THE PROPERTIES OF SOME CARIBBEAN PINE PULPS, AND THEIR RELATIONSHIP TO WOOD SPECIFIC GRAVITY VARIABLES

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(Received 11 January 1977)

ABSTRACT

Twenty Caribbean pine trees were pulped individually, and the properties of these pulps were compared to each other and to those of pulps of five other softwood species. There was substantial tree to tree variation, but overall the properties compared favourably with those of pulps from the commercially better established species. X-ray densitometry of the wood was used to estimate the amount of wood in various specific gravity classes. By using such data it was possible to account for considerably more variation in pulp and paper properties than could be done by using overall specific gravity or percentage latewood. Histograms showing percentage in each specific gravity class differed markedly in shape for trees with the same overall specific gravity.

Keywords: *Pinus caribaea*, X-ray densitometry, densitometry, specific gravity, pulp properties, paper properties, percent latewood.

INTRODUCTION

Pinus caribaea Morelet is an important plantation species in many subtropical and tropical countries, where it is hoped that it may produce a suitable raw material for pulp. Earlier investigations have shown that pulp quality varies between samples of the raw material (Palmer and Tabb 1973) and that whole tree specific gravity varies almost twofold (Palmer and Gibbs 1971). This large among-tree variation has led to a continuing joint study by the Commonwealth Forestry Institute (C.F.I), Oxford, and the Tropical Products Institute (T.P.I.), London, with two objectives:

a) to select and breed trees with superior pulping characteristics, to reduce variation, and to increase average pulp quality, and

b) to examine the feasibility of selection *via* relatively simple wood densitometry measurements rather than from the laborious direct pulp evaluations, from correlations between wood and pulp properties.

The latter study objective is reported here.

MATERIALS AND METHODS

The part of these studies reported here has involved material from twelve-year-old commercial plantations in Fiji, where the mainland race is grown extensively (*Pinus caribaea* var. *hondurensis* Barrett and Golfari). At this age the trees were about 15 m in height, and 30 cm in d.b.h. Twenty trees were sampled at random in each of five plots on three sites (Drasa, two plots;

Seaqaqa, two plots; Nausori Highlands, one plot). Increment cores from these one hundred trees were removed at breast height, and examined by X-ray densitometry at Oxford, and values of overall sp. gr. (not extracted) obtained (throughout, sp. gr. was measured at 12% moisture content volume). The trees were ranked into five sp. gr. classes and from each class, four individuals were selected showing different densitometric patterns. After half of these, two per class, had been propagated vegetatively to preserve their genotypes for subsequent clonal testing, all twenty trees were felled.

Transverse sections 30 cm thick were removed at 10% intervals of the total tree height, starting at 5%. A subsample of each disc was extracted with benzene/alcohol and examined densitometrically from pith to bark, and the remainder was used for pulping and pulp and paper quality evaluation. There was little or no compressionwood. Chips from each tree were subjected to four sulfate (Kraft) digestions (each in duplicate) to obtain pulps with a range of yield and pulp properties. These pulps were subjected to beating, in duplicate, of 0, 1, 3, 5 and 7 min, to yield a total of 800 pulps. These were fabricated into handsheets and strength and other properties evaluated. These values were 'adjusted' to 500 Canadian Standard Freeness and 35 kappa by the standard technique of interpolation from regressions. Fiber lengths were estimated on the pulps by Bauer-McNett fractionation (8 classes).

Since so many imponderable variables at different laboratories apparently affect pulp properties quite markedly (e.g. see Ekstam 1953), comparisons with other workers' results are not very meaningful. Thus, for comparative purposes, commercial chips of other species were obtained and treated in the same manner. These were Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), southern pine, Scots pine (*Pinus sylvestris* L.) grown in the U.K., and Swaziland-grown loblolly (*P. taeda* L.) and Mexican weeping (*P. patula* Schiede and Deppe) pines. These species likely represent a spectrum of the competing raw materials. No wood or fiber properties were measured for these. Full details of procedures, standards, results, etc. are given in a T.P.I. bulletin (Burley et al., in preparation).

These data were also used in an attempt to show that the pulp and paper properties of Caribbean pine are predicted better using densitometric variables than by the usual overall specific gravity.

