual board sizes rather than nominal sizes) are given by log height class in Table 8. Conversions showed a marked decrease for increasing log height class (Fig. 3). Generally, percentage conversion decreased with s.e.d. (coefficient of determination = 0.96). This reflects both the smaller piece size of upper logs and greater log asymmetry associated with the heavier branching higher up the stem. The latter appears as hollows and large flanges associated with very large branches. A comparison can be made with the sample of logs sawn from Hull's stand where piece size of upper logs was greater and branch size smaller. In Hull's stand, conversions for butt, second, and third logs were 50.9% (s.e.d. 461 mm), 54.4% (s.e.d. 391 mm) and 54.4% (s.e.d. 357 mm) respectively.

TABLE 7–Mean sample log parameters by log height class

Log position	No. logs	Log length (m)	S.e.d. (ub) (mm)	Taper (mm/m)	Sweep (mm/m)	Defect core (mm)	Max.* partial DC (mm)	Vol. (ub) (m^3)
Butt	15	4.7	426	29	9	299	278	0.917
Second	15	5.5	361	12	7			0.684
Third	9	5.0	282	20	8			0.424

* Largest defect core associated with a single pruning lift

TABLE 8–Mean quality and conversion parameters by log height class

Log position	No. logs	Mean s.e.d. (ub) (mm)	Mean s.e.d.- defect core (mm)	Mean defect core (mm)	Mean Pruned Log Index	Mean conversion (% round)	Mean recovery of "high value" grades (% sawn)		
							Clear	+ Clear 1 face	All "high value" grades
Butt	15	426	127	299	4.6	51.9	20.6	36.5	73.3
Second	15	361				48.9			12.7
Third	9	282				43.1			7.9

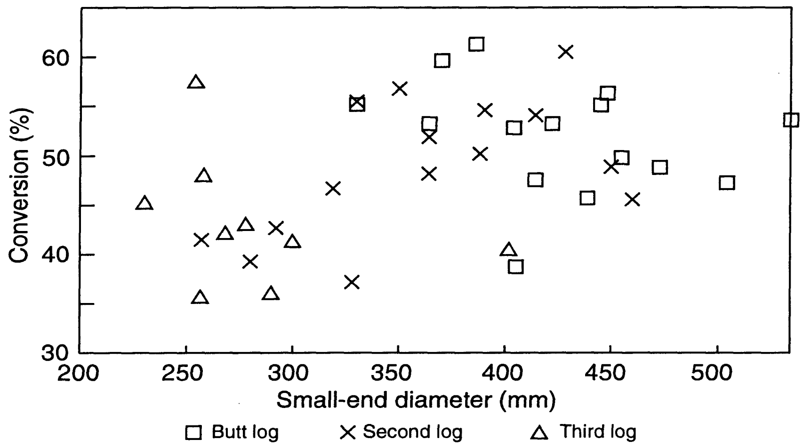

FIG. 3–Relationship between total conversion and small-end diameter of sample tree logs from the Macrocarpa A stand.

The percentage of timber graded as "Clear both faces" and "Clear both faces plus Clear 1 face" is summarised in Table 8. Generally, clears recovery was poor, reflecting large defect cores. In Fig. 4 percentage Clear both faces for each butt log is graphed against an index of log quality, Pruned Log Index (PLI) (Park 1989). There is an expected trend of increasing clears recovery with increasing PLI. Clears recovery plotted on another measure of pruned log quality, s.e.d. – DC, resulted in a very similar pattern.

The "high value" grades are considered here to be Clear both faces, Clear 1 face, Select A and B, and the weatherboard/exterior finish grade. Total "high value" grade recovery is provided in Table 8. Introducing the weatherboard/exterior finish grade diverted 1.42 m^3, or 29.5% of what would otherwise be Dressing grade (i.e., 1.42 m^3 of 4.81 m^3). Of the 274 boards that remained in Dressing grade, 40% were there solely on the basis of sap content, 32% on the basis of large branches or large branches plus sap, and the remaining 28% because of various other combinations of defects.

