Assessment of Wood Qualities for Tree Breeding

IV. Pinus pinaster Ait. Grown in Western Australia

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(Received for publication January 22, 1966)

Part 1. — Four Provenances from Somerville

Introduction

An examination of the wood characters of material from ten trees from each of four provenances of *Pinus* pinaster, viz. Corsican, Esterel, Landes and Leiria was undertaken recently to determine the extent of the differences between provenances (NICHOLLS et al., 1963). These trees were selected as good quality stems and were obtained from a single plantation compartment at Gnangara in Western Australia.

Analyses of the results showed that only small differences in tracheid length existed, but that basic density values from trees of the Corsican provenance were markedly lower than those from trees of the Landes and Leiria provenances. In that work, the sampling procedure and method used for the determination of spiral grain were not considered to be satisfactory as a basis for conclusively demonstrating between provenance differences.

The Gnangara trees were planted in 1931 as part of a provenance trial, and in that year, the same seed sources were used to conduct a similar trial at Somerville, some 16 miles to the south. Though these two plantations are subject to the same general climatic conditions, (equivalent to the standard for Perth), they differ with respect to soil types. Gnangara is situated on the deep grey Bassendean sands, Somerville on the brown sands of the Spearwood Dunes system with limestone influence (MCARTHUR and BETTENAY, 1960; BETTENAY et al., 1960), and whereas at Gnangara, phosphatic fertilizers were required for the establishment of the pine plantations, for most of Somerville, including the site of the provenance trial, super-phosphate has never been used (Forests Dept., Western Australia, 1965). Silvicultural treatment within each trial was identical; thinning was carried out in 1952 (HOPKINS, 1960). Consequently, the Somerville plantation offers experimental material which is similar to the Gnangara stock, except for fatcors of the soil and the associated fertilizer treatment.

To supplement the findings of the previous investigation it was planned to study the differences in wood characters between the four provenances using material from the Somerville plantation. In addition, by utilizing a procedure whereby values of mean grain deviation are obtained with respect to the trees axis (NICHOLLS, 1963), it was hoped to overcome the limitations of the previous work and to demonstrate any inter-provenance differences for spiral grain. The wood from successive growth rings from the pith was examined to determine the following: (a) ring width, (b) per cent. late wood, (c) average tracheid length, (d) basic density, (e) longitudinal shrinkage, (f) incidence of compression wood and (g) incidence of spiral grain.

SPURR and HSIUNG (1954), ZOBEL et al. (1960), and DINWOODIE (1961) have concluded in recent reviews, that though a considerable number of investigations have been conducted to examine the effect of site factors on wood characters, the published results are contradictory and confusing. GÖHRE (1958) has suggested that much of the contradiction is due to differences in sampling techniques and to the interpretation of results. In addition, FIELDING and BROWN (1960) have drawn attention to the fact that very few investigations dealing with the effect of site factors on wood characters have been carried out where the trees in the stands for comparison originate from a common seed source. Therefore, values for wood characters obtained from the Somerville trees were compared with those from the Gnangara trees to provide indications of between-site differences which would be attributable mainly to edaphic factors.

Material

Although each provenance was planted in a separate compartment at Somerville, the four compartments were adjacent, and the material for examination was taken from the corners of the compartments which were contiguous and separated from one another by narrow breaks. The overall area sampled was reasonably uniform. The selection of trees and the collection of specimens were carried out by officers of the Western Australian Forests Department.

For the Gnangara study, the systematic variation of wood characters within the stem was taken into account in determining the sampling position in the tree and each specimen was taken at such a height as to show 26 annual rings (NICHOLLS et al., 1963). The Somerville trees were also sampled according to this procedure but as specimens were collected 20 months later than those from Gnangara the Somerville specimens should show 27 rings if a precise comparison of results from the two sites is required.

The trees for examination were felled, and, in each case after marking the direction of the tree axis, a 6 cm thick disk was removed from midway along the appropriate internode. Immediately following collection, specimens were wrapped in polythene, forwarded to the Melbourne laboratory, and stored in a refrigerator until required for examination.

It was found after examination that 75 per cent. of the specimens had a ring count of 26, in one instance a count of 25 was registered, and the remainder showed 27 growth rings. It was not possible to resample the trees, so that these age differences should be taken into account when assessing the results. Tree data and sampling heights are set out in Table 1.

Experimental Procedure

From each disk, a diametrical strip, ¾ cm. wide, and containing the pith, was sawn to include the mark showing the direction of the tree axis. Each strip was divided into two end-matched pieces, to provide specimens along a diameter for the determination of angles of grain deviation, and material from the shorter of the two radii for the determination of ring width, per cent. late wood, longitudinal shrinkage, basic density and average tracheid length.

The detailed subdivision of the above-mentioned strips and the procedure for their examination was similar to that outlined by NICHOLLS et al. (1963), but varied in that wood characters were determined for every growth ring, and angles of grain deviation for each ring were taken as the mean of values from two opposite radii. Furthermore, these angles were referred to a planed transverse surface

Table 1. — Details of *Pinus pinaster* trees supplying specimens for the analysis of wood characters. — All trees were planted in 1931 and originated in Somerville, Western Australia. Sampling height was chosen to show a ring count of 26 years.

