Use of Beta Rays for Early Assessment of Wood Density Development in Provenance Trials

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In a country so heavily dependent on exotic forestry as New Zealand it is inevitable that some errors of seed selection should have been made in the past, but very fortunate that so few occurred among the most widely planted species. Possibly the mere presence of the more spectacular failures — for example, 3,000 acres of unthrifty Pinus ponderosa var. scopulorum ENGELM. (WESTON 1957) — has stimulated the establishment of very extensive provenance trials which now include 28 species, mainly Pinus, and cover more than 1,000 acres.

The assessment of provenance trials on this scale is a major undertaking when morphological characters alone are to be considered; but for most species wood characters are also of considerable importance. Because evaluation of wood properties usually requires something more than visual measurement, two problems arise. First, rapid techniques must be developed that will adequately assess the variability within provenances. Second, it is desirable to be able to predict future wood characters at an early age when most conifers are only just beginning to produce "outer" wood (as compared with earlier production of "juvenile" or "core" wood). All too frequently correlations between the wood properties of core wood and outer wood are not strong enough to permit young trees to be used for predicting future developments.

The work described in this paper was undertaken to find out how beta ray techniques could be used to speed prediction of wood density development in young trees. The beta ray equipment has been fully described by HARRIS (1969) but is essentially a modification of that developed by CAMERON et al. (1959). The species examined were P. taeda L., P. elliottii var. *elliottii* ENGELM., P. *elliottii* var. densa LITTLE et DOR., P. caribaea var. hondurensis BARR. et GOLF, and P. caribaea var. bahamensis BARR et GOLF. These species were included in the first of many extensive trials established since 1955, and may therefore indicate the sort of problems that will arise as the later trials grow old enough for assessment in this way. The P. taeda trial was planted in 1955 and the P. elliottii and P. caribaea trials in 1956.

P. taeda and P. elliottii are the two southern pines that show most promise for forestry in New Zealand. Their main value arises from their ability to form productive stands on moderately leached clay soils, north of latitude 38° S. Consequently there are several areas where these species have a definite, though limited, place in forest establishment. Their main disadvantages, as seen in existing stands, are poor stem form, poor branching characters, and proneness to form deep bark pockets around the branches. The most disappointing feature of their wood properties is that, contrary to the type of wood forrned in the south eastern states of U.S.A., very little latewood is formed in trees in New Zealand, at least in the early stages of growth. Wood therefore tends to be of low density and mechanically weak.

There are in short, good grounds for attempting to improve the wood properties of southern pines by tree breeding (including provenance selection) or by any other means available. On the other hand future plantings will necessarily be limited, so that it would be difficult to justify a very intensive programme of improvement in New Zealand. If it should prove possible to make significant improvements by provenance selection alone, or by using trees selected in other countries, this would be a most satisfactory outcome of the current programme.

Scope of the Trials

A complete description of the design of the trials is unnecessary to the development of this paper, but will be published elsewhere (C. J. A. SHELBOURNE pers. comm.). Briefly, the seed sources include bulked seed lots from 20 or more trees and also some single tree progenies from selected sites in U.S.A. and the Caribbean. In addition there are single tree progenies (open-pollinated) collected from New Zealand stands and from plus trees selected in Australia by the Queensland Forest Service.

Trials of all species were originally established in Waitangi Forest (lat. 35° S) and in Rotoehu Forest (lat. 38° S), but the P. elliottii and P. caribaea failed at Rotoehu so that comparisons of the same "origins" (i.e. provenances or progenies) on two sites are available only for P. taeda. The trials contain up to eight replications of single tree progenies and up to three replications of other seed sources.

Methods

Fifteen trees of each origin were examined by taking a 5 mm increment core from pith to bark at the third internode above ground level. From a further five trees of each origin a 10 mm increment core was taken from pith to bark at the same level. Equal numbers of borings, both 5 mm and 10 mm, were taken from each replication as far as possible.