RESULTS AND DISCUSSION

Wood properties

The sp. gr. scan for two typical trees at 5% of their height is shown in Fig. 1. Growth is rapid, there is some compressionwood next to the pith, and there is a very wide range in sp. gr., perhaps quite startling to those not familiar with the wood of the subtropical pines. In Fiji, sp. gr. variations delineating annual rings are due to the dry season, but in younger trees, growth is continuous for a variable period ranging up to five years, during which time the annual rings are ill-defined or not discernible at all. The second tree has higher sp. gr. because of its higher proportion of latewood (arbitrarily defined as wood > 0.6 in sp. gr.) which is itself of higher average sp. gr., and also because of its high sp. gr. earlywood. Bands of wood of contrasting sp. gr. in both the earlywood and the latewood are also apparent, and these probably are because of droughts and wetter periods. Whole tree sp. gr. varied from 0.45 to 0.75.

From the densitometric scans can be prepared sp. gr. histograms, such as those in Fig. 2, which show the percentage of wood in various classes for whole trees. Width of the classes is 0.05 in the figure. The wide range in sp. gr. is again evident, but the very important point illustrated is that trees with the same overall sp. gr. (0.45 in numbers 1 and 2, 0.57 for numbers 4 and 5) may have markedly different histograms (tree number 3, included for comparison, has sp. gr. 0.75). If one designates latewood as having sp. gr. of 0.6 or greater (though with the data available from densitometry, discussions about latewood

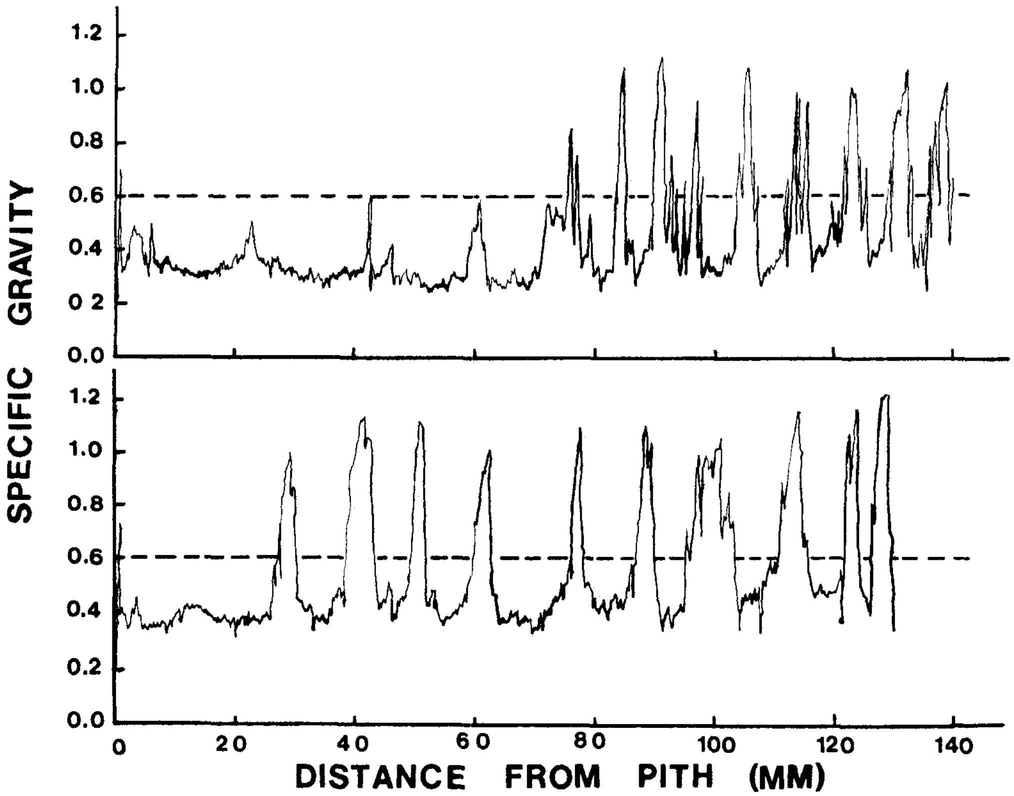

FIG. 1. Specific gravity profiles for two contrasting trees at 5% of their heights. The lower tree started to produce latewood earlier than the upper one, and has more and denser latewood, and denser earlywood. The dotted lines indicate the arbitrarily chosen boundary, sp. gr. = 0.60, between earlywood and latewood.

