VARIATION IN SOME WOOD PROPERTIES OF *PSEUDOTSUGA MENZIESII* PROVENANCES GROWN IN NEW ZEALAND

M. J. F. LAUSBERG, D. J. COWN, D. L. McCONCHIE, and J. H. SKIPWITH

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Received for publication 12 March 1996; revision 9 August 1996)

ABSTRACT

Significant areas of *Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco (Douglas-fir) have been planted in New Zealand using a relatively small number of provenances. The resource is regarded as suitable for a range of structural products, with little information available on provenances in terms of wood quality. Two provenance trials were sampled—34-year-old trees of 39 provenances across six sites, and 19-year-old trees of six provenances across three sites—and wood density patterns were examined for 10 provenances on four sites with 30 trees per provenance. There was a strong site effect on properties measured and correlations between growth rate and density were negative on all sites and at most five-ring group positions. Juvenile wood extended to between 10 and 15 rings. In the 34-year-old trial, significant differences were found both within and between sites for density, stem diameter, and level of heartwood. Differences between provenances in resin contents were also significant. Two Californian provenances, Stinson Beach and Mad River, were found to be of consistently high density and diameter growth on all sites. In the 19-year-old trial there were significant differences within and between sites for density but diameter differences were significant only between sites. The results indicate that the Ashley Forest provenance is superior, having good diameter growth and higher wood density.

Keywords: provenances; wood properties; *Pseudotsuga menziesii*.

INTRODUCTION

Pseudotsuga menziesii var. *menziesii* is a native of western North America where it is the most commercially important timber species. In New Zealand, however, it is the second most important exotic timber species after *Pinus radiata* D. Don. It is considered superior to *P. radiata* on some moist high-altitude sites as it has the advantage of being more tolerant of wind, snow, and low winter temperatures, while maintaining competitive growth rates. The *Ps. menziesii* resource exceeds 60 000 ha (Miller & Knowles 1994)—about 5% of the total plantation forest area—mostly located in the Central North Island. Increasingly, new plantations are being established on cooler South Island sites.

The timber is well accepted in international markets where its reputation is built on "old crop" North American timber (200–500 years old). The "old crop" is considered superior in several aspects to "second growth" (100–150 years), the most important being higher wood density and lower corewood proportions (Jozsa *et al.* 1989). This material is recognised as a good structural timber because of its adequate wood density, straight grain, and good dimensional stability. Less than 18% (Miller & Knowles 1994) of the original "old crop" or mature growth North American timber is now available for use owing to conservation pressures, and the harvest is increasingly composed of second-growth timber. The recovery of sawn timber used in high-quality products is also decreasing because of the smaller diameters at breast height (dbh), higher proportion of juvenile wood, and larger knots in second-growth timber (Middleton & Munro 1989).

Pseudotsuga menziesii covers a wide geographic range in North America, from northern British Columbia to Mexico, and displays considerable genotypic variation in growth and wood properties (McKimmy & Campbell 1982).

In New Zealand plantations *Ps. menziesii* has been planted at a relatively steady rate averaging 1500 ha/year (Miller & Knowles 1994), based on a relatively small number of North American provenances, with little information available for comparison of wood quality between these provenances. Information on factors affecting quality will be increasingly necessary in order to maintain its good reputation. Wilcox (1978) reported large variations in wood density, stem form, and other traits between the provenances. Research on timber yields in New Zealand by Whiteside *et al.* (1977) and McConchie (pers. comm.) found that the most important variables affecting structural grade recovery were branch size, basic density, and log diameter. Hence, this study examined the effects of provenance and site on *Ps. menziesii* wood properties.

MATERIALS

The material used in this report came from *Ps. menziesii* provenance trials established in 1959 and 1974. The older trial, consisting of 39 provenances, was established at six sites: Rapanui, Kaingaroa, Gwavas, Golden Downs, Hanmer, and Rankleburn. Wood samples from four sites (to give maximum site variation) were used in this study (Kaingaroa, Golden Downs, Hanmer, Rankleburn) with 10 provenances sampled at each site (Table 1a). Provenance selection was based on those commonly used in plantation forestry (C.J.A.Shelbourne and J.T.Miller, pers. comm.) and therefore relevant to the resource to be harvested in the future.

The second trial was established in Kaingaroa, Golden Downs, and Rankleburn Forests. The six seed sources (Table 1b) used in the trial have since that time been used extensively in the New Zealand planting programme. All plots were thinned to 600 stems/ha between 1973 and 1980. Those at Rankleburn were thinned again in 1990 and at Hanmer in 1993. Pruning was carried out for access only. Two New Zealand provenances were examined—Kaingaroa bulk and Ashley (coastal Oregon provenance originally), both of which are planted in North and South Island forests.