The wood density of the 5 mm increment cores was estimated in two ways. The green volume of the core was first determined by measuring its length to the nearest millimetre and multiplying by a standard conversion factor. This estimate of volume was then divided into the oven-dry weight of the core to determine basic density in g/cm^3. As a running check of the conversion factor, the method of maximum moisture content was also used to estimate the basic density of one core in every ten. The green volume of the 10 mm increment cores was determined by water immersion, and the cores were then weighed after oven drying at 102° C.

The results of this initial survey of wood density were used to select certain provenances for examination with the beta ray densitometer. For this the 10 mm increment cores were reconditioned to 10% moisture content and machined to 4 mm in tangential width. They were then boiled in two changes of methanol for 24 hours to remove resin, and were again reconditioned to 10% moisture content before running through the apparatus. This moisture content corresponded with equilibrium conditions in the laboratory, which was air conditioned at 55% relative humidity and 21° C.

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Two criteria were used to select other origins for examination with the densitometer. Those whose growth rate and stem form suggested suitability for future plantings were selected first. Additional origins to provide a fuller geographical coverage were then added so that correlated trends of density variation could be detected if present.

Results

A. Gravimetric Estimates of Wood Density

Pinus taeda:

Variations within and between origins are illustrated in *figure 1*. The first nine are arranged in geographical sequence from West to Northeast (Arkansas to Maryland). Progenies 384-7 are of Queensland origin and 433-7 from New Zealand. Provenance 371, from Georgia was not planted at Waitangi, but *figure 1* affords comparison of all other origins as grown in both forests, and shows that wood density is consistently higher at Waitangi than at Rotoehu. Taken overall, differences between origins are not very large, though there are significant differences between extreme values, and there are also indications that inland provenances (e. g. 367 Howard Co. and 368 Ashley Co., both in Arkansas) are producing wood with higher density than coastal provenances. The New Zealand progenies also have relatively high density.

Pinus elliottii and P. caribaea:

These two species have been grouped together, partly because of their obvious similarities, and partly because the present study shows some common developmental trends in wood density from south to north of their combined range as will be described later. Variations within and between origins are illustrated in *figure 2*, in which origins are arranged in geographical sequence from south to north viz. provenance 309 is *P. caribaea* var. *hondurensis*,

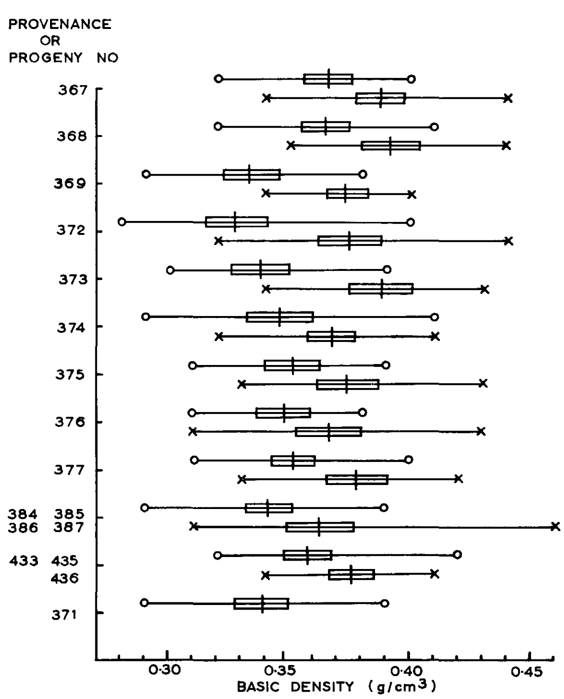

Figure 1. — Variation of basic density of *P. taeda* within and between sites. The mean value for each origin is indicated by the vertical line, two standard errors about the mean are indicated by the box, and the total range of values by the horizontal line o———o Rotoehu Forest x———x Waitangi Forest.