Conversion of logs by height class into the main categories—mill residues, Clears (including Clear 1 face), other "high value" grades, and low grade boards—is indicated in Fig. 5. A large proportion of the knotty timber from the knotty cores of pruned logs was

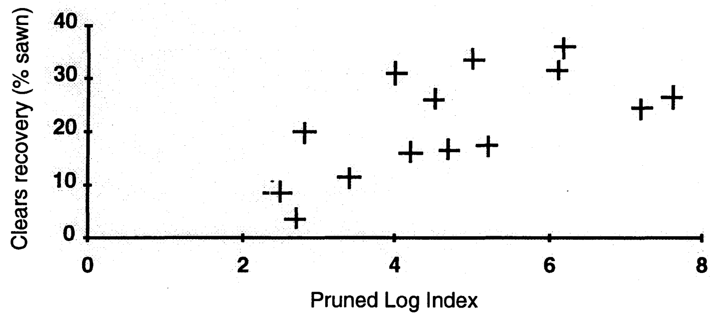

FIG. 4–Clears recovery from butt logs against Pruned Log Index (timber clear on both faces).

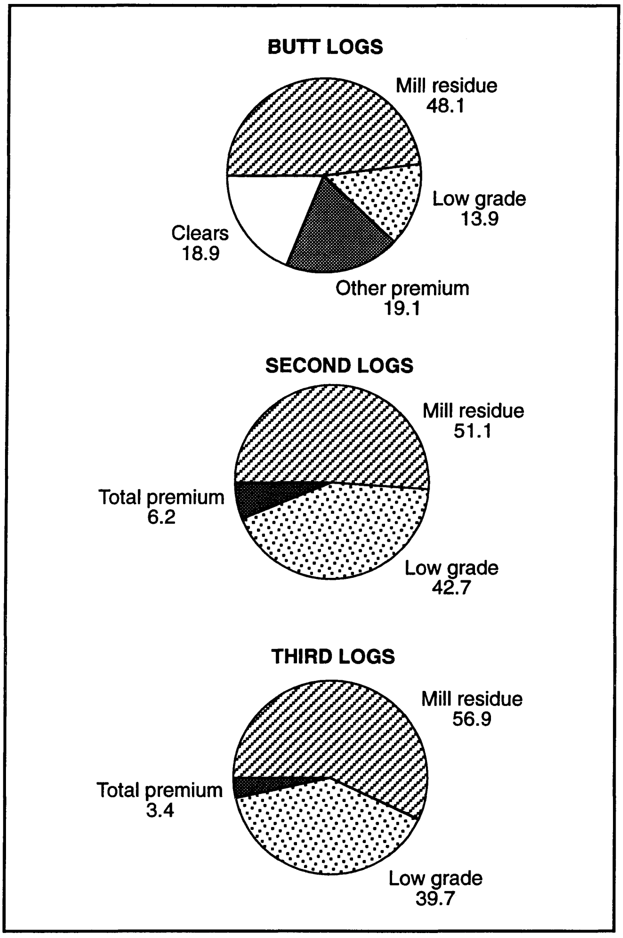

FIG. 5–Sawlog conversion (%) by log height class.

suitable for weatherboard/exterior finish grade, and so overall "high value" grade recovery was very good. Conversion of second and third logs into "high value" grades was low, mainly because of large branches and the presence of sapwood.

In the above analysis, the "high value" grade recovery in second and third logs was reduced by the presence of sapwood. To some degree this may be an artefact of the SANZ rules. *Pinus radiata* treated to H1(low decay hazard) rating is allowed for exterior use with a paint finish while *C. macrocarpa*, which is treatable to H1, is not. However, the exclusion of *C. macrocarpa* sapwood in exterior use where clear or no finish is required is apparently justified because *C. macrocarpa* sapwood cannot be pressure treated with waterborne CCA salts to H3. The Light Organic Solvent Process (LOSP) is another way of treating to H3. It appears that the use of this system to treat *C. macrocarpa* has not been adequately researched. Several samples were provided for exploratory testing. A limited degree of preservative penetration occurred and this indicates further research is warranted.

The 15 butt logs were divided into two sets, nine lightly fluted and six moderately fluted. Mean s.e.d. values for the two sets were 418 mm and 439 mm, while conversions were 52.6% and 49.0% respectively.The difference in conversion is likely to be a consequence of the fluting.

