WOOD DENSITY OF PINUS CARIBAEA VAR. HONDURENSIS GROWN IN FIJI

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ABSTRACT

During 1980, increment core samples were collected from **Pinus caribaea** var. **hondurensis** Barr. & Golf. (Caribbean pine) on 38 sites throughout the afforested areas of the two main islands of Fiji. In addition, 110 trees were felled and sectioned to give information on the relationship between increment core wood density and density of the merchantable stem to 100 mm diameter. Good correlations between increment core and whole-tree values were established.

Consistent patterns of wood density increase with tree age and decrease with height in the stem were recorded. Together, tree age and site altitude were shown to account for 85% of the variation observed in plantations ranging in age from 8 to 25 years.

On a 15-year rotation, high altitude (> 300 m) and low altitude (< 300 m) sites can produce timber with average basic densities of 515 and 465 kg/m³. Equivalent values for a 25-year rotation would be 540 and 475 kg/m³ respectively.

INTRODUCTION

Caribbean pine was introduced to Fiji in 1955 and since then has proved the most suitable exotic softwood for the prevailing conditions. By 1980, pine plantations covered 32 000 ha and current plans of the Fiji Pine Commission call for an estate of some 60 000 ha by 1986.

Studies of Caribbean pine in its native habitat around the Caribbean and Central America (Wangaard *et al.* 1955; Longwood 1962; Hughes 1970) indicate that the species exhibits a high degree of variability in wood density within trees, between trees, and between sites. Estimates of average basic density range from 580 to 680 kg/m³ in mature stands.

Caribbean pine has been widely planted as an exotic in the Southern Hemisphere since the 1950s and there is now a substantial body of literature on the wood properties of relatively young crops. It is apparent that such plantations, while capable of producing timber of merchantable size on short rotations, often show significantly different patterns of wood density development. For instance, Harris (1977) compared wood density levels in wood samples from Malaysia, Fiji, Australia, and New Zealand and reported average site outerwood values ranging from 400 kg/m³ (New Zealand) to 900 kg/m³ (Malaysia). Such variation in intrinsic properties can have a profound influence on utilisation and hence on industrial development. Research in South Africa (de Villiers 1974) has shown that the steep radial density gradient in Caribbean pine sometimes results in a portion of the timber outturn falling below the 400 kg/m^3 minimum density permitted for structural members in that country.

In view of Fiji's substantial investment in Caribbean pine it is important to establish the nature of the raw material which will be the basis of a large export-orientated wood industry. A joint research programme was initiated between the Fiji Department of Forestry and the New Zealand Forest Research Institute (FRI) in 1978, financed under the New Zealand Bilateral Aid Programme. During 1980 an extensive survey of wood properties was undertaken by the FRI in an effort to quantify variations in important wood properties. The following report on wood density covers part of that survey.

METHODS

A two-stage sampling approach was adopted, whereby increment core samples were collected from 38 sites in order to describe radial wood density trends. At each of 18 sites, trees were felled to provide data on increment core/whole tree relationships and vertical density patterns.

At the 38 sites (Fig. 1 and Table 1), diametric 5-mm increment cores were removed at breast height from 30 trees selected at random. At each site soil samples