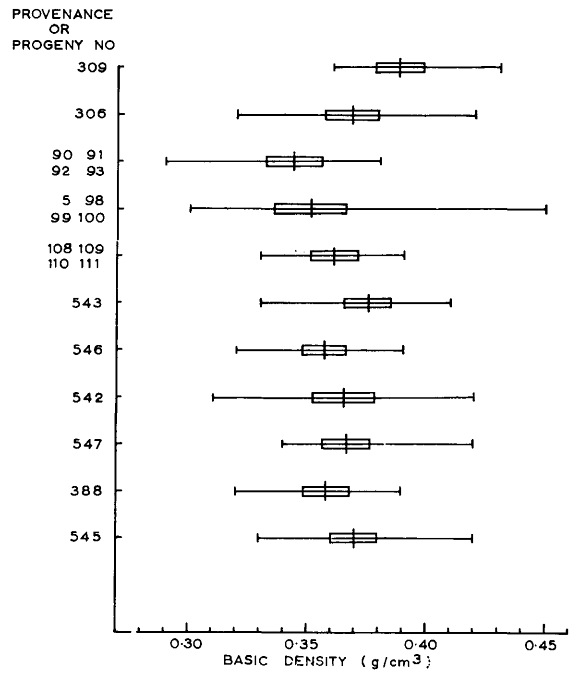

Figure 2. — Variation of basic density of *P. caribea* and *P. elliottii* in Waitangi Forest. The mean value for each origin is indicated by the vertical line, two standard errors about the mean are indicated by the box, and the total range of values by the horizontal line.

306 is *P. caribaea* var. *bahamensis*, progenies 90—93 are *P. elliottii* var. *densa* from Fort Myers in Florida, and the following origins from 5 through to 547, which are all *P. elliottii* var. *elliottii*, extend from Gainesville, Florida to Hazelhurst, Georgia. The final two progenies, 388 and 545, are from plus trees selected in Queensland. Here again, differences between origins do not appear to be very large. The provenance producing wood with highest mean density at this age is *P. caribaea* var. *hondurensis* which does not produce acceptable form under New Zealand conditions.

Despite the apparent relative uniformity of wood density in all origins, visual examinations of the increment cores suggested that latewood was better developed in some than in others, or was beginning to be more strongly developed in the outer growth layers. Measuring the average wood density of entire increment cores from young trees (up to 14 years in this instance) failed to reveal some of the differences between them because the results provided no weighting for the relative volumes of the outer and inner growth layers. Most trees have low density wood near to the pith, but any effect of increasing density in the relatively narrow outer growth layers tends to be outweighed in increment cores by the width of the central growth layers.

There are, of course, many ways of overcoming these difficulties — by sampling at fixed radial intervals or by weighting results in proportion to the volumes of wood in each growth layer. In this study the beta ray densitometer was used to examine trends of development of earlywood, latewood and mean density in trees of each origin.

B. Densitometer Examination of Wood Density

The densitometer revealed distinct differences in wood development between the two forests in New Zealand, and between certain of the origins examined. It also showed that conditions in this country produce wood with characters quite different from *P. taeda* and *P. elliottii* grown in North Carolina.

Trends of wood development are often obscured by the length and apparent complexity of the densitometer records as they emerge from a chart recorder. A graphical method of summation (HARRIS 1969) has therefore been developed to illustrate the salient features. Three parameters are recorded from the densitometer curve for each annual growth layer. These are (i) maximum density — usually found in the last formed region of the latewood, (ii) minimum density — usually about the centre of the earlywood and (iii) mean density for the entire growth layer. These values are then plotted for each growth layer from pith to bark, and, in the present instance, average values have been calculated for the five trees examined from each origin *(figures 3—9)*. The diagrams provide a picture of the "limiting envelope" for variations in wood density, and of the mean values, growth layer by growth layer, from pith to bark.

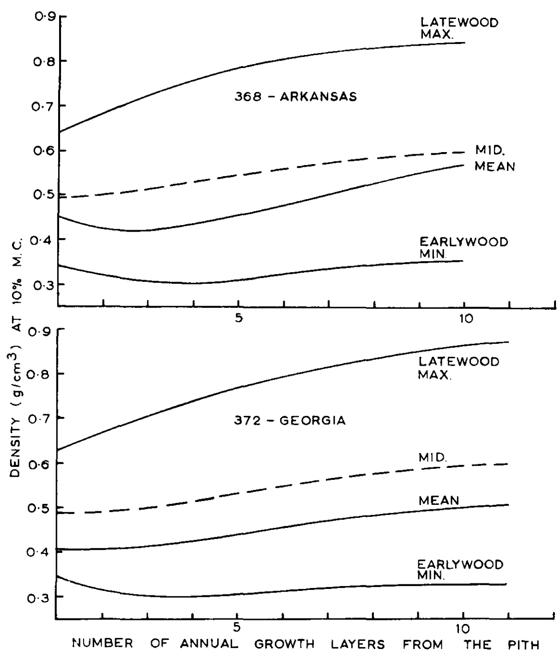

Figure 3. — *P. taeda*-Provenances 368 and 372. Radial patterns of wood density variation in Waitangi Forest.