Eight butt logs and one second log had insect damage. Damage was very localised, affecting only 33 boards (5.4% of boards by volume) in the entire study, and was confined to or immediately adjacent to large pruned knots. There were also often small amounts of associated decay in and around the branches with a few instances of damage along the pith. Attack by the native two-toothed longhorn borer (*Ambeodontus tristis* Fabricius) was the main cause, with a few minor instances of other borer damage, probably from the pine bark anobiid (*Ernobius mollis* L.).

After sawing the timber was transported in moist humid atmospheric conditions to Rotorua where it was held under cover, filleted, and air dried (under cover). Within several weeks, end checking was apparent and this developed up to 300 mm from board ends. Checking eventually ceased, with checks closing up and becoming less visible. Equilibrium moisture content of around 18% was attained after 6 months' drying (December 1991–June 1992). A number of boards that included pith or were close to the pith exhibited an undulating surface indicating internal collapse. Drying and wood properties will be reported separately.

Pulping Study

If a large forest estate of *C. macrocarpa* is to be contemplated, attention will need to be given to the disposal of pulpwood quality arisings.The use of *C. macrocarpa* as raw material for pulping would depend on its suitability and the continuity of an adequate supply of wood. To set up the correct pulping "recipes" and avoid changes in end product quality, pulpmills require large constant supplies.

Kraft pulp

The basic densities of topwood and slabwood chips were each about 400 kg/m^3. Chemical analysis of chips found that:

- The dichloromethane solubles (resinous substances) of the topwood and slabwood were 1.7% and 0.7% respectively;
- The Klason lignin content of both samples was a high 34% (6% units higher than *P. radiata*);

- From the carbohydrate analysis, the glucose content was low indicating low cellulose content;
- A further 14% of topwood mass and 17% of slabwood mass were unaccounted non-structural material.

On the basis of these results, extractives-related problems would not be expected during processing of *C. macrocarpa.*

Both chip sources pulped readily to bleachable grades of pulp requiring only 1000 H factors to reach kappa 30. This compares very well with easily pulped *P. radiata* samples. Yields were very poor, being only 38% and 36% usable screened pulp for topwood and slabwood samples respectively, some 7–9% lower yield than from *P. radiata.* This was a consequence of the high lignin and non-structural components and the low cellulose content.

Alkali consumption was normal for a softwood (in spite of the lignin and non-structural content) and bleachable grades of pulp should be produced from an effective alkali charge of 15% (as Na_2O).

Cupressus macrocarpa fibres collapsed easily on beating and showed a very high level of conformability. After beating for only 1000 revolutions, topwood handsheets had a sheet density of over 800 kg/m^3. Density of slabwood handsheets was only slightly lower.

Both topwood and slabwood pulps produced paper with good tensile and burst strength, the topwood pulps responding slightly better to beating than the slabwood pulps. Stretch properties were about average for a softwood pulp. However, the tearing strength of both pulps was very low, the tear index being only about 9 mN.m^2/g at 100 tensile index.

Handsheets from both pulps showed good light-scattering properties, important for high-quality printing papers. However, the light-scattering coefficient is still only around half of that for a hardwood pulp and so *C. macrocarpa* is unlikely to substitute for a hardwood in this capacity

Fibre lengths (length weighted) as determined by the Kajaani test were 1.96 mm for toplogs and 1.87 mm for slabwood (*see* Table 9 for comparative data). Fibre coarseness (mass of fibre per unit length) was very low. Coarseness, short fibre length, and high density of paper after minimal beating indicate that the fibres are thin-walled and collapse readily. The reinforcing value in paper, a property normally expected from a softwood pulp, would be particularly low.

TABLE 9–Density, fibre length, and coarseness of several species

Wood source	Chip basic density (kg/m^3)	Fibre length (mm)	Fibre coarseness (mg/m)
Cupressus macrocarpa topwood	405	1.96	0.138
C. macrocarpa slabwood	403	1.87	0.146
Eucalyptus regnans	465	0.75	0.07
Mixed hardwoods		0.97	0.10
Pinus radiata 9-year-old	335	1.97	0.18
P. radiata 18-year-old toplogs	408	2.71	0.25
P. radiata slabwood, Kaingaroa	438	2.93	0.305
P. ponderosa	350	2.00	0.13

Sources: Kibblewhite *et al.* (1991); R.P.Kibblewhite unpubl. data

Mechanical pulping

In the chipping operation, a proportion of *C. macrocarpa* chips did not cleave satisfactorily. Long and stringy pieces passed through the 40-mm screen.