Provenance	Tree No.	Class	Tree Height m.	G. B. H. O. B. cm.	Sampling Height m.
Landes	L 1	Dom.	18.8	94.6	2.82
	L 2	Dom.	18.0	80.0	2.28
	L 3	Co-Dom.	16.5	85.6	2.45
	L 4	Dom.	17.7	86.4	3.82
	L 5	Dom.	17.9	88.8	3.82
	L 6	Dom.	17.6	76.1	2.90
	L 7	Co-Dom.	16.0	80.5	1.98
	L 8	Co-Dom.	17.0	89.5	3.05
	L 9	Dom.	18.0	77.4	3.77
	L 10	Dom.	17.4	77.4	3.66
Leiria	P 1	Co-Dom.	22.0	92.6	4.12
	P 2	Co-Dom.	22.7	88.9	6.10
	P 3	Co-Dom.	22.0	85.6	3.25
	P 4		22.6	92.0	4.27
	P 5	Dom.	24.3	96.5	5.50
	P 6	Co-Dom.	22.9	97.7	4.73
	P 7	Co-Dom.	22.9	86.3	4.32
	P 8	Dom.	24.5	94.0	4.27
	P 9	Co-Dom.	23.2	85.6	4.27
	P 10	Dom.	24.1	104.1	3.97
Esterel	M 20	Dom.	18.0	91.5	3.50
	M 21	Dom.	17.7	86.4	2.28
	M 22	Co-Dom.	16.5	88.2	2.45
	M 23	Co-Dom.	15.9	71.7	2.52
	M 24	Dom.	18.0	82.5	1.98
	M 25	Co-Dom.	16.8	67.9	2.59
	M 26	Dom.	20.2	101.8	2.59
	M 27	Dom.	17.9	86.4	2.82
	M 28	Dom.	18.4	85.0	2.82
	M 29	Dom.	19.0	83.8	2.59
Corsican	C 1	Co-Dom.	14.4	83.8	2.14
	C 2	Dom.	15.7	81.3	1.98
	C 3	Dom.	14.1	85.1	1.60
	C 4	Dom.	16.0	100.0	2.07
	C 5	Co-Dom.	14.4	97.8	1.93
	C 6	Co-Dom.	15.7	82.5	1.98
	C 7	Co-Dom.	14.5	78.1	3.25
	C 8	Co-Dom.	13.8	76.2	1.98
	C 9	Co-Dom.	13.5	96.5	2.28
	C 10	Co-Dom.	14.2	80.0	1.91

on each diametrical strip, this surface having been aligned from the marks showing the direction of the tree axis.

Results and Discussion

Detailed results were obtained for each tree for the selected wood characters, but because of the unavoidable differences in ring count in a proportion of the specimens, an arbitrary division was made between core and mature wood, and growth rings were numbered from the pith for the first 14, and from the bark for the last-formed 12. By this device, the effect of age in rings close to the pith, and of short term changes in climatic conditions in later formed rings was more clearly expressed when values for wood characters were grouped to form provenance means.

However, since each provenance was differentially affected by the number of trees involved in sampling discrepancies, the effect of small changes in sampling position on wood characters should be kept in mind. There is, generally, an increase in tracheid length from ground level to some definite height in the tree, follwed by a decrease thereafter (Dinwoodie, 1963). Basic density decreases with increasing height in tree (Spurr and Hsiung, 1954); and, throughout the lower parts of the stem, there is little variation in grain inclination with change in height (Nicholls, 1963). There is thus good reason to expect some influence on two of these features but whether as a result of height or internode change is open to question. Dinwoodie (1963) reported that there are indications that tracheid length is a function of internode number rather than distance from the top or bottom of the tree, and he preferred to sample on a internode rather than a height basis. The data of Nicholls and Fielding (1965) also support that view.

The present study was based on internodal sampling and therefore the change in basic density and average tracheid length per internode change in height was obtained for typical material. Calculations were carried out using values derived from the examination of successive internodes from the butt logs of two trees of the Esterel provenance, and additionally, data previously obtained from two sets of specimens sampled at different internodes in five Leiria and six Esterel trees from Gnangara (Nicholls *et al.*, 1963). The results of these analyses are set out in *Table 2.* These values can be used to adjust tracheid length and basic density results from individual trees so that data can be compared on the basis of a common sampling position.

Table 2. — Mean change in average tracheid length and basic density per internode change in height within the tree.

Provenance	Average tracheid length (mm.)		Basic density (g/cc.)	
	Core wood	Mature wood	Core wood	Mature wood
Esterel 1	.18	.16	.012	.008
Esterel 2	.22	.14	—.002	.000
Esterel (6 trees)	.21	n. c.[1])	.005	n. c.[1])
Leiria (5 trees)	.34	.19	—.007	.011

[1]) n. c. — not calculated.

(i) Comparison of provenances: —

The means for each provenance, for ring width, percentage late wood, average tracheid length, basic density and grain deviation have been plotted against growth ring number and are shown in *Fig. 1.* Some appreciation of the extent of differences between provenances can be obtained from this presentation, but in addition, the results for ring width, late wood percentage, tracheid length, and basic density were subjected to analyses of variance. The conclusions from these analyses are summarised below.

Ring Width — On the average, there was no significant difference in growth rate between provenances, but the interaction of provenances with age was highly significant. For the core wood, the Corsican provenance generally had significantly greater ring widths than the other provenances, which were similar except for rings 2 and 3, where the Leiria trees had significantly greater widths than all others. For rings 1—6 from the bark, the Landes trees had significantly smaller ring widths than those of the other provenances.