METHODS

At each site, 30 trees per provenance were assessed for visible quality features and wood density, to give a good estimation of the mean and standard deviations. The 30 trees per

TABLE 1–Provenances sampled in the trials

Seedlot	Provenance
(a) 34-year-old trial	
580	North Bend, Oregon
635	Florence, Oregon
642	Berteleda, California
647	Mad River, California
649	Dehaven, California
654	Casper, California
658	Stewart Point, California
659	Stinson Beach, California
660	Santa Cruz, California
r530	Kaingaroa Forest, New Zealand
(b) 19-year-old trial	
593	Ashley Forest, New Zealand
839	Kaingaroa Forest, New Zealand

provenance were selected randomly from several plots within each site to remove the between-plot variation, but for a few provenances there were insufficient trees available (three provenances had only 18–20 trees remaining). The field assessment involved assigning indices for form, internode length by height class, and branch diameter by 5-m-log height classes. Breast height diameter over bark was recorded and one 5-mm pith-to-bark increment core was taken at the same height (1.4 m). Trees in 1959 and 1974 trials were 34 and 19 years old respectively in 1993 at the time of sampling.

Properties Assessed

DBHOB

Diameter at breast height over-bark. This is a standard and simple measure of performance as it gives an indication of growth rate.

Wood density

The pith-to-bark core was taken for gravimetric density analysis using the maximum moisture content method (Smith 1954). The cores were measured in five-ring groups to give data on the radial variation in wood density. The five-ring groups were also measured for length in order to weight the density values according to growth rate (equivalent to disc values). Growth rings from ring 25 to the outside ring (approximately 35) were left as a 10-ring group. Previous research (Josza *et al.* 1989; Abdel-Gadir & Krahmer 1993; Josza & Middleton 1995) has shown that *Ps. menziesii* has a period of low-density juvenile wood that extends about 10–30 rings from the pith and forms a cylindrical core up the stem.

Branching

Both size and spacing along the stem were assessed.

The average branch diameter for each log, assessed visually, was assigned to one of three classes. *Pseudotsuga menziesii* grown in New Zealand generally has a narrow range in branch diameter, therefore the classes represented the following branch sizes: Class 3 = average branch size greater than 4 cm; Class 2 = branches between 2 and 4 cm; Class 1 = smaller branches. Branch angle was graded as either flat (F) or steep (S).

The internode index consisted of a subjective visual assessment as N (no internode) or I (internodes present) based on the whole log. An internode was classed as being present if the regular distance between nodes was greater than about 30 cm.

Stem form

This was a visual assessment of the presence of defects such as double leaders, sweep, and kinks. The tree was given a 1, 2, or 3 rating depending on general form, taking into consideration any defects. A rating of 1 was given for a perfect tree and 3 to a severely malformed tree.

Heartwood

The heartwood diameter was measured on the increment cores and expressed as a percentage of breast height cross-sectional area.

Compression wood

From the cores, compression wood was graded as 0 = no compression wood, 1 = trace, 2 = moderate, or 3 = severe.

Resin content

Resin percentage was calculated from the five-ring group samples for the Kaingaroa site only. Extraction was done using methanol in a Soxhlet extractor for 72 hours, the resin content being the percentage weight loss.

Statistical tests

ANOVA (analysis of variance) was used for all statistical testing. Differences were taken as being significant at the 95% confidence level, with differences at the 99% confidence level being highly significant.

RESULTS AND DISCUSSION

Wood Density

34-year-old trial

The general trend in breast-height wood density over all sites and provenances was an increase from pith to bark (Table 2), as has been found previously in New Zealand and elsewhere (Harris & Orman 1958; Harris 1978, 1985; Jozsa *et al.* 1989; Abdel-Gadir & Krahmer 1993).

The inner 10 growth rings were of significantly lower density (at the 99% confidence level) than the outer growth rings, suggesting a juvenile core of at least 10 growth rings. The difference in density from the pith zone to the outerwood was 65 kg/m^3. Jozsa *et al.* (1989) found density in *Ps. menziesii* trees of a similar age to the trees of this study increased from

TABLE 2–Average radial density (34-year-old trial)

	Growth rings from the pith					
	1-5	6-10	11-15	16-20	21-25	26-35
Density (kg/m³)	382	383	421	420	435	447

about 405 kg/m³ at ring 5 to about 505 kg/m³ at ring 30; the trees they sampled in Canada (Vancouver Is.) had higher wood density and a steeper radial density gradient than the trees in these provenance trials. This was also observed by Ghali (1979) in 45-year-old trees in New South Wales. For comparison, *P. radiata* shows a radial density gradient of about 100 kg/m³ for trees of the same age (Cown 1992).