Mechanical pulping of *C. macrocarpa* proved to be surprisingly difficult mainly because the motor loadings were highly unstable and fluctuations of up to 1.5 megawatts were experienced. Peaks of 1.0 megawatt are usual.

Effluent from the chip plug-screws was highly coloured. For a commercial operation this may have environmental pollution implications.

A total of 15 TMP pulps were produced but only seven CTMP pulps were made as it became impracticable to proceed further.

Two main measures of mechanical pulpability are freeness and energy input.

Freeness is a measure of the rate at which water drains through a "pad" of pulp. It is an important measure for papermaking as, prior to drying and compressing stages, water must drain from the pulp. Freeness is generally inversely correlated with tensile strength. The lower the freeness, the more solitary and compact are the fibres and hence the lower the drainage. In making newsprint from *P. radiata* TMP, a freeness of 150 would be appropriate while corresponding values for CTMP and kraft would be 250 and 400. (Screening and cleaning systems can reduce pulp freeness by 30–40% prior to papermaking.) Inspite of the refiner instability problems, freeness values in the commercially usable range were obtainable from *C. macrocarpa*.

Energy input is the refiner energy input required to produce a pulp with a particular set of properties (usually measured by freeness). To reach a freeness of 150, the *C. macrocarpa* chips required 915 kWh/odt more energy than *P. radiata* chips.

Thermomechanical pulp: Pulps from *C. macrocarpa* had substantially less long fibre and slightly more fines than *P. radiata* ones, indicating that the resulting paper would be weaker but have a slightly better printing capability. As energy input increased, the amount of long fibre decreased and fines increased. Paper from *C. macrocarpa* TMP had substantially lower tear, burst, and tensile indices and a lower specific elastic modulus than paper made from *P. radiata* TMP. As refiner energy input increased, these paper properties (with the exception of tear) improved but at a much lower rate than for *P. radiata*. *Cupressus macrocarpa* sheet densities were lower than for *P. radiata*. While *C. macrocarpa* paper had lower brightness, both light-scattering coefficient and opacity properties were superior to *P. radiata*, a consequence of the higher proportion of fines (the lower brightness probably outweighs these advantages).

Chemithermomechanical pulps: Seven CTMP were produced but their freeness levels were excessively high, well above any commercial pulps, and could not be reduced significantly with a higher refiner energy input. Consequently, only three of the pulps were tested for papermaking potential. These were found to have poor strength properties and showed only a marginal response to further energy input.

Further research will be required to examine the suitability of *C. macrocarpa* pulpwood arisings for use in fibreboard, particleboard, and untested pulping processes, e.g., cold soak treatment followed by mechanical pulping.

CONCLUSIONS

One of the most important observations from this investigation is that, in terms of stand volume, piece-size, and sawlog quality, the 27-year-old pruned and thinned *C. macrocarpa* stand (Macrocarpa A) could justifiably be harvested. For the particular site conditions pertaining to the study stand, *C. macrocarpa* must be rated similarly to *P. radiata* as a short-rotation species

Macrocarpa A stand was 10 m shorter than adjacent same-aged *P. radiata* stands but had greater dbh development. A simulated *P. radiata* stand "grown" under the same site conditions and regime as the *C. macrocarpa* study stand "produced" an identical total standing volume. A small highly stocked *C. macrocarpa* stand (Macrocarpa B) had poor height development. Although this may be partly attributable to site, it is possible height suppression was associated with high stocking.

In terms of log quality, basal area, and total standing volume, the Macrocarpa A stand has been severely disadvantaged by thinning to 171 stems/ha at age 21 years.The removal of over half the stand basal area and total standing volume brought an apparently minimal response in stem growth but an immediate and sustained response in large-branch diameter growth. At the time of the study, 68% of the volume of unpruned logs were classified as "large-branched sawlogs" and this percentage is likely to increase. Large branches have developed basal flanges on the stem. In log making at harvest time these will need to be trimmed. Trimming times on the study trees were about half an hour, some 20 minutes longer than expected. This could translate into significantly higher harvesting costs. Large branches and flanges also distort the log cross-section symmetry, with adverse consequences in sawing conversion and increases in the percentage of sawn pieces containing sapwood.