should soon hopefully disappear), it is interesting that tree #1 has 18% latewood, whose sp. gr. is 0.825. Tree #2 has only 13% latewood, of sp. gr. 0.730. Thus #1 has *more* and *denser* latewood, but has the same overall sp. gr., because #2 has denser earlywood. Tree #4 has 38% latewood, of sp. gr. 0.835; comparable figures for trees #5 and #3 are 31% and 0.875, and 64% and 0.900. This illustrates why the correlation between latewood percentage and sp. gr. can never be perfect, though r^2 is 0.94 for the twenty trees used here. The principle of differing sp. gr. histograms but the same average sp. gr. applies also to individual rings within a cross-section. Obviously one would not expect trees #1 and 2 to yield the same kind of pulp, despite their identical sp. gr., because of differences during cooking—for instance those described by Gladstone and Ifju (1975), and also during beating.

Mean pulp fiber lengths for the twenty trees ranged from 2.78–3.20 mm with an overall mean of 3.04 mm.

Pulp and paper properties

Table 1 shows what we consider to be the key pulp properties; the final column is a very subjective "value" or "worth" index, the product of yield, tear and burst, $\times 10^{-3}$, which was also used by Keays and Hatton (1971, a and b) for comparing pulps made from different parts of trees. From this evidence, it is clear that Caribbean pine does not fare badly in comparison with other species, being slightly better than