The parameter $\dfrac{\text{mean density — minimum density}}{\text{maximum density — minimum density}}$

has been termed the "latewood ratio" for a particular growth layer (HARRIS 1969). As an aid to visual estimation of this parameter the locus of points midway between the lines for maximum and minimum densities has been drawn as a dashed line on most diagrams, since this corresponds to a latewood ratio of 0.5. Because trees from some origins produced no discernible latewood under New Zealand conditions, the mid-point line obviously serves no useful function and has been omitted from the relevant diagrams e. g. fig. 6 (lower).

Pinus taeda:

Figures 3 and 4 illustrate wood density development in three provenances that are widely separated geographically, and also in *P. taeda* grown in North Carolina. Only minor differences show up between the provenances when grown in New Zealand, the most significant being the superior latewood ratio developed in the slightly denser

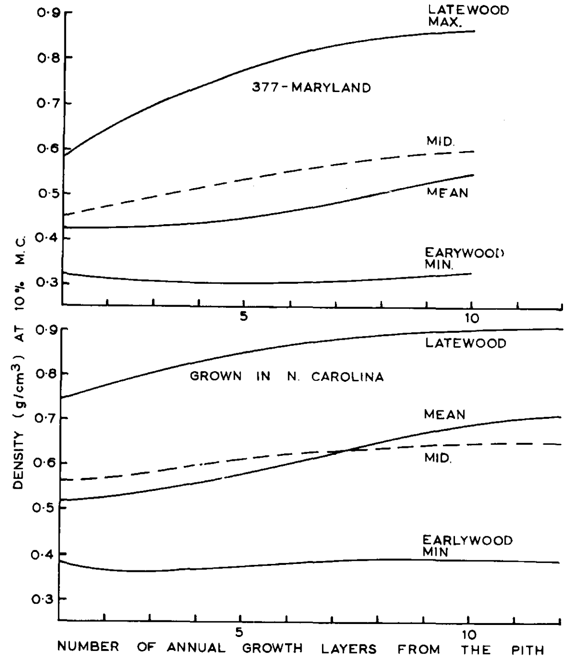

Figure 4. — *P. taeda*-Provenance 377 from Waitangi Forest and young trees grown in North Carolina. Radial patterns of wood density variation.

Arkansas provenance (368) already referred to *(fig. 3* — upper). This is indicated in the diagram by the steep approach of the line for mean density towards the mid-point line.

By way of contrast the young trees from North Carolina *(fig. 4* — lower) are of higher density throughout the growth layers: earlywood minima and latewood maxima are both denser than in the New Zealand grown trees by about 0.05—0.10 g/cm³. Mean density is therefore relatively high, even in the region of the pith, but it also increases much more rapidly from the pith outwards due to the rapid increase in latewood ratio. The line for mean density crosses the mid-point line at about the seventh growth layer,