All provenances were averaged to give the mean radial density pattern for each site (Fig. 1). There were significant differences between all sites at the 99% confidence level. The mean radial density pattern for the Rankleburn site followed a different profile from those of the other sites. This may have been due to the timing of the thinning operation which could have varied by as much as 7 years between sites. If some sites were thinned before crown closure and some after, the effects of competition could explain the drop in density at the Rankleburn site.

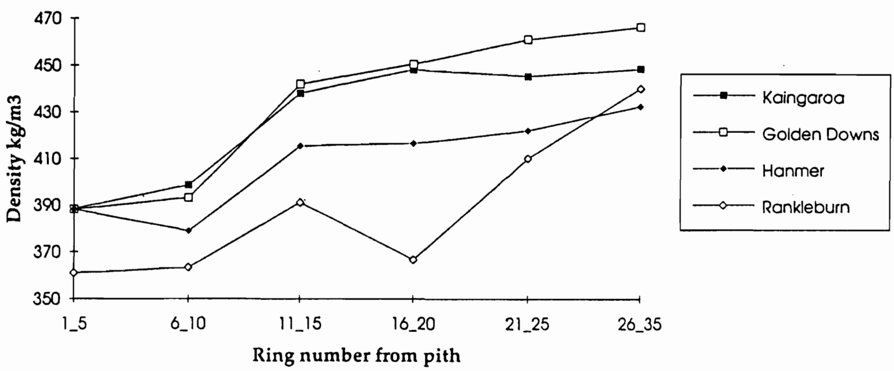

FIG. 1–Mean radial density patterns on all four sites.

The site variation in mean density followed the patterns established for *P. radiata*, with Golden Downs corresponding to high, Kaingaroa to medium, and Hanmer and Rankleburn to low (outerwood densities being 466 kg/m³, 448 kg/m³, 440 kg/m³, and 432 kg/m³ respectively), giving a difference of about 15 kg/m³ between successive zones. For *P. radiata* the outerwood densities for the high, medium, and low zones at age 35 would be about 515 kg/m³, 480 kg/m³, and 445 kg/m³ respectively (Cown 1992) with a difference of 35 kg/m³ between successive zones. Therefore, the effect of site on density for *Ps. menziesii* seems to be less than that reported for *P. radiata* since the difference in outerwood densities between the zones is not as large.

All the trees were averaged to give a radial pattern in density for each provenance on each site (Fig. 2–5). The stocking in the Kaingaroa trial was variable after the thinning, ranging from 309 to 845 stems/ha. Harris (1974) calculated that about one-third of the variation in wood density could be related to growth rate. This variation in stocking may have had an effect on growth rate and density since conditions may not have been uniform for some provenances, making interpretation of the data difficult.

The differences between provenances within each site were significant at the 95% (or better) confidence level. When breast height weighted densities were calculated, provenance

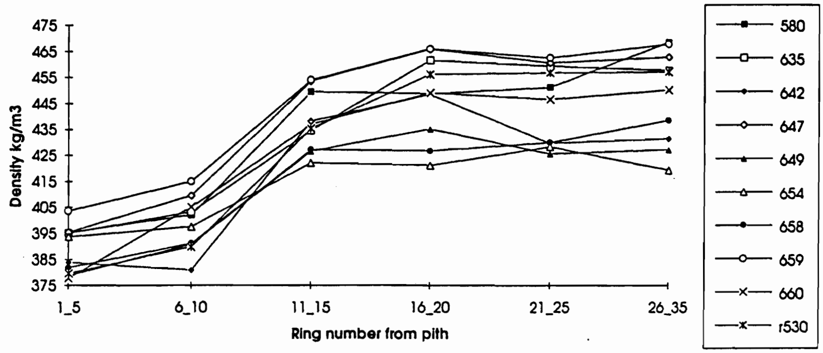

FIG. 2–Radial density patterns for all provenances (Kaingaroa).