Percentage Late Wood — In the core wood, there were significant differences in percentage late wood between means for the provenances, but these effects were not consistent for all rings. For rings 1—6 from the pith, the four provenances had similar percentages, but for rings 7—13, the Landes and Corsican trees had significantly lower percentages of late wood than those of the Leiria or Esterel provenances. For the mature wood, the Corsican provenance had, generally, significantly lower late wood percentages than the other provenances, which did not differ significantly from each other.

Average Tracheid Length — The mean tracheid length for the Corsican trees was highly significantly lower than

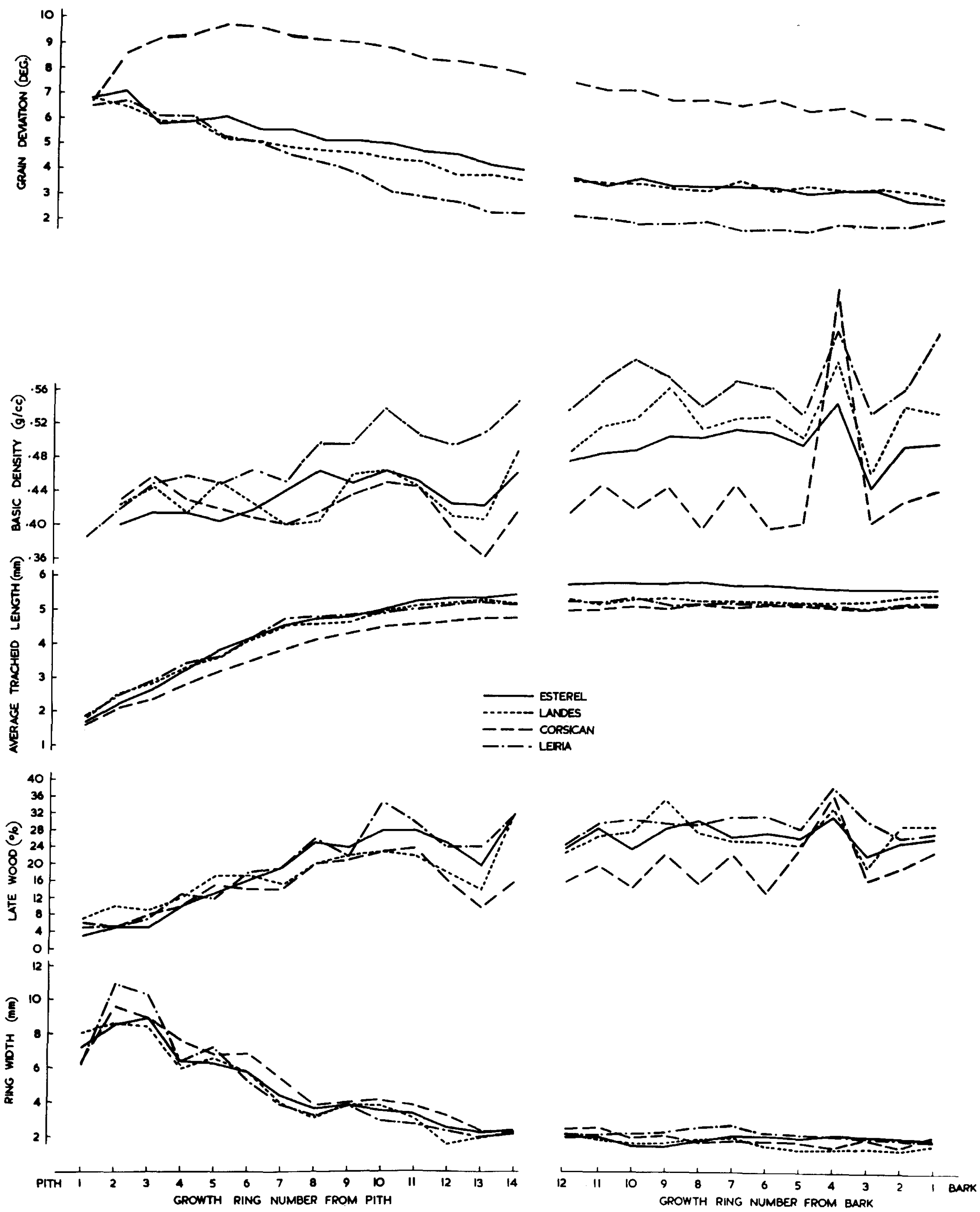

Figure 1. — The mean variation through successive growth rings of five wood characters for 10 trees from each of four provenances of *Pinus pinaster*, viz. Corsican, Esterel, Landes, and Leiria. Specimens showed a nominal 26 growth rings and these have been numbered from the pith for the first 14, and from the bark for the remaining 12.

all other means for all growth rings in the core wood zone. The other provenances were similar for rings 1—9 from the pith, but for rings 10—14, the Esterel trees had longer tracheids than those of Leiria and Landes. For the mature wood, throughout all rings, the mean for the Esterel provenance was significantly higher (1% level) than those for the other provenances, which did not differ significantly from each other.

Basic Density — The mean basic density for the Leiria provenance was significantly higher than the means for the other provenances for all rings. For the mature wood, there was no significant difference between the means for the Esterel and Landes trees, but both were significantly greater than the Corsican mean.