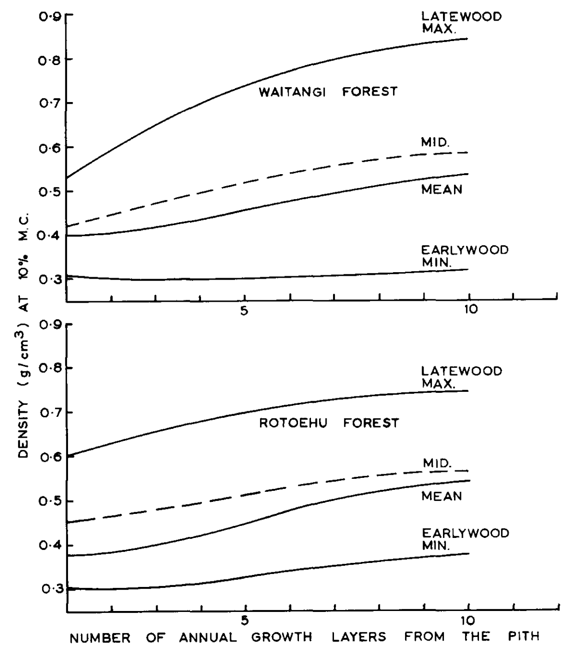

Figure 5. — *P. taeda*-Progenies of plus trees selected in Queensland grown in Waitangi and Rotoehu Forests. Radial patterns of wood density variation.

which indicates a latewood ratio greater than 0.50 from this point onwards.

The high wood density of *P. taeda* from North Carolina as compared with New Zealand can therefore be attributed both to the overall density of the constituent parts of the annual growth layers, and to the more extensive development of latewood within a few growth layers from the pith.

Fig. 5 illustrates differences between the two forests in the wood density of progenies of plus trees selected in Queensland. Latewood in trees from Waitangi is denser than in trees from Rotoehu. This suggests that latewood and earlywood densities must be regarded as being independent variables, equally with latewood ratio.

Certain differences between progenies also showed up consistently on both sites. For example, the progenies of trees selected in New Zealand produced denser latewood than the progenies of trees selected in Queensland.

Pinus elliottii and P. caribaea:

P. elliottii grown in North Carolina *(fig. 6* — upper) shows many similarities with *P. taeda* from the same state in development of wood density. None of the trees in the New Zealand trials *(figs. 7 and 8)* are even beginning to approach the latewood ratios achieved within five or six growth layers from the pith in the North Carolina trees.

No discernible latewood whatever has been produced so far by either variety of *P. caribaea.* The positions of annual growth layers could only be estimated approximately from the periodic concentrations of resin canals. *Fig. 6* (lower) illustrates the density characteristics in wood of this type. Although mean density is actually higher than in the various origins of *P. elliottii,* as noted from *Fig. 2,* there are, as yet, no indications of increasing density as the trees grow older.

Three of the single tree progenies of *P. elliottii* var. *densa* from Fort Myers Fla. were similar to *P. caribaea* in development of wood density, but two were beginning to form latewood in the outer growth layers (not illustrated). The

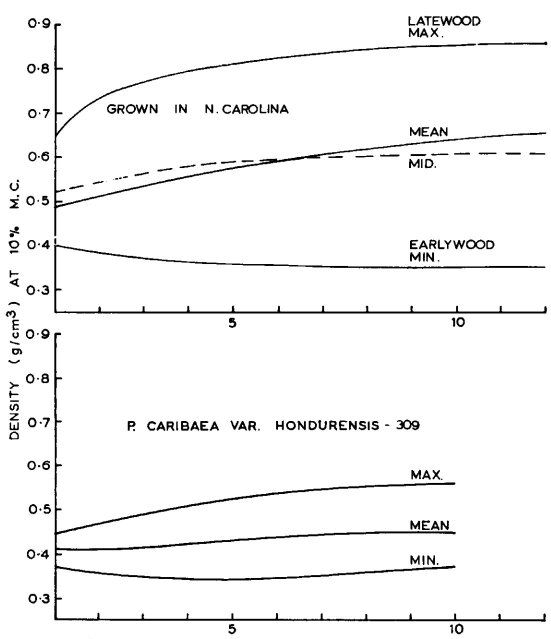

Figure 6. — Radial patterns of wood density variation in (upper) young trees of *P. elliottii* var. *elliottii* grown in North Carolina and (lower) *P. caribaea* var. *hondurensis* grown in Waitangi Forest.