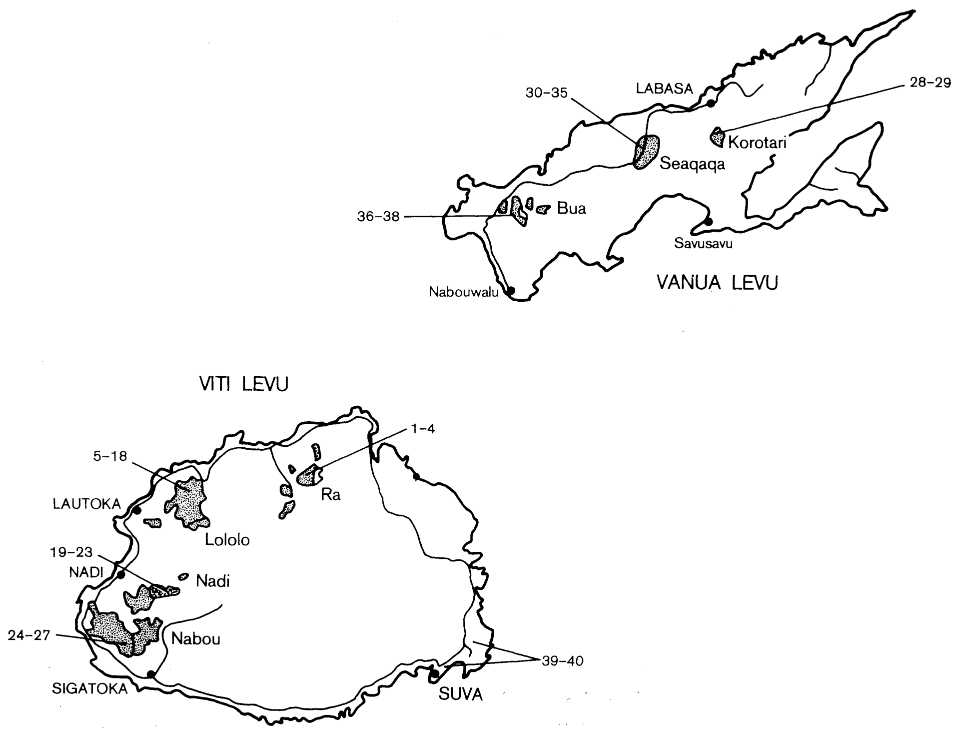

FIG. 1—Location of sample plots

TABLE 1—Location of sample plots

Region	Site No.	Forest	Elevation (m)	Planted
Viti Levu	*1	Ra (Nadarivatu)	760	1955
	*2	Ra (Lewa Valley)	610	1962
	3	Ra (Nadarivatu)	610	1963
	*4	Ra (Koro No. 2)	305	1967
	*5	Lololo (Tavakubu)	200	1957
	*6	Lololo	105	1967
	7	Lololo (spacing trial)	165	1969
	8	Lololo	395	1971
	9	Lololo	135	1971
	10	Lololo	610	1972
	*11	Lololo	305	1972
	12	Lololo	440	1974
	13	Lololo	410	1974
	14	Lololo (Drasa Seed Orchard)	60	1960
	*15	Lololo (Drasa)	70	1962
	16	Lololo (Drasa)	120	1964
	17	Lololo (Drasa)	90	1966
	*18	Lololo (Drasa)	130	1967
	*19	Nadi (Nausori Highlands)	455	1956
	*20	Nadi (Nausori Highlands)	505	1962
	21	Nadi (Nausori Highlands)	640	1964
	*22	Nadi (Nausori Highlands)	535	1967
	23	Nadi (Nausori Highlands	490	1969
	*24	Nabou (Nawaicoba)	75	1967
	*25	Nabou	75	1965
	26	Nabou	105	1974
	27	Nabou	90	1974
Vanua Levu	28	Korotari	60	1971
	29	Korotari	80	1972
	*30	Seaqaqa	100	1962
	*31	Seaqaqa	90	1967
	32	Seaqaqa	110	1967
	*33	Seaqaqa	280	1969
	34	Seaqaqa (spacing trial)	150	1971
	35	Seaqaqa	90	1972
	36	Bua (Lekutu Village)	30	1972
	37	Bua	105	1975
	38	Bua	30	1976
Felling sites only	*39	Colo-i-Suva	280	1961
	*40	Verata	300	1961

* Felling site

were collected for analyses of pH, nitrogen, phosphorus, and moisture-retention capacity. Basic densities were determined on the wood (before and after resin removal) by five-ring growth zones using the maximum moisture-content method (Smith 1954). On the 18 sites where trees were felled, 5 or 10 trees (previously sampled by increment borer) were chosen for more intensive sampling, and wood discs were recovered from the butt, breast height, 5-m, 10-m, 15-m . . . etc. positions, to a top diameter of 100 mm. In all, 110 stems were felled and treated in this manner. In the laboratory basic densities were measured on five-ring wood blocks using conventional methods (water immersion for volume determination, followed by oven-drying).

RESULTS

Within- and Between-tree Density Variation

All stems showed the expected pattern of increasing density from the pith outwards, although in some stems values for the inner rings were anomalously high because of resin deposits. The average breast-height pattern (Fig. 2) showed a gradient from 400 kg/m^3 (resin-free) in the inner rings to around 570 kg/m^3 after 10 rings from the pith. Wood density decreased with height above the ground in stems of all ages at an average rate of 5 kg/m^3/m (Fig. 3). In crops 15–25 years old, basal discs averaged 550 kg/m^3 (unextracted) and 20-m discs about 450 kg/m^3.