Grain Deviation — For the mean grain deviations from the tree axis shown in *Fig. 1,* the inferiority of the Corsican provenance throughout all growth rings, and the superiority of the Leiria trees for all rings, other than 1—6 from the pith, were clearly discernable, and did not require statistical confirmation.

Longitudinal Shrinkage — Means for longitudinal shrinkage have not been illustrated. On the basis of past experience (see for example, NICHOLLS *et al.*, 1963), there is little point in examining growth rings outside the immediate central core. In the present study, values in excess of 0.2 per cent. were not found beyond the second growth ring from the pith, except in rings which contained compression wood. The results did not show any practical differences between provenances for this character.

The incidence of compression wood was not taken into account in forming the above-mentioned means. Compression wood was deliberately avoided in selecting material for examination, and though a small residual was encountered in the specimens in spite of these precautions, it was randomly distributed, and affected only 3 per cent. of the total results.

From previous work, it was concluded (DADSWELL and NICHOLLS, 1959; NICHOLLS and DADSWELL, 1965) that average tracheid length, basic density and spiral grain are characters which provide much of the information required to evaluate wood quality. Thus, the present results may be used to discuss the wood qualities of the provenances relative to one another. On this basis, the Corsican trees would not be expected to yield wood of high quality, as they exhibited the greatest angles of grain deviation, the shortest tracheids, and the lowest density. The Leiria trees on the other hand, had the highest density, desirable low angles of grain deviation and medium tracheid lengths. However, if the factor of tracheid length was the most critical in appraising wood quality, the Esterel trees would be given the highest rating.

Generally, the differences between provenances indicated by the Somerville results, were similar to those revealed by the examination of the Gnangara material. In both cases, the Esterel trees showed greater tracheid lengths in the mature wood region, and the Corsican trees had the shortest tracheids, the lightest wood and the least late wood percentage. Adjusting tracheid length and basic density values as though all specimens had been taken from internodal positions corersponding to a ring count of 26, resulted in small changes in the position of the mean but not of sufficient magnitude to alter the conclusions arising from the between-provenance analyses.

(ii) Effect of site: —

A comparison of the means for the wood characters of the Gnangara and Somerville trees should indicate the effect of site differences, and as previously discussed, these differences should be associated with factors of the soil. Analyses of variance were carried out to test the significance of the differences between sites for means of ring width, percentage late wood, average tracheid length and density. The conclusions from these analyses are summarised below.

Ring Width — For the core wood, there was a highly significant difference in ring width between sites and also a highly significant interaction of site with provenance. Generally, the site effect was not significant for the Landes trees, but highly significant for the other provenances, the Gnangara trees having wider rings than those from Somerville. For the mature wood, the site effect was significant at the 5 per cent. level, Gnangara trees having wider rings than Somerville trees. For both the core and the mature wood, within provenances, the site effect varied significantly with year of growth.

Percentage Late Wood — For the core wood, there was generally no significant difference in percentage late wood between site means, but the interaction of site with provenance was significant at the 5 per cent. level. This site effect was highly significant for the Landes provenance, where the mean for the Gnangara trees was greater than that for the Somerville material, but not significant for the other provenances. For the mature wood, on the other hand, the mean difference between sites was highly significant and consistent for the four provenances, percentage late wood, being higher in trees from Gnangara, than in those from Somerville. For both the core and mature wood, within provenances, the site effect varied significantly from ring to ring.

Average Tracheid Length — For the core wood, the site effect on tracheid length was highly significant and consistent for all provenances, the means for the Somerville trees being higher than those for the Gnangara stock. However, the differences between site means varied with ring number from the pith. For the Leiria trees, these differences were fairly constant, but for the other provenances, they generally increased with increasing ring number from the pith. For the mature wood, there were insufficient data from the Gnangara trees of the Landes provenance to allow an adequate site comparison. For the other three provenances however, the site effect was highly significant, Somerville trees having longer tracheids than those from Gnangara, this effect being consistent for all rings.

Basic Density — For the core wood, the effect of site on basic density was highly significant, the mean for the Gnangara material being higher than that for the Somerville trees. This effect was consistent for all provenances, but the effect of site within provenances varied significantly from ring to ring. Differences between site means tended to be small at rings close to the pith. For the mature wood, on the average, there was no significant difference between site means but the effect of site varied significantly with provenance and year of growth.

From this analysis there is evidence, that in the core wood, there was a significant interaction of site with provenance for ring width and percentage late wood, but in all other cases, both in the core and the mature wood, any site effect was consistent for all provenances. This interaction may be due to the use of fertilizers at Gnangara. At that plantation, fertilizer was applied five times during the period of juvenile development, compared with a single application in later years (NICHOLLS *et al.*, 1963). ZOBEL *et al.* (1961) have discussd the possibility, that within a species, certain varieties, or individual trees, may exhibit a differential response to fertilizer treatment with respect to volume growth or wood quality. Thus, during the early life of the trees, though conditions were more favourable for growth at Gnangara than at Somerville, judged by the means for ring width, the differences between the two sites for this feature were greatest for the Esterel and not significant for the Landes trees. On the other hand, during the same period, the only significant difference between sites for late wood percentage, was for the Landes provenance, which showed higher percentages at Gnangara than at Somerville.