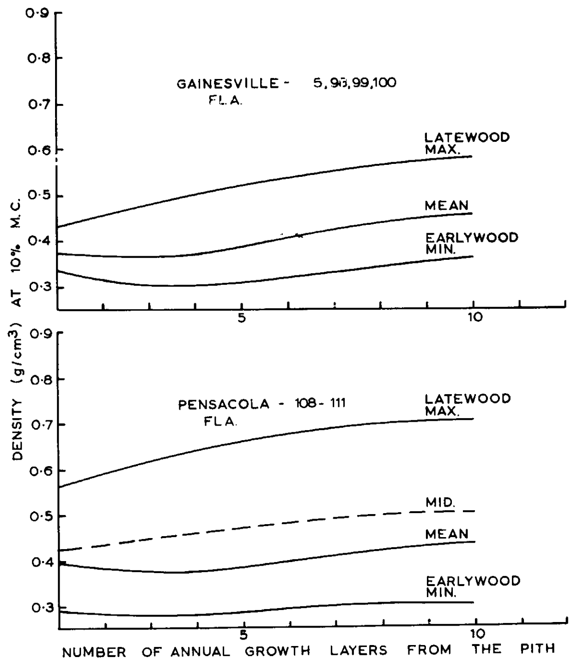

Figure 7. — *P. elliottii* var. *elliottii* grouped single tree progenies from Gainesville and Pensacola grown in Waitangi Forest. Radial patterns of wood density variation.

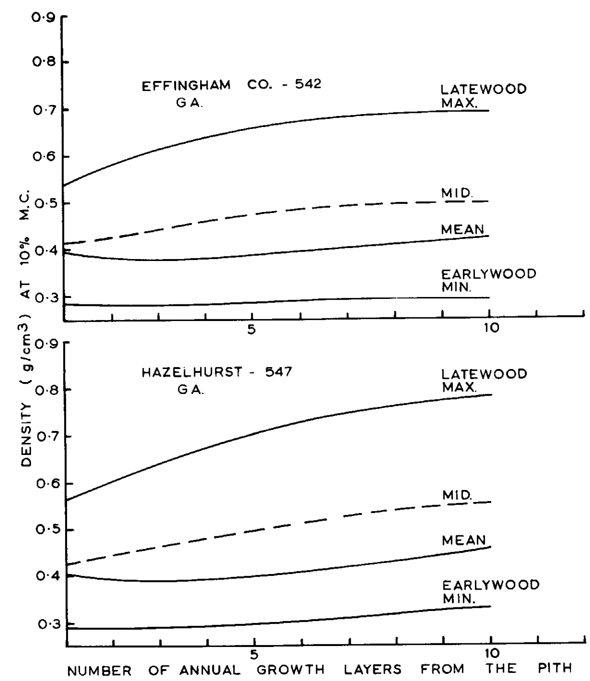

Figure 8. — *P. elliottii* var. *elliottii*-Provenance 542 and 547 grown in Waitangi Forest. Radial patterns of wood density variation.

remaining origins, which were all *P. elliottii* var. *elliottii,* showed a rather consistent increase in latewood density from south to north of the range examined *(figs. 7 and 8)* but no significant changes in earlywood density.

As in *P. taeda,* some distinct differences could be detected between single tree progenies which suggests that wood density could be modified by tree selection in both species.

Discussion

The results outlined above will obviously have some interesting implications when progenies or provenances are selected for future afforestation in New Zealand. However the object of this paper is rather to examine how densitometric methods can facilitate judgements of this kind. In general terms it can be said that densitometer records provide a useful basis for extrapolations, and so avoid dependence on conventional correlations that are usually based on retrospective assessments of several years' growth. Densitometer records provide a year by year assessment of density trends more readily and often more accurately than other methods. Of course they need not, and probably should not, exclude other techniques of measurement or assessment.

Mean densities of the 20 borings from each origin as determined by conventional gravimetric methods, and mean densities of the five borings measured with the densitometer actually show very close agreement when densitometer values are converted to basic density equivalents. But, in future, wood density estimated by taking 5 mm cores from 25 trees will be used to select five trees for examination with the densitometer. In this way sampling errors that may easily arise when using as few as five trees will be avoided by deliberately selecting trees that are stratified with respect to wood density. For example, the five selected trees could include three with wood density about the average for the group to be examined, and two representing extreme values within it.

Extrapolations of future wood density would appear to be simpler for the young trees of *P. taeda* and *P. elliottii* from North Carolina than for those grown in New Zealand. Developmental curves for the North Carolina trees *(figs. 4 and 6)* flatten off at age 10—12 years and future trends are therefore reasonably predictable. This is in agreement with general observations of the extent of corewood in southern pines growing in the southeastern U.S.A. (e. g. Zobel and Rhodes 1956).