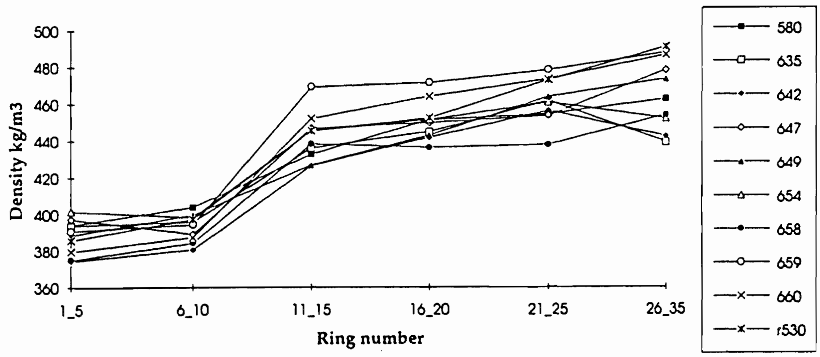

FIG. 3–Radial density patterns for all provenances (Golden Downs).

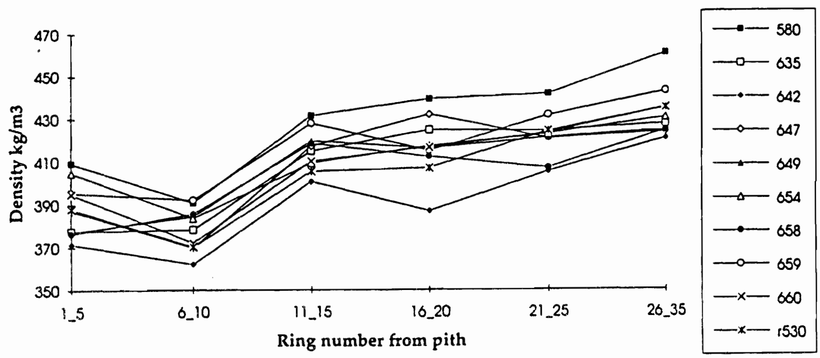

FIG. 4–Radial density patterns for all provenances (Hanmer).

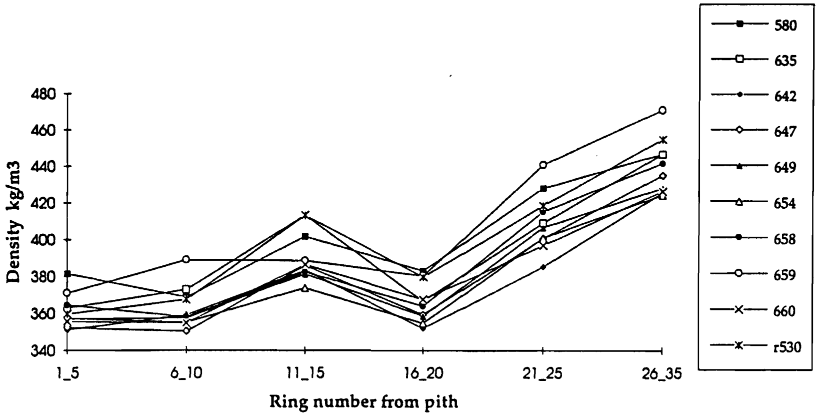

FIG. 5–Radial density patterns for all provenances (Rankleburn).

659 (Stinson Beach) was ranked in the top two for wood density at all sites, and provenance 642 (Berteleda) was in the bottom two for density at three sites and fourth from the bottom at the Kaingaroa site. The significance of this can be judged from the finding of McConchie (pers. comm.) that a 25% increase in wood density leads to an increase in recovery of acceptable structural lumber (F5+) of approximately 20%, assuming the same log diameter and branch size. Since provenance 642 from the Golden Downs site had a density of 432 kg/m^3 and provenance 659 had a density of 460 kg/m^3 (about 6.5% higher) it is estimated that provenance 659 would yield approximately 5% higher recovery of F5+. McConchie (pers. comm.) also defined the relationship between log diameter and sawn timber conversion for a given sawpattern. Applying this to the trial data, provenance 659 would have approximately 1% higher conversion. These two parameters support provenance 659 as a superior provenance for future plantation requirements on a wide variety of sites. From the average diameters for all provenances on all sites, a 3% range in conversion could be expected between the fastest and slowest growing provenances.

Walford (1985) found similar wood density differences between Kaingaroa and Golden Downs Forests, but it is not valid to compare the data directly because they were in whole-tree format. Average tree wood density values were 394 kg/m^3 and 416 kg/m^3 for Kaingaroa and Golden Downs respectively, while the current study results indicate 433 kg/m^3 and 443 kg/m^3 for outerwood.