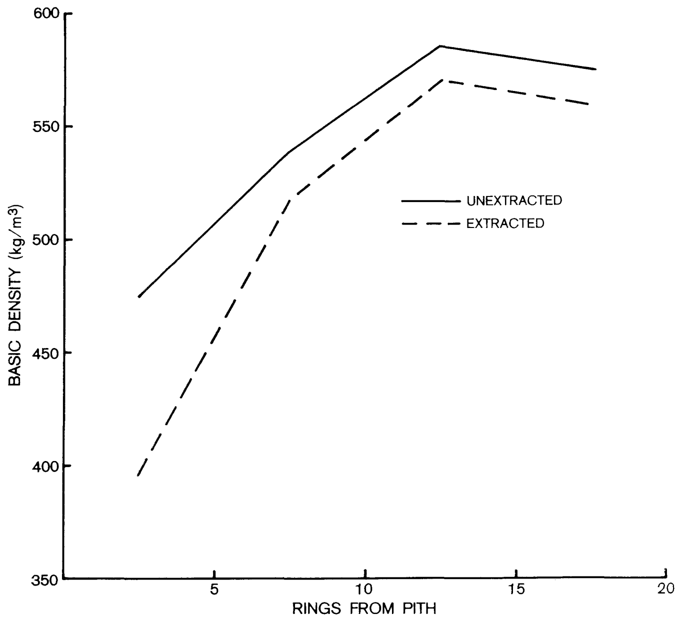

FIG 2—Mean radial density distribution

The data in Table 2 illustrate the extent of variation found in diameter, volume, and basic density of the 110 felled trees. Overall average standard deviation for whole-tree density was 50 kg/m^3, indicating that deviation of $\pm$ 100 kg/m^3 from crop means is relatively common. This is a very significant source of variation, and intensive analyses of growth-rate/density relationships failed to reveal a consistent association.

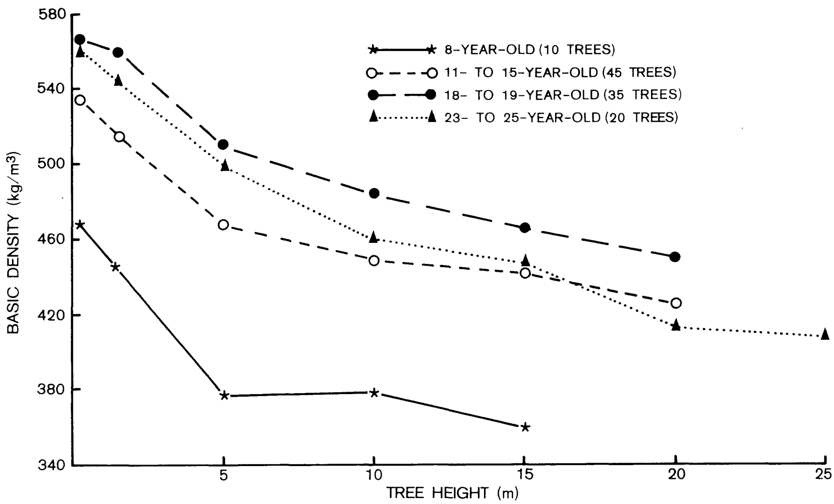

FIG. 3—Vertical distribution of wood density

TABLE 2—Statistics of felled trees

	Site	Planted	No. of trees	D.b.h. (cm)		Volume (m^3)		Whole-tree basic density (kg/m^3)	
				Mean	s.d.	Mean	s.d.	Mean	s.d.
1	Ra	1955	5	46.1	4.0	1.30	0.26	446	52
2	Ra	1962	5	32.8	2.4	0.69	0.05	461	41
4	Ra	1967	5	22.9	2.9	0.20	0.05	518	43
5	Lololo	1957	10	28.3	2.1	0.46	0.12	534	78
6	Lololo	1967	5	31.6	3.4	0.60	0.11	500	27
11	Lololo	1972	10	24.2	3.0	0.29	0.09	404	43
15	Lololo	1962	10	29.9	3.0	0.53	0.14	534	66
18	Lololo	1967	10	24.4	2.9	0.30	0.08	462	44
19	Nadi	1956	5	37.0	6.0	1.02	0.42	494	58
20	Nadi	1962	5	36.6	3.8	0.90	0.26	520	55
22	Nadi	1967	5	28.2	2.2	0.43	0.09	461	18
24	Nabou	1967	5	25.3	1.9	0.27	0.03	497	73
25	Nabou	1965	5	33.0	5.5	0.65	0.24	456	47
30	Seaqaqa	1962	5	31.6	3.2	0.62	0.17	589	60
31	Seaqaqa	1967	5	31.1	3.6	0.59	0.11	480	46
33	Seaqaqa	1969	5	31.7	6.0	0.54	0.25	456	56
39	Colo-i-Suva	1961	5	27.7	3.2	0.39	0.11	483	58
40	Verata	1961	5	26.8	1.7	0.47	0.07	469	34