By comparison corewood development is by no means complete in the New Zealand trees. Examination of 30 year old trees from Rotoehu Forest *(fig. 9)* suggests that *P. taeda* will require about 17 years and *P. elliottii* 20 years or more to reach the same stage of development as the young trees from North Carolina.

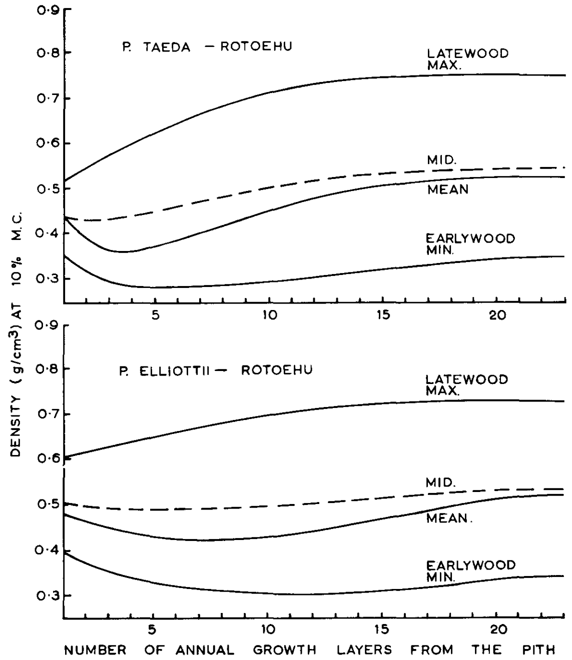

Figure 9. — ***P. taeda*** **and** ***P. elliottii*** **var.** ***elliottii*** **grown in Rotoehu Forest. Development of radial patterns of wood density variation in older trees than those in the provenance trials.**

This does not necessarily mean that the trees in the provenance trials must be 5—10 years older before results can be usefully evaluated. If utilised after a short rotation — as pulpwood, for example — the current results would require little extrapolation, and, incidentally, the relatively low wood density might be used to advantage for certain types of pulp. But even if, as seems more likely, the trees will be used mainly for sawn timber, the densitometric data can still provide useful information. The aim will then be to achieve the earliest possible development of wood density appropriate to a general purpose softwood. If 0.48 g/cm^3 at 10% moisture content (approximately 0.40 g/cm^3 basic density) would be acceptable, the aim should be to select provenances or progenies that will produce wood of this density as close to the pith as possible. A small corewood of lower density could largely be eliminated for critical uses by appropriate grading rules, for example by excluding all timber containing pith, whereas a large zone of corewood can pose real problems.

Whatever the end use, densitrometric curves afford a ready means of comparing developmental trends, and also levels of achievement at various stages of development, between closely similar groups of trees. Their unique value lies in the insight they provide to the three independent variables that determine the mean density of each annual growth layer. In this paper the parameters of maximum and minimum density, together with latewood ratio, are offered as a comprehensive basis for studying how mean wood density varies. Where older trees of the same species are available for comparison we believe that trend lines for these parameters can be extrapolated to predict wood production with a degree of confidence that will increase as more experience is gained in this type of assessment.

Acknowledgements

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Summary

A beta ray densitometer has been used to measure density variations in the wood of 13—14 year old trees from provenance trials of *Pinus taeda*, *P. elliottii* and *P. caribaea*. From the densitometer charts three sets of values are abstracted to examine the components of variation in mean density, growth layer by growth layer, from the centre of the tree outwards. These parameters are the maximum (latewood) density, minimum (earlywood) density, and latewood ratio, for each growth layer. When plotted as a graph from pith to bark the trend lines for these characters provide a unique basis for comparing trees of different provenances and for examining the effects of environment.

The particular value of this method of assessment, as applied to young provenance trials, is that it enables limited extrapolation to predict the essential characters of future wood production. Extrapolations can be made with even greater confidence when similar trend lines from older trees of the same species are available for comparison.

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