The highly significant site effect which is evident for percentage late wood in the mature wood reflects the differences in water availability between the two sites. In this respect LARSON (1957) postulated that, within a climatic province, the better site judged by moisture-holding capacity should produce the lower percentage of late wood. The lower late wood percentages of the Somerville trees are therefore not unexpected, since the Somerville soil is representative of the Karrakatta association of the Spearwood Dunes system, has a higher fraction of fine particles, and hence a better moisture-holding capacity than the Gnangara soil of the Bassendean association (McArthur and Bettenay, 1960; Bettenay *et al.*, 1960; and Perry, 1965). However, Perry (1965) points out that this is an over-simplification, and the important point is the amount of moisture in the soil profile which is available at the depth of the mature *P. pinaster* root system. The Karrakatta series rests on limestone at depths varying from a few feet to sixty feet and at Somerville the limestone is above the water table. The only moisture available to the trees in summer is that which is held in the soil profile above the limestone and *P. pinaster* dies out on the shallower phases of this series. In other words, mature trees are generally under fairly severe moisture stress by the end of summer even on the deeper phases of this series. On the other hand, at Gnangara, the coarse, grey sand of the Bassendean series meets the water table at about ten to twelve feet and so moisture is readily available to the trees throughout summer.

Fig. 1 shows, at the fourth growth ring from the bark of the Somerville trees, an abrupt rise and fall in percentage late wood and basic density. This ring was formed in the 1959/60 season and therefore the atypical behaviour of the wood characters may be attributable to climatic abnormalities during these years. Meteorological data for the Perth area covering the period 1957—1962 (see *Table 3)* reveal that the outstanding irregularities for the particular season were an above average rainfall for January and March 1960, together with below average mean maximum temperature for these months, and in the case of March only,

Table 3. — Meteorological data for the Perth area for the years 1957 to 1962.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall (mm.)												
1962	1.78	8.4	0.8	8.6	151.3	151.9	153.9	86.3	62.5	52.8	38.4	13.5
1961	10.4	8.1	41.6	98.0	60.0	163.1	189.6	151.0	47.7	24.4	4.1	21.1
1960	26 9	5.6	57.6	18.3	135.2	112.9	187.5	64.5	64.8	26.9	7.6	8.6
1959	5.8	8.6	5.3	36.0	42.1	194.5	77.7	117.0	30.5	53.3	35.8	13.2
1958	5.6	1.0	0.8	23.6	98.1	70.0	425.0	57.2	44.2	65.0	11.7	12.5
1957	18.3	1.3	7.1	67.2	111.0	298.0	116.9	145.9	28.7	47.5	1.5	5.3
Mean Maximum Temperature (⁰ C.)												
1962	34.5	31.3	27.1	26.6	22.3	19.2	17.8	18.2	20.0	20.4	24.6	29.1
1961	32.4	31.3	29.0	22.0	22.1	19.1	17.7	18.0	21.4	22.5	27.1	28.7
1960	27.1	29.3	25.6	22.5	19.8	17.8	16.0	17.6	19.2	22.5	25.8	29.0
1959	29 0	31.0	29.2	23.5	22.0	19.3	19.3	20.0	20.2	22.0	24.8	26.7
1958	31.6	30.2	29.0	24.6	21.5	18.1	17.0	17.8	19.1	20.3	27.0	25.5
1957	30.2	30.1	28.1	23.5	22.0	18.1	16.1	18.1	19.8	22.2	26.5	28.1
Monthly average for Rainfall and Mean Maximum Temperature												
Rainfall (mm.)	7.9	11.4	20.3	45.9	128.5	185.8	172.4	143.7	82.5	55.4	21.3	14.9
Mean max. temp. (⁰C.)	29.1	29.3	27.2	24.8	20.1	18.1	17.3	17.9	19.1	21.0	24.6	27.1

	Hours of Sunshine		
	Jan.	Feb.	March
1962	321.3	290.6	286.7
1961	293.9	273.9	280.3
1960	319.4	288.3	243.2
1959	312.2	272.5	261.3
1958	308.9	301.4	301.2
1957	340.9	314.6	279.6

a decrease in the number of hours of sunshine. During these months the trees would normally be forming late wood, so that the increased precipitation, lower temperatures, and greater cloudiness should favour increased radial growth which would be manifest as an increase in percentage late wood, and hence an increase in wood density. This explanation is supported by the findings of Paul and Marts (1954) who observed the effect of irrigating longleaf pine growing on deep, sandy soils, and noted that the period when late wood was being formed could be extended when sufficient soil moisture was available. It is also in agreement with the generalization put forward by Larson (1957) for slash pine, that a high mid-season rainfall promotes late wood development.

In connection with the variation in the percentage late wood and basic density values during the 1959/60 season, it is to be noted that the influence of climatic factors in relation to the above-mentioned abrupt changes was not equal for all provenances at Somerville, and was not evident at Gnangara. At each site the Corsican trees had generally the lowest values for these features, and preliminary studies, carried out by the Forests Department, Western Australia, on the influence of prevailing weather conditions on wood production have some bearing on the present discussion. These early studies indicate that the potential for radial growth in autumn and early winter is not present in the Corsican provenance (Forests Dept., Western Australia, 1965). However in the 1959/60 season the Corsican trees (from Somerville) showed the greatest increases in percentage late wood and basic density. It would appear from that evidence, that at the Somerville site, the full potential of the Corsican trees with respect to density, is not being realized because of limiting moisture conditions. This effect may be present to a lesser degree in the other provenances grown at Somerville, but it is not apparent at all in the trees from Gnangara. For the latter site however, the influence of rainfall during the summer months is not expected to be as great as that at Somerville for reasons already discussed with respect to soil-moisture relationships.