Harris (1978) showed that *Ps. menziesii* exhibited a decrease in density over the first five rings or so and then increased slowly thereafter (from around 400 kg/m^3 at the pith to as high as 520 kg/m^3 in outerwood at age 40 years). In the present study the average for the Hanmer site showed a similar trend, with density at 390–380 kg/m^3 at rings 1–5 and rings 6–10 respectively and then increasing to 415 kg/m^3 for rings 11–15. The other sites did not show this initial drop in average density but there were individual provenances within sites which conformed to this pattern.

19-year-old trial

Radial density trends for the two provenances on both sites in this trial are indicated in Fig. 6. Provenance 593 (Ashley Forest) was significantly higher at both Kaingaroa and

Golden Downs at the 99% confidence level. The difference between the sites was also significant at the 99% confidence level.

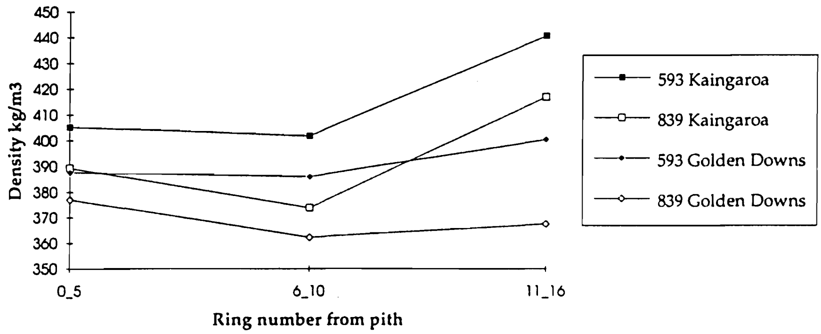

FIG. 6–Mean radial density patterns from both sites in the 19-year-old trial.

Diameter

34-year-old trial

The length of all five-ring segments was recorded for all increment cores (Fig. 7).

There were significant differences in radial increment for the five-ring groups between provenances at all sites. Kaingaroa had significant differences (at 99% confidence level or better) between the provenances for ring groups 16–20 and 21–25. Golden Downs had significant differences (at 95% confidence level) between the provenances for ring groups 11–15 and 16–20. Hanmer had significant differences (at 99% confidence level or better) between the provenances for ring groups 11–15 and 16–20. Rankleburn had significant differences (at 95% confidence level or better) between the provenances for all ring groups. For all the ring groups there were significant differences (at the 99% confidence level) between the sites.

Ranking for diameter growth for all sites showed provenance 647 (Mad River) in the top four and provenance 580 (North Bend) was consistently ranked in the bottom four.

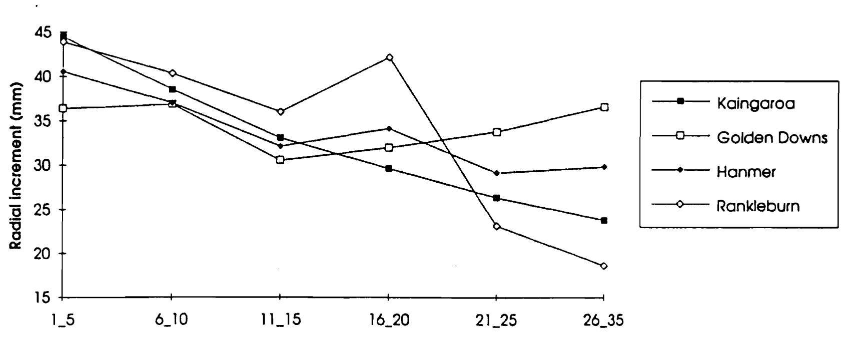

FIG. 7–Mean radial increments for five-ring groups on all sites

Correlations between wood density and growth rate varied with radial position and site (Table 3). There was a negative relationship between diameter growth and wood density for all but two five-ring group positions on the Hanmer site, although the correlations were often weak and statistically insignificant. Overall, there was a tendency for reduced density with increased diameter growth, which agrees with the findings of Harris (1974). The Rankleburn site exhibited the strongest correlations, and Hanmer had the weakest. The Kaingaroa and Golden Downs sites had similar correlations. The Rankleburn site had large variation in stocking which led to a wide range in diameters being recorded and this may, in part, explain the stronger correlations.