Relationships Between Increment Core and Whole-tree Densities

Using data from felled trees, a number of regressions relating increment-core-segment densities to whole-tree values were tested. It was concluded that a single regression equation would suffice to predict tree density from the density of the outer five rings at breast height. For sample plot mean data the following relationship was derived:

$$\text{Crop mean density} = 0.74 \times \text{mean density of outer 5 rings (including resin)} + 66 \quad (R^2 = 0.81)$$

Influence of Tree Age and Site on Wood Density

Whole-tree densities were estimated for all 38 sites using the plot mean breast-height-outerwood densities in the regression given above, and the derived values were plotted against tree age (Fig. 4). Age alone accounted for 61% of the overall variation, but it was apparent that altitude also had an effect. A multiple regression analysis using both age and altitude gave the result:

$$\text{Crop mean density} = 606 - \frac{1235}{\text{Age}} - 0.12 \times \text{site altitude} \quad (R^2 = 0.85)$$

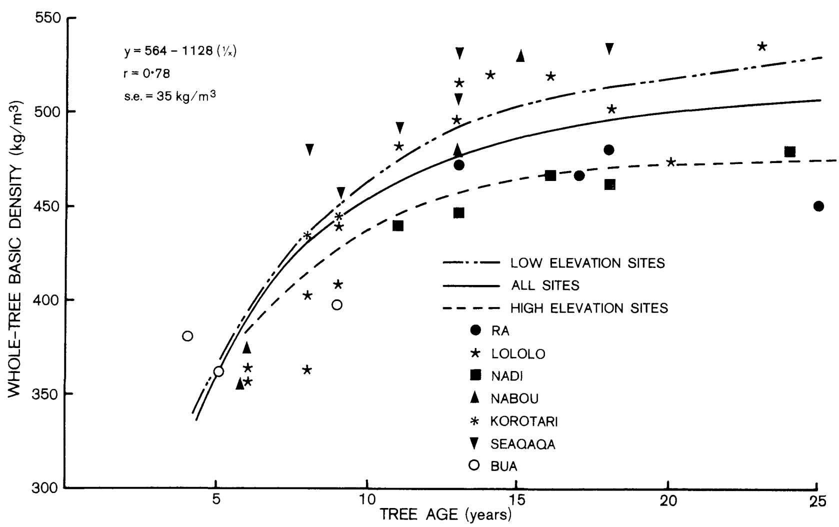

FIG. 4—Relationship between tree age and wood density

In order to investigate site effects more intensively the core densities for rings 6–10 were used in the whole-tree predictive equation to give estimates of plot densities at age 12 years for each location (Table 3). At this age, elevation accounted for 66% of the variation:

$$\text{Crop mean density at 12 years} = 511 - 0.13 \times \text{site altitude} \quad (R^2 = 0.66)$$

Other site parameters (soil pH, nitrogen, phosphorus, and moisture-retention capacity, and such temperature and rainfall data as were available) were used in a multiple regression analysis with 12-year density. The only factor giving a significant improvement over elevation alone was soil moisture-retention capacity (measured as a percentage of oven-dry weight):

TABLE 3—Whole-tree densities and estimated densities at age 12 years

	Site	Age at sampling (years)	Basic density (kg/m³)		
			B.h. outer 5 rings	Whole-tree	At age 12 years
1	Ra	25	522	452	334
2	Ra	18	562	482	430
3	Ra	17	542	467	445
4	Ra	13	552	474	462
5	Lololo	23	636	537	534
6	Lololo	13	610	517	504
7	Lololo	11	564	483	501
8	Lololo	9	461	407	460
9	Lololo	9	505	440	493
10	Lololo	8	400	362	400
11	Lololo	8	455	403	438
12	Lololo	6	394	358	*
13	Lololo	6	404	365	*
14	Lololo (Drasa)	20	554	476	469
15	Lololo (Drasa)	18	590	503	501
16	Lololo (Drasa)	16	614	520	492
17	Lololo (Drasa)	14	614	520	481
18	Lololo (Drasa)	13	583	497	475
19	Nadi	24	561	481	420
20	Nadi	18	536	463	421
21	Nadi	16	545	469	445
22	Nadi	13	515	447	430
23	Nadi	11	506	440	458
24	Nabou	13	558	479	479
25	Nabou	15	629	531	531
26	Nabou	6	418	375	*
27	Nabou	6	395	358	*
28	Korotari	9	509	443	495
29	Korotari	8	496	433	504
30	Seaqaqa	18	635	536	467
31	Seaqaqa	13	599	509	491
32	Seaqaqa	13	629	531	514
33	Seaqaqa	11	575	491	509
34	Seaqaqa	9	528	457	510
35	Seaqaqa	8	559	480	550
36	Bua	9	450	399	452
37	Bua	5	400	362	*
38	Bua	4	430	384	*