On a study sample of 15 trees from the Macrocarpa A stand, the incidence of all branches in second and third logs was relatively constant at about 20 per metre of stem. Radial incidence of branches appeared to be independent of aspect and slope, with similar numbers on the uphill and downhill sectors. However, large-branch development predominated on the downhill side of trees where there was less shading from neighbours. Likewise, the proportion of green branches was highest on the downhill side of trees and also increased with increasing height up the stem.

Sample trees had high proportions of heartwood ranging from a mean 70% of under-bark butt log volume to corresponding values of 64% and 56% for second and third logs. Mean number of annual rings of sapwood varied from 4.1 at stump to 5.2 at the top of sawlogs, with an almost constant mean depth of sapwood of 40 mm over the sawlog zone.

Butt logs were classified as either lightly or moderately fluted. In the study sample, the six moderately fluted butt logs had a 3.6% average lower sawing conversion than the lightly fluted ones.

The mean sawing conversion (sawn timber as a percentage of round log volume) for butt logs (51.9%) was similar to that obtained in a corresponding study on a 52-year-old *C. macrocarpa* stand. However, conversion for second and third logs was considerably lower (48.9% and 43.1% compared to 54.7% and 54.4% in the older *C. macrocarpa* stand). This lower conversion reflected both small size and log asymmetry caused by large branch flanges and associated flutes and hollows. Clears recovery from pruned butt logs was low as defect core sizes were quite large, with a mean for sample logs of 299 mm. The mean branch stub occlusion depth was 15.4 mm.

Recovery of all "high value" grades of timber (includes Clears, Select, and weatherboard/finish grades) by log height class was 72%, 13%, and 8% of sawn timber for butt, second, and third logs respectively. The low recovery for second and third logs reflected the presence of sapwood and large branches. Knots in the lower grades were mostly intergrown and this timber found a ready market as panelling and sarking.

Two-thirds of the butt logs sampled had insect (and to a smaller extent fungal) attack associated with large pruned branches. There was no evidence of current insect infestations although the main culprit, the two-toothed longhorn borer, is capable of attacking heartwood in standing trees. A small but significant portion of sawn timber (5.4%) was downgraded by insect damage.

Some relatively minor drying degrade occurred. This was in the form of end checking and some collapse in boards containing pith or from close to the pith.

The pulping study revealed that *C. macrocarpa* is not well suited to the three pulping processes investigated. For the kraft process, yields are poor in comparison to *P. radiata*, and pulps lack strength and reinforcing capabilities (a consequence of high lignin and non-structural substances and low cellulose content). *Cupressus macrocarpa* pulps readily to bleachable grades with normal chemical consumption. With only light beating, the short low-coarseness fibres collapse producing dense paper with good light-scattering properties. However, tear strength is very poor for a softwood. Kraft *C. macrocarpa* pulp is similar to that from very young *P. radiata* and has some properties reminiscent of hardwood pulps but without their more favourable attributes. Commercially, *C. macrocarpa* might be used in the kraft process as part of a mix with a more-favoured pulp species—softwoods for their reinforcing qualities and hardwoods for their favourable optical properties.

Cupressus macrocarpa appears to be more difficult to chip than *P. radiata*, proving somewhat "stringy" with resulting screening problems. TMP can be produced but in this study highly unstable refiner motor loadings resulted, with high energy consumption and large energy consumption peaks. Pulps can be made within the accepted commercial range of freeness. In comparison to *P. radiata*, pulps had substantially less long fibre and more fines while resulting paper had low strength properties (tear, burst, tensile, and stretch) and low brightness. Compared with *P. radiata*, strength properties improved at a much lower rate with increasing refiner energy input. TMP could be made from *C. macrocarpa* but it would be far more costly and inferior in quality to *P. radiata* TMP.

CTMP is unlikely to be made commercially from *C. macrocarpa* with existing technology. In the study, refiner energy loadings were very high and unstable, and the resulting pulp properties were well outside any commercially acceptable range.

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