TABLE 3—Correlations between diameter growth and wood density for all sites and radial positions

Site	Growth rings					
	1–5	6–10	11–15	16–20	20–25	26–35
Kaingaroa	–0.05	–0.37	–0.32	–0.29	–0.26	–0.22
Golden Downs	–0.15	–0.20	–0.44	–0.13	–0.29	–0.21
Hanmer	–0.03	–0.22	–0.17	0.03	0.02	–0.11
Rankleburn	–0.29	–0.40	–0.46	–0.37	–0.39	–0.18

Heartwood

34-year-old trial

The effect of site on heartwood was significant at the 95% confidence level (Table 4). The differences in the heartwood percentage between the provenances within the Kaingaroa and Hanmer sites were significant at the 99% and 95% confidence levels respectively. The differences between the provenances on the Golden Downs and Rankleburn sites were not significant at the 95% confidence level.

TABLE 4—Heartwood percentage for all provenances and sites in the 34-year-old trial

Site	Heartwood percentage by provenance										Mean
	580	635	642	647	649	654	658	659	660	r530	
Kaingaroa	47	47	44	46	47	44	47	40	54	45	46
Golden Downs	39	42	44	44	39	45	45	40	45	40	42
Hanmer	44	45	50	47	48	50	50	53	54	48	49
Rankleburn	45	55	50	61	57	57	63	47	57	50	54
Mean	43	45	46	46	45	46	47	44	51	45	**46**

19-year-old trial

There was no significant difference within sites for heartwood percentage at the 95% confidence level but the Kaingaroa site had significantly higher heartwood percentage at the 99% confidence level (Table 5).

The heartwood assessment indicates that *Ps. menziesii* is significantly influenced by site conditions, but that there is no strong overall geographic (i.e., north to south) trend.

TABLE 5–Heartwood percentage for both provenances and sites in the 19-year-old trial

Site	Heartwood percentage by provenance		Mean
	593	839	
Kaingaroa	37	35	36
Golden Downs	27	26	27
Mean	32	31	**31**

Tree Indices

34-year-old trial

For the purposes of data manipulation the letters assigned to some tree indices were converted to numbers as follows: branches > 4 cm were classed 3, branches 2–4 cm = 2, branches <2 cm = 1; steep branches =1, flat branches =2; no internode =0, internode present =1. The maximums and minimums in Tables 6 and 7 are the range in values between the provenances for each site.

There were significant differences (99% confidence level) in diameter between provenances within the Kaingaroa, Hanmer, and Rankleburn sites and within the Golden Downs site. There was also a significant difference at the 99% confidence level between sites, except for Kaingaroa and Hanmer which showed no significant difference in diameter at the 95% confidence level. Branch size increased with height. Internode index decreased with height, and there were far fewer internode logs present in *Ps. menziesii* stands than in *P. radiata* ones.

TABLE 6–Site means for weighted disc density, diameter, branch size, and branch angle for the 34-year-old trial.

Site	Density	Diameter at 1.4 m	Branch index by log				Branch steepness
			1	2	3	4	
Kaingaroa							
Min	415	379	1.5	1.8	1.9	*	
Max	452	460	1.9	2.1	2.4		
Mean	433	422	1.7	2.0	2.1		1.6
Golden Downs							
Min	429	357	1.7	1.9	2.1		
Max	460	411	1.9	2.1	2.3		
Mean	443	378	1.8	2.0	2.2		1.5
Hanmer							
Min	391	381	1.4	1.9	2.0	2.1	
Max	432	441	1.9	2.1	2.1	2.4	
Mean	413	417	1.7	2.0	2.1	2.2	1.4
Rankleburn							
Min	373	406	1.5	1.8	2.0	2.0	
Max	407	500	2.1	2.2	2.5	2.8	
Mean	389	454	1.6	2.0	2.2	2.3	1.3
Overall mean	420	418	1.7	2.0	2.1	2.3	1.4

* The trees on the Kaingaroa and Golden Downs sites were not tall enough for a fourth log

TABLE 7–Site means for internode component and stem form for the 34-year-old trial.

Site	Internode index by log				Form
	1	2	3	4	
Kaingaroa					
Min	0	0	0	*	1
Max	0.3	0.3	0.2		1.2
Mean	0.2	0.1	0.0		1.1
Golden Downs					
Min	0	0	0		1
Max	0.1	0	0		1.2
Mean	0.0	0.0	0.0		1.1
Hanmer					
Min	0.1	0	0	0	1
Max	0.3	0.3	0.1	0	1.1
Mean	0.2	0.1	0.0	0.0	1.0
Rankleburn					
Min	0	0	0	0	1.1
Max	0.1	0	0	0	1.4
Mean	0.0	0.0	0.0	0.0	1.1
Overall mean	0.1	0.1	0.0	0.0	1.1

* The trees on the Kaingaroa and Golden Downs sites were not tall enough for a fourth log

The branch angle averaged between steep and flat, suggesting that the method of assessment needs to be changed in order to better evaluate this parameter. On the whole, the trees had good form and to obtain differences between provenances would require a more comprehensive form evaluation.