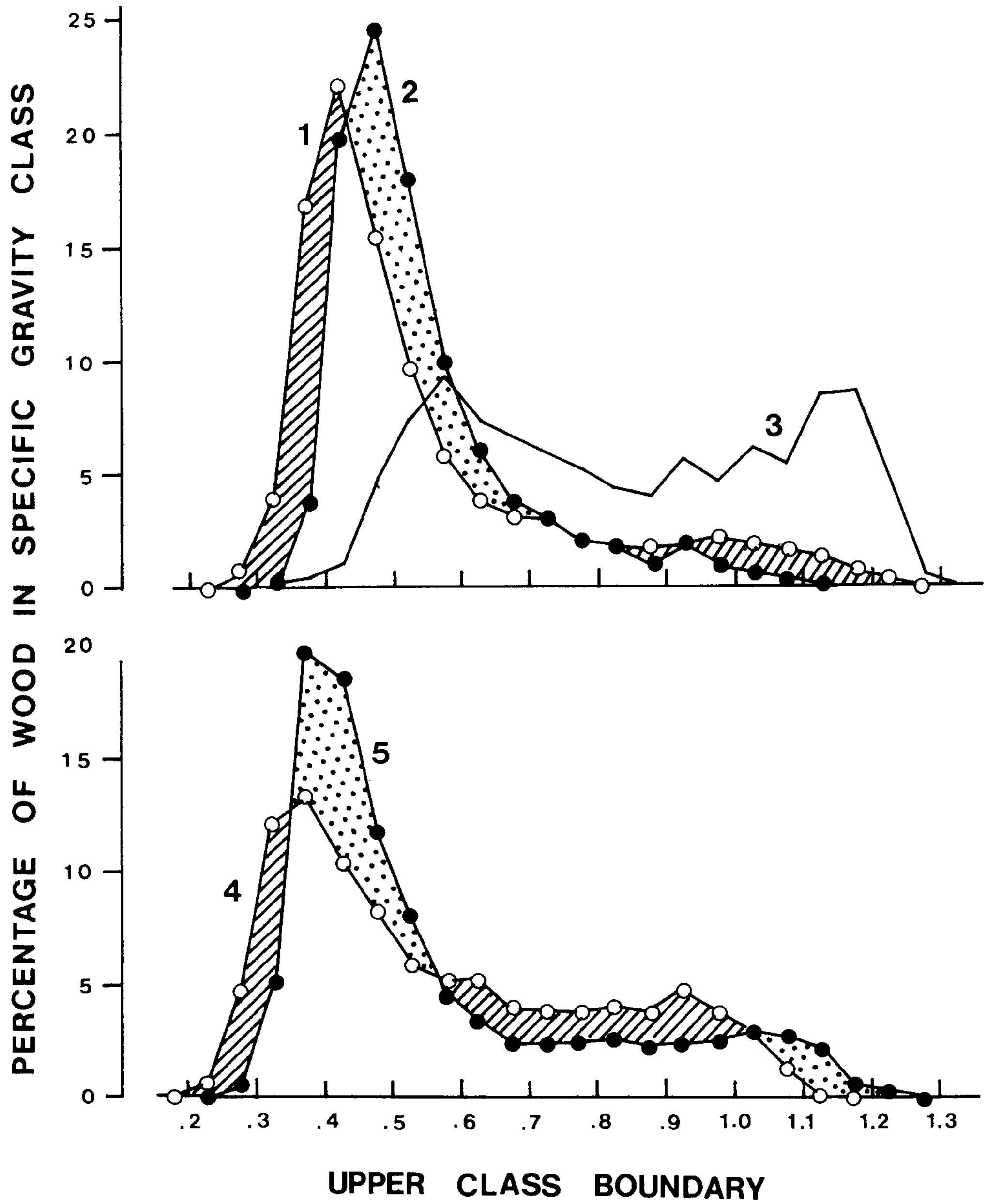

FIG. 2. Overall specific gravity histograms for five trees. Class width is 0.05. Trees #1 and 2 have overall sp. gr. 0.45, 4 and 5 have overall sp. gr. of 0.57. Number 3 is the histogram for the densest tree, sp. gr. 0.75.

southern pine, on the average, in the listed properties, and in value, being markedly inferior only to Douglas-fir. There is however a very substantial range among trees, with the best ones being quite good, but the worst being appalling. Presumably we can already be fairly sure that some trees should be favored over others in breeding for

TABLE 1. *Summary of pulp and handsheet properties at C.S.F. 500 and Kappa No. 35*

Species	A Yield, %	B Burst factor	C Tear factor	'Value' = AxBxCx10^{-3}
Douglas-fir	42.9	63.8	186	509
Mexican weeping pine	44.1	68.8	136	413
Loblolly pine	45.5	70.0	129	410
'Southern' pine	45.0	57.3	156	404
Scots pine	46.0	71.1	139	455
Caribbean pine, mean	45.3	63.3	165	476
Caribbean pine, range	42.4-47.4	58.8-75.5	127-209	321-620

future planting stock. The usual strong inverse correlation between tear and burst was apparent, though for example, the tree with the best tear was not worst, but 16th in burst, so had better than average value, partly because of better than average yield.

Wood property—pulp property correlations

Correlations or multiple correlations were run between pulp properties of the twenty trees and the following variables: overall specific gravity: percentage latewood: percentage of wood in the sp. gr. classes < 0.2 (a), 0.2 – 0.35 (b), 0.35 – 0.50 (c), 0.50 – 0.65 (d), 0.65 – 0.80 (e), 0.80 – 0.95 (f), 0.95 – 1.10 (g), 1.10 – 1.25 (h), and > 1.25 (i): and the percentages of wood in each of the eight fiber length fractions. Not all trees contained wood of every class, and for many species one would not expect wood to occur in the f or even the e class.

Table 2 shows the values of r^2 between the variables, i.e. the proportion of variation "explained" by the independent variables

TABLE 2. *Coefficients of determination (r^2 values) between pulp and wood properties of Caribbean pine*

Independent variables	Yield	Burst	Tear
Overall specific gravity	0.14	0.17	0.40*
Percentage latewood	0.40*	0.23*	0.48*
Specific gravity classes, all	0.62	0.54	0.73
Specific gravity classes, b-h	0.57*	---	---
Specific gravity classes, b, f, i	---	0.43*	---
Specific gravity classes, a, c-h	---	---	0.72*
Fiber length classes, all	0.33	0.44	0.81**
Best three sp. gr. classes and best three fiber length classes, combined	0.68*	0.67*	0.83***

* significant at 5% level; ** significant at 1% level; *** significant at 0.5% level.

a: wood of sp. gr. < 0.2, b: sp. gr. 0.2-0.35, c: sp. gr. 0.35-0.50, d: sp.gr. 0.50-0.65,
e: sp. gr. 0.65-0.80, f: sp. gr. 0.80-0.95, g: sp. gr. 0.95-1.10, h: sp. gr. 1.10-1.25,
i: sp. gr. > 1.25.

of the first column, with the asterisks indicating statistical significance at the 5%, 1%, and ½% probability levels. Because of the small error degrees of freedom, especially when all sp. gr. classes were used, significance does not occur until some variables are dropped and the error degrees of freedom increased. Thus the fourth number in each column shows the maximum significant r^2 value. Tear was highly significantly related to the fiber length fractions; the other two variables were not related to any number or combination of these. The final row shows the combined effect of the best three sp. gr. and the best three fiber length classes.