Although the means for the basic density of the mature wood from the two plantations were not significantly different, these averages were strongly influenced by the atypical results for the 1959/60 season. In such a case, the between-site differences are more accurately portrayed by comparing values of basic density for each growth ring under review, rather than by comparing averages which have been unduly weighted by a particular value. The Gnangara trees were then found to have, in general, greater basic density values than those from Somerville, consistent with the observed differences in percentage late wood referred to above.

The analysis also showed that the Somerville trees had longer tracheids than those from Gnangara. Growth rate is known to affect tracheid length (see, for example, Spurr and Hyvärinen, 1954), and from a review of other work and a study using *Picea* material, Dinwoodie (1961, 1963) is of the opinion that for the comparison of two trees of different growth rates, the tree with the more rapid height growth will have the longer tracheids. The height growth at Somerville was some 13 per cent. greater than that at Gnangara (see *Table 1* and Nicholls *et al.*, 1963) so that the longer tracheids in the Somerville trees are not unexpected. However, it should be noted that the Gnangara trees received applications of fertilizer in 1933, 1934, 1936, 1939, 1942 and 1958 (Nicholls *et al.*, 1963) whereas fertilizer was not used at Somerville, and BISSET *et al.* (1951) for *P. pinaster,* and POSEY (1964) for *P. taeda,* have demonstrated a shortening of tracheid lengths following fertilizer treatment. It is not unreasonable therefore to suggest that the differences in tracheid lengths in the present case could also be attributed to differential fertilizer treatment. If the relationship recorded in *Table 2* is used to adjust the Somerville tracheid length values to those appropriate to specimens taken from the internode corresponding to a ring count of 27, a between-site difference for tracheid length still remains.

Conclusions

The results of the present investigation have confirmed the general findings of the previous study with respect to differences in wood characteristics between the four provenances. The observations also support the contention that trees of the Corsican provenance are inferior in wood quality to those of the other provenances, and that the Leiria provenance offers the best potential for the improvement of wood characters in *Pinus pinaster* grown in Western Australia.

Marked between-provenance differences in grain deviation were found, and since this feature is known to be inherited, these differences should be recognized in future selection programmes if the aim is to improve stability and strength of material to be used as sawn timber. On the other hand, longitudinal shrinkage has been found to be unimportant and could be disregarded as a selection factor.

A further point for consideration in the choice of a provenance of *P. pinaster* for future afforestation in the areas covered by these investigations refers to moisture stress in relation to wood characters. It would appear that for a given set of conditions, certain provenances are better adapted than others and thus enable the full potentialities for these characters to be realized.

Part 2. — Leiria Material from Gnangara and Somerville

Introduction

In Part 1 of the present study, differences were observed in the means percentage late wood and average tracheid length following the comparison of data from the examination of trees from two plantations and originating from one seed source. Differences in percentage late wood were ascribed to dissimilarities in moisture-holding capacities between the two sites and differences in tracheid length were associated with differential rate of height growth and/or fertilizer treatment. Further specimens from the Gnangara and Somerville plantations were examined to study the effect of site factors on percentage late wood and average tracheid length.

Material

At Gnangara, trees of the Leiria provenance were planted over a large area in 1941 from a single seed batch obtained from Portugal. Silvicultural treatment of the area was uniform, and the stands were given applications of super phosphate in 1941, 1943 and 1960. Site quality differences in the area are primarily due to variations in water availability, resulting from differences in the depth of the natural water table, or in the position of a deposition horizon of iron-organic, friable coffee rock, which is permeable to roots, but offers a retention zone for water and nutrients (Forest Dept., Western Australia, 1965). These site quality differences cover a range in tree growth from an average height of 13.8 m. to one of 18.4 m. The same seed source was also used to establish plantings at Somerville in 1941 but fertilizer was not used at that plantation. Thinning was carried out at both plantations in 1958.

Table 4. — Details of *P. pinaster* trees of Leiria provenance planted in 1941.

Location	Tree No.	Class	Tree Ht. m.	D. B. H. o. b. cm.	Sampling height m.
Somerville	D 1	Pre-dom.	18.2	25.2	1.83
	D 2	Dom.	18.0	25.0	1.83
	D 3	Dom.	17.1	24.2	0.92
	D 4	Pre-dom.	18.5	25.8	1.83
	D 5	Dom.	17.5	20.9	0.75
	D 6	Dom.	18.0	21.8	0.82
	D 7	Pre-dom.	18.0	24.1	1.83
	D 8	Dom.	18.5	22.6	1.83
	D 9	Dom.	17.3	25.6	1.83
	D 10	Pre-dom.	19.0	25.8	1.07
Gnangara High quality site	A 1	Dom.	18.4	27.0	0.69
	A 2	Pre-dom.	19.0	26.8	0.85
	A 3	Dom.	17.9	23.7	0.72
	A 4	Pre-dom	18.6	27.0	0.97
	A 5	Pre-dom.	19.4	27.5	0.69
	A 6	Pre-dom.	19 6	29.8	1.37
	A 7	Pre-dom	19.7	28.8	1.05
	A 8	Pre-dom.	19.1	27.8	0.75
	A 9	Dom.	18.4	23.4	0.89
	A 10	Pre-dom	19.6	29 8	0.89
Gnangara Intermediate quality site	B 1	Pre-dom.	12.2	16.0	0.95
	B 2	Dom.	11.9	15.0	0.59
	B 3	Pre-dom.	12.5	17.6	0.95
	B 4	Pre-dom.	12.9	15.0	0.69
	B 6	Pre-dom.	13.8	19.1	0.85
	B 7	Dom.	13.4	19.6	1.22
	B 10	Dom.	13.3	16.6	0.92
	B 11	Pre-dom.	13.7	19.1	0.77
	B 12	Dom.	12.9	17.4	1.17
	B 13	Dom.	11.6	15.5	1.15