Overall provenance ranking depends on the weighting given to density and diameter as well as site. From this study, provenance 647 (Mad River) was ranked second for density and third for diameter on the Kaingaroa site, while provenance 654 (Casper) was ranked third for density and second for diameter on the Golden Downs site. Provenance 659 was top for diameter growth and second for density on the Hanmer and Rankleburn sites.

19-year-old trial

Provenance averages for weighted disc density, diameter, branch size per log, branch angle, internode component per log, and form for each provenance on each site and overall means are given in Table 8.

Difference in diameter between provenances within sites was not significant at the 95% confidence level but there was a significant difference in diameter between sites at the 99% confidence level. Provenance 593 (Ashley Forest) on both sites had a significantly higher density with no significant reduction in diameter compared to the 839 (Kaingaroa bulk) provenance.

Branch size increased with height and the internode component when present was confined to the first log. Overall form was not as good as the 34-year-old trial due mainly to the low scores for stem straightness which will improve with age. The Ashley Forest provenance has, in a proportion of its stems, a tendency to numerous wiry branches, stem

TABLE 8–Provenance means for weighted disc density, diameter, branch size per log, branch angle, internode component per log, and form for provenances and sites in the 19-year-old trial.

Provenance	Density (kg/m^3)	Diameter	Branch size Log 1	Branch size Log 2	Steepness	Internode Log 1	Internode Log 2	Form
Kaingaroa								
839	387	190	1.5	*	1.5	0.5	*	1.7
593	408	191	1.6		1.5	0.5		1.9
Mean	398	191	1.6		1.5	0.5		1.8
Golden Downs								
839	367	254	1.9	1.8	1.4	0.1	0.0	1.2
593	394	255	1.8	1.9	1.2	0.3	0.0	1.2
Mean	381	255	1.9	1.9	1.3	0.2	0.0	1.2
Overall mean	389	223	1.7	1.9	1.4	0.3	0.0	1.5

*The trees on the Kaingaroa site were not tall enough for a second log.

sinuosity, and other malformation. However, some trees in the Ashley stand are usually very good (J.T.Miller, pers. comm.). These facts need to be kept in mind when selecting for breeding.

Resin Content

Resin content between the provenances at Kaingaroa was significantly different at the 99% confidence level (Table 9). The radial pattern showed that the inner five growth rings contained significantly higher levels of resin than all other rings (at 99% confidence level) and growth rings 6–10 showed significantly higher levels of resin than growth rings 16–25 (at the 95% confidence level). These inner segments largely contain the heartwood zone, with associated higher levels of extractives.

TABLE 9–Resin content for all provenances in Kaingaroa.

Provenance	Rings from the pith/Resin content (%) 1–5	6–10	11–15	16–20	21–25	26–35
580	3.95	2.68	2.39	1.90	2.95	1.92
635	2.56	1.91	1.55	1.59	1.64	2.08
642	2.72	2.53	1.91	2.33	1.58	1.84
647	1.49	1.89	1.57	1.28	1.10	1.48
649	1.50	1.90	1.37	1.33	1.27	1.07
654	3.53	2.25	2.13	1.69	1.93	1.87
658	2.42	1.74	1.88	1.32	1.36	1.70
659	3.65	1.75	1.56	2.10	1.47	1.72
660	3.74	2.25	2.27	1.80	1.63	2.06
r530	3.38	2.08	1.74	1.76	2.33	1.94
Mean	2.83	2.08	1.81	1.69	1.66	1.75

Comparing the Trials

Although there is no specific evidence, it is plausible to suggest that both Kaingaroa seedlots r530 and 839 may be similar in origin and nature (most well-grown Kaingaroa stands of the past were basically of the same Washington ancestry) (Miller, pers. comm.). Kaingaroa r530 compared well with the other provenances on the sites in the older trial (on three of the sites it was in the top four for density).The Ashley Forest provenance should therefore rank highly for density relative to all provenances.