Although these values of r^2 are not high, the derivation of them is based on shaky procedures (see below), and the spectre of Type 1 errors is looming large; we can perhaps claim that the densitometric variables do aid the prediction of pulp properties. This is indicated by the steady increase in r^2 values in the first, second, and fourth numbers in each column, i.e. from overall sp. gr., through percentage latewood to densitometric variables. Percentage latewood in this case was also derived (almost effortlessly) from the densitometer traces, and the r^2 values here may be better than if percentage latewood had been estimated by the standard (rather subjective) procedures. The poor correlations with overall sp. gr. may be due to the extreme within-tree sp. gr. range, which problem is overcome by the use of densitometric variables.

It is curious that, although at least one method of assessment of specific gravity variation within growth increments (Green and Worrall 1964) was devised expressly for producing some index of wood properties useful for pulp and paper quality prediction, this, and subsequent methods of densitometry, seem to have been fully exploited only by dendrochronologists, who may now apply the principles they established concerning ring widths, to such variables as maximum latewood specific gravity and can consequently utilize hitherto "complacent" species of tree. Other uses, for example, have been in the determination of the effects of silvicultural treatments on earlywood and latewood quality (Parker et al. 1976). Also densitometry has been rather generally used for the estimation of overall specific gravity, percentage latewood etc. (at tremendously greater cost than the standard methods) while a large amount of the information provided by it is not used at all for some types of investigations. For a review, see Parker and Kennedy (1973).

The final row of Table 2 combines the best three sp. gr. classes and the best three fiber length classes to "explain" about two-thirds of the total variation. This perhaps is scarcely enough to allow indirect selection for pulp quality from increment-core wood properties, but certainly is adequate for at least initial screening. Presumably some refinements of our pulping techniques are required, or other variables such as fibril angle should be measured also.

The size of these correlation coefficients is disappointing, particularly since in many tree species, especially those of long established and major commercial importance, the correlations among pulp and paper properties and the characteristics of the raw material are quite clear, with the latter occasionally "explaining" (as evidenced by r^2 values) even more than 95% of the variation in the former. The current authors, however, perhaps because such high r^2 values consistently elude them, suspect that the situation in reality is not so straightforward. First, we suspect that some editors at least, when presented with articles of similar content for publication will naturally favor those with the better r^2 values, so that a bias will appear in the literature! Second, and more seriously, it is evident that many authors have treated data in an inappropriate fashion, often applying analysis of variance and regression analysis without first checking the validity of such.

In the current study we have used the standard method of interpolating from regressions the strength values of papers at fixed kappa number and Canadian standard freeness, and assumed, as have previous authors, that such point estimates are error-free. Of course they are not, and as a small example the data of Tamolang and Wangaard (1961) may be considered. These authors investigated the strengths of hardwood pulps, and showed their raw data graphically, for instance in their Fig. 2. We have reworked these data, which show strength versus permanganate number (usually five cooks) at seven beating times. Linear regressions had been fitted from which strength at permanganate number twelve was read (though only four of the regressions appear to be statistically significant at the 5% level). These interpolated values allowed a linear regression to be derived between strength and beating time at fixed permanganate number; r^2 (our estimate) is 0.994. However, if the point estimates from the former seven regressions were to be replaced, as they should be, by the point estimate plus the residuals, i.e. the deviations from the plotted line, we will have a replicated regression (five replications usually), a) not in the same position, and b) with $r^2 = 0.920$. Though this is a minor decrease in r^2, the coefficient of determination, it represents an enormous increase in $1 - r^2$, the coefficient of nondetermination, or the proportion of unexplained variation. This latter increases from 0.006 to 0.080, i.e. more than 12 times. The final regression was then used by the original authors for still further interpolations, and again the assumption of no error was made. The problem here is that the only error considered by most authors is the lack of fit, while the pure error is forgotten. This has been discussed by Draper and Smith (1966), but still it seems we need to be reminded of it.

CONCLUSIONS

Individual 12-year-old trees of Fiji-grown Caribbean pine produced pulps differing markedly in quality and yield, with moderate properties on the average. Overall tree to tree specific gravity variation was high, but only the tearing strength of the papers produced was related to specific gravity. Trees with identical specific gravity nevertheless had their wood distributed very differently in various specific gravity classes, as was shown by X-ray densitometry. When densitometric variables were used, together with fiber lengths, about two-thirds of the tree to tree variation in pulp and paper properties could be accounted for.

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