* Stands too young for prediction

Crop mean density at 12 years = 569 − 0.14 × site altitude − 1.78 × soil moisture-retention capacity

$R^2 = 0.77$)

At this age, stands located at less than 300 m elevation averaged 500 kg/m³ compared to 430 kg/m³ for those above 300 m. Projected to a rotation of 15 years, these figures become 515 and 465 kg/m³ respectively (Fig. 4).

Influence of Tree Spacing on Wood Density

Two of the sites visited were originally established as spacing trials. Both areas (Lololo 1969 and Seaqaqa 1971) consisted of plots planted in square patterns at 2.1, 3.0, 3.7, and 4.0 m. Fifteen trees were sampled at random in each treatment (Table 4).

In both trials there were highly significant differences in growth rates associated with initial stocking levels and a clear trend of decreasing density with increasing tree size. However, using the relationship between tree age and density as a guide (Fig. 4), it can be calculated that the maximum differences between plot means are equivalent to the density changes associated with only 1–2 years' growth. Hence the influence of tree age on density dominates over the relatively small effects of spacing.

TABLE 4—Influence of spacing on tree size and wood density

Forest	Spacing (m)	D.b.h. (cm)	Wood density (kg/m^3)	
			Outer 5 rings	Whole-tree
Lololo	2.1 × 2.1	20.8	573	490
1969	3.0 × 3.0	24.6	565	484
	3.7 × 3.7	25.4	562	482
	4.3 × 4.3	27.6	555	474
Seaqaqa	2.1 × 2.1	19.6	545	469
1971	3.0 × 3.0	24.7	539	465
	3.7 × 3.7	23.4	531	459
	4.3 × 4.3	27.8	497	434

CONCLUSIONS

Although Caribbean pine is notoriously variable in wood density when planted as an exotic (de Villiers 1974; Harris 1977; Plumptre 1977), the wood of the pine in Fiji would be classified as being of medium to high density. This is fortunate in so far as problems of low density corewood are minimised and the timber should be satisfactory as a general-purpose softwood.

Within trees there was an appreciable density gradient both radially and vertically, but inner-ring values rarely dropped to 360 kg/m^3 (extracted). Hence the very low figures quoted for Caribbean pine in several other countries (Boone & Chudnoff 1972; Bower *et al.* 1976; Barnes *et al.* 1977; Resch & Bastendorff 1978; Woods *et al.* 1979) do not seem to apply to Fiji. At the same time, the extremely high outerwood values quoted by Harris (1977) and Plumptre (1977) are not approached in Fijian timber. The maximum values recorded for mean outerwood densities ranged up to 655 kg/m^3, but most were in the range 500–600 kg/m^3.

As in all other studies, between-tree variation was found to be appreciable, but unrelated to tree diameter within stands. However, it does not necessarily follow from this that growth rate has no influence on wood density (refer to the conclusions of Palmer & Gibbs 1977). In fact, examination of the two spacing trials at Lololo and Seaqaqa showed conclusively that silvicultural conditions can affect wood properties. All the trees grown at wider spacings had slightly lower average densities.

Mean crop densities were determined by regression from the increment core data and it was found that by far the most important influences on wood density were tree age and site elevation. Together they accounted for 85% of the variation in the crops sampled. Thus the situation seems to be much more clear-cut than in East Africa, for instance, where models using altitude, rainfall, temperature, and moisture deficit could explain a maximum of only 52% of the variation (Plumptre 1977). It was calculated that stands below 300 m would have an average basic density of 515 kg/m^3 at age 15 years, compared to 465 kg/m^3 for those at higher elevations. Should longer rotations be employed, such as the proposed 25-year sawlog regime for Seaqaqa, densities would average 540 and 475 kg/m^3 for low and high altitude sites respectively.

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