CONCLUSIONS

There was a strong site effect on the properties measured. Golden Downs had the lowest average diameter with the highest average density, and Rankleburn had the reverse trend with highest diameter and lowest density. There was no difference between Kaingaroa and Hanmer in terms of diameter but Kaingaroa had higher density. Correlation between growth rate and density was negative on all sites and for most five-ring group positions. From radial wood density trends, juvenile wood (low density) could be said to extend between 10 and 15 rings from the pith. In the older trial, there were significant differences both within and between sites for wood density, diameter and heartwood development. Differences between provenances in resin contents were also significant. Stinson Beach (California) provenance was of consistently high density on all sites in the older trial while but (California) provenance was of consistently low density. Mad River (California) provenance ranked highly for diameter growth on all sites and it ranked high for density on two sites. Therefore, Stinson Beach and Mad River provenances (both Californian) would seem to have the best potential for future selection on the basis of diameter growth and wood quality.

In the younger trial there were significant differences within and between sites for density but diameter differences were not significant within sites. This points to Ashley Forest provenance as being superior (over the Kaingaroa bulk) since no diameter growth was lost for higher density.

The silvicultural regimes applied to these trials, in particular the uneven stocking of some plots after thinning, may have affected some of the results, particularly branch size, angle, and tree diameter.

REFERENCES

ABDEL-GADIR, Y.A.; KRAHMER, R.L. 1993: Genetic variation in the age of demarcation between juvenile and mature wood in Douglas-fir. *Wood and Fibre Science 25(4)*: 384–94.

COWN, D.J. 1992: New Zealand radiata pine and Douglas-fir: Suitability for processing. *New Zealand Ministry of Forestry, Forest Research Institute, FRI Bulletin No.168.*

GHALI, M.B. 1979: Mechanical and physical properties of Douglas-fir grown in New South Wales. *Australian Forest Industries 9*: 225–32.

HARRIS, J.M. 1978: Intrinsic wood properties of Douglas-fir and how they can be modified. Pp.235–9 *in* James, R.N. (Comp.) A Review of Douglas fir in New Zealand. *New Zealand Forest Service, Forest Research Institute, FRI Symposium No.15.*

———1985: Effects of site and silviculture on wood density of Douglas fir grown in Canterbury Conservancy. *New Zealand Journal of Forestry 30(1)*: 121–32.

HARRIS, J.M.; ORMAN, H.R. 1958: The physical and mechanical properties of New Zealand-grown Douglas fir. *New Zealand Forest Service, Forest Research Institute Technical Paper No. 24.*

JOZSA, L.A.; MIDDLETON, G.R. 1995: A discussion of wood quality attributes and their practical implications. *Forintek Canada Corp. Special Publication No.SP-34.*

JOZSA, L.A.; RICHARDS, J.; JOHNSON, S.G. 1989: Relative density. Pp.5–22 *in* Kellogg, R.M. (Ed.) "Second Growth Douglas-fir: Its Management and Conversion for Value". Chapter 1.

McKIMMY, M.D.; CAMPBELL, R.K. 1982: Genetic variation in the wood density and ring width trends in coastal Douglas-fir. *Silvae Genetica 31(2/3)*: 43–55.

MIDDLETON, G.R.; MUNRO, B.D. 1989: Log and lumber yields. Pp.66–74 *in* Kellogg, R.M. (Ed.) "Second Growth Douglas-fir: Its Management and Conversion for Value". Chapter 7.

MILLER, J.T.; KNOWLES, F.B. 1994: Introduced forest trees in New Zealand. Recognition, role, and seed source. 14: Douglas-fir *Pseudotsuga menziesii* (Mirbel) Franco. *New Zealand Forest Research Institute, FRI Bulletin No.124(14)*.

SMITH, D.M. 1954: Maximum moisture content method for determining the specific gravity of small wood samples. *United States Department of Agriculture, United States Forest Service, Forest Products Laboratory, Paper No.2014*.

WALFORD, G.B. 1985: The mechanical properties of New Zealand-grown Douglas-fir. *New Zealand Forest Service, Forest Research Institute, FRI Bulletin No.94*.

WHITESIDE, I.D.; WILCOX, M.D.; TUSTIN, J.R. 1977: New Zealand Douglas fir timber quality in relation to silviculture. *New Zealand Journal of Forestry 22(1)*: 24–44.

WILCOX, M.D. 1978: Genetic resources and supply of Douglas fir seed in New Zealand. Pp.210–7 *in* James, R.N. (Comp.) A Review of Douglas-fir in New Zealand. *New Zealand Forest Service, Forest Research Institute, FRI Symposium No.15*.