Ten dominant, or pre-dominant trees of good form were randomly chosen from each of three sites, viz. from Somerville, and from a high and an intermediate quality site at Gnangara. All trees were sampled by removing wedge-shaped pieces along a north-south diameter, and at such heights as to show 21 complete growth rings in each specimen. All sampling was completed within a period of one week. Tree data and sampling heights are set out in *Table 4.*

Experimental Procedure

As before, material from the shorter of the two radii in each specimen was used to determine ring width, percentage late wood and average tracheid length, using the procedures described by NICHOLLS *et al.* (1963). Ring width and percentage late wood were determined for each growth ring of each specimen and average tracheid lengths were ascertained for the late wood of growth rings 2, 3, 5, 7, 9, 11 13, 20 and 21 in each case.

Results and Discussion

Detailed results for the selected wood characters were obtained for each tree, and these were averaged for each site according to growth ring number. The mean variations from pith to bark for these results are set out in *Fig. 2.*

From *Table 4,* it is clear that with respect to height growth, the Somerville trees are comparable with those from the high quality site at Gnangara, and that both are superior to the trees from the intermediate site. The same relationship holds for ring width (see *Fig. 2)* except for the growth rings immediately adjacent to the bark. These last-formed rings show the effect of the 1960 fertilizer treatment

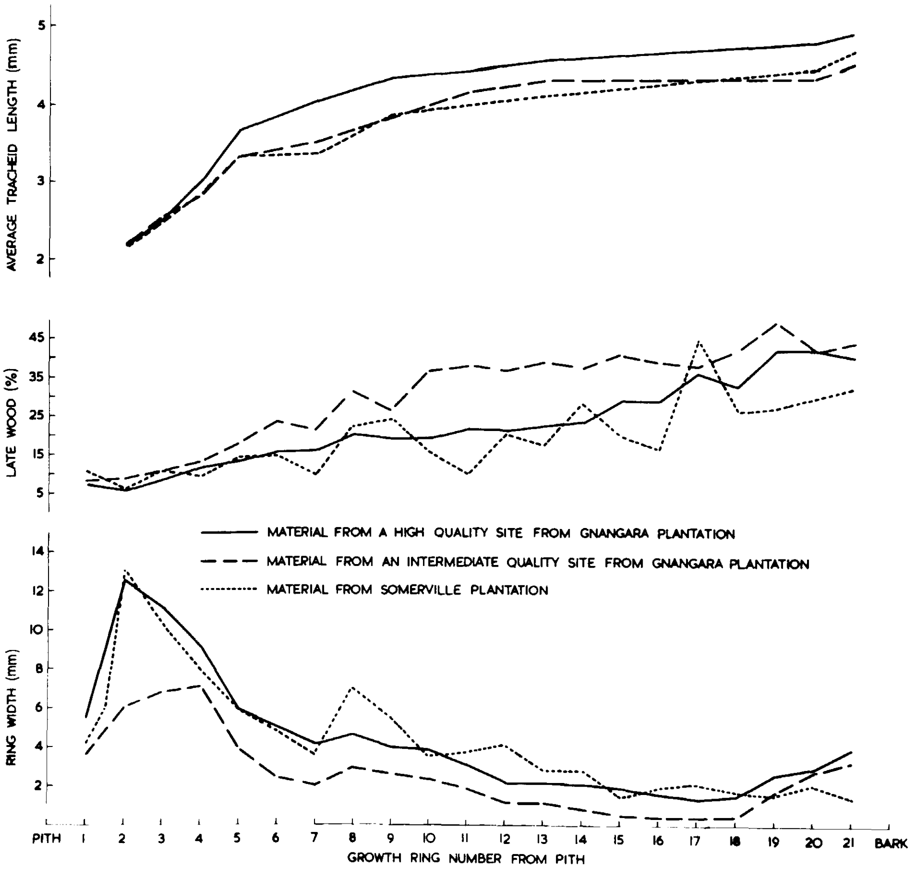

Figure 2. — The mean variation from pith to bark for ring width, percentage late wood, and average tracheid length, for 10 trees of the Leiria source of *Pinus pinaster* from each of three sites.

on the Gnangara trees, especially those from the intermediate quality site.

It can be seen from *Fig. 2* that beyond the first six rings from the pith, the effect of site on percentage late wood is readily discernable, the Somerville trees having the least, those from the high quality Gnangara site a larger percentage, and those from the intermediate site at Gnangara the greatest percentage of late wood. It was noted in Part 1 that the mature trees at Somerville are generally under severe moisture stress by the end of summer, so that the low percentages of late wood from that plantation are associated with slow rates of growth during the time of late wood formation. On the other hand, the Gnangara trees are not subjected to moisture stress, and site differentiation is governed by the depth of the moisture retentive deposition horizon. The shallower position of this layer at the high quality site results in proportionally more early wood formation (Larson, 1957), and hence a lower proportion of late wood in the trees from that site compared with those from the intermediate quality site.

Also from *Fig. 2*, it may be seen that the late wood percentage of the growth ring formed in the 1959/60 season exhibited a sharp increase for the Somerville trees, although this was not apparent in the wood originating from the Gnangara sites. This is consistent with the observations reported in Part 1 for the 1931 plantings.

From *Fig. 2* it is apparent that tracheid lengths are greatest in the specimens from the high quality site at Gnangara and generally similar in the material from the other two sites. Both the high and intermediate quality sites at Gnangara received the same fertilizer treatment, so that for these sites it is reasonable to associate the longest tracheids with the trees exhibiting the fastest height growth as in Part 1.

The Somerville trees however produce shorter tracheids than those from the high quality Gnangara site although both groups of trees exhibit similar rates of height growth. This shortening may be associated with fluctuations in diameter growth rate. Bisset *et al.* (1951) have demonstrated the reduction in tracheid length accompanying sudden increases in growth rate. In this respect, it can be noted that a macroscopic examination of the specimens showed that multiple rings were non-existent in the material from the high quality site at Gnangara, almost non-existent in that from the intermediate site, and markedly prevalent in the material from Somerville. This variation in ring texture may be explained in terms of soil moisture availability during summer and autumn. The Somerville trees do not have access to a deep water table, and growth can virtually cease when the trees are subjected to severe moisture stress during these seasons. Resumption of growth is associated with summer and autumn rains. Site quality differentiation at Gnangara is related to water availability so that interrupted growth can be expected at the poorer quality site, but to far lesser degree than at Somerville. Therefore, it might be expected that the trees from Somerville, and to a lesser extent those from the intermediate quality Gnangara site would have shorter tracheids as a result of this interrupted growth. Even though the fluctuations in growth rate are apparent as a change in the texture of the middle or transition zone of the annual rings, the effect on tracheid length cannot necessarily be related only to these portions of the ring. NICHOLLS and DADSWELL (1962) investigated the change in tracheid length across a growth ring in which a false ring was present and found that tracheid shortening took place before the formation of the false ring. B SSET *et al.* (1951) have also observed that there is not necessarily exact temporal registration between growth increase and shortening of the tracheids. Tracheid lengths were determined in specimens from the last-formed late wood, but the Somerville trees were found to have shorter tracheids than those from the high quality Gnangara site even when tracheid length comparisons were carried out using material from the early wood of typical rings. It should be emphasised also that although the Somerville sites generally are of high natural fertility, the 1941 planting was on a shallower soil phase than was the 1931 planting, and although the 1941 trees exhibited numerous multiple rings, such formation was not observed in the wood from the 1931 trees. It is not unreasonable therefore to associate the relatively poor tracheid lengths of the 1941 Somerville trees with these atypical conditions of fluctuating growth.

Conclusions

Aspects of the present study have served to exemplify the complex nature of environmental influence on wood characters, particularly in relation to those factors which are associated with moisture availability to the mature tree. Wood quality can be improved by the choice of parents with desirable wood characters, but expected gains may not be realised if proper attention is not also given to growing conditions and the maintenance of even rates of growth. It is evident, that the use of fertilizer treatment at deficient sites which would otherwise not support pine plantations, can enable them to produce trees which may be reasonably comparable in wood volume and quality to those grown on naturally fertile sites.

Acknowledgements

The author wishes to thank the Conservator of Forests, Forests Department, Western Australia, for the wood specimens used in this investigation, and particularly Dr. E. R. HOPKINS for supervising their collection. Grateful thanks are also expressed for the meteorological data used to prepare *Table 2*.

Appreciation is also recorded of the assistance of Misses G. DOUGLAS and J. SIBTHORPE in the carrying out of the detailed measurements on which the results of the investigation have been based, and of the assistance of Miss N. DITCHBURNE, Division of Mathematical Statistics, C. S. I. R. O., in the statistical analyses and for helpful discussions relating to them.

Summary

The wood characters of material from ten trees from each of four provenances of *Pinus pinaster*, viz., Corsican, Esterel, Landes and Leiria have been examined. These trees formed part of a provenance trial at Somerville plantation. Analysis of the results has provided an indication of the extent of variation between these four provenances.

In the core wood, trees from the Corsican source had significantly shorter tracheids than those of the other sources, and in the mature wood zone, trees of the Esterel provenance had markedly longer tracheids than those of the other three. The basic density values for the Leiria trees were generally greater than those for the other sources, and wood from the Corsican trees was generally less dense than that from trees of the other sources. There were marked differences between angles of grain deviation among the four provenances, with the Corsican trees showing the greatest, and the Leiria trees the least angles of deviation.

Results have been compared with data previously collected from an examination of specimens from the Gnangara plantation. The Gnangara trees had shorter tracheids and greater density values than the Somerville trees for the core wood, and in the mature wood zone the Gnangara stock had a higher percentage late wood and shorter tracheids than material from Somerville. The differences in percentage late wood have been related to differences in moisture-holding capacity of the soils between the two sites, and tracheid length differences have been associated with factors causing differential height growth between the two plantations.

Soil-moisture relationships with wood characteristics were further investigated by the examination of additional specimens of the Leiria provenance from these plantations.

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