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TROPICAL FORESTRY PAPER
No. 17



PINUS CARIBAEA

VOLUME 2: WOOD PROPERTIES

BY

R. A. PLUMPTRE

UNIT OF TROPICAL SILVICULTURE
COMMONWEALTH FORESTRY INSTITUTE
UNIVERSITY OF OXFORD
1984

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Pinus caribaea var. hondurensis in seven year old progeny trial selection at Threeways, Melville Island, Northern Territory, Australia. (Photograph by R.D. Barnes)

Foreword

This seventeenth Tropical Forestry Paper compiles and evaluates the voluminous data now available in published or unpublished form on the structure and properties of wood of Pinus caribaea from natural and exotic locations. This species is widely planted in the tropics and some eight million hectares may be established by the turn of the present century. This volume indicates the type of properties to be expected from such an extensive natural resource and compares them where possible with well known species; hence it will be invaluable in determining optimum processing and use.

Mr. R.A. Plumptre is a core member of the Unit of Tropical Silviculture where he conducts research on wood anatomy, technical properties, kiln drying and appropriate processing of tropical, industrial species. Prior to coming to Oxford he had many years' experience as a wood technologist in Uganda. He has also acted as a consultant for FAO, ODA and various companies. He is thus well aware of current problems and needs in forest products research and utilization.

Dr. J. Burley
Acting Head of Department of Forestry

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Introduction

Volume 1 of this monograph on Pinus caribaea Morelet published in 1973 contains information on the species in its natural environment and an account of its use as a plantation tree including its silviculture, mensuration and protection. In addition there was a short section on tree improvement and wood properties and one on economics and management. It was planned at the time of writing Volume 1 that a more comprehensive Volume 2 should be written dealing with wood properties and uses of the wood.

This volume is intended to bring the wood properties section of Volume 1 up to date and amplify it to become a comprehensive survey of the current state of knowledge on the wood properties of the species in its natural environment and in plantations. It is complementary to Volume 1 in that no attempt is made to cover any of the same ground other than that dealing with wood properties and uses.

Figure 1 shows the natural distribution of the species and since Volume 1 was written the planting of the species has continued at an increasing rate so that by the end of the century it is expected that up to eight million hectares will have been planted around the tropics. Provenance trials have been extended and some fifty countries now have replicated variety and provenance trials of the species. Figure 2 shows the distribution of these provenance trials throughout the tropics.

Since Volume 1 was written the early provenance trials have grown to an age where tests of wood properties are possible and reasonable estimates of wood properties in future years can be made from these tests done on relatively young material. The state of the art is, therefore, considerably more advanced than it was ten years ago and there is now good reason to summarise it in a single publication.

This volume is divided into a number of sections dealing with the general characteristics of the wood naturally and plantation grown, and its anatomy, its properties as solid wood and solid wood defects, physical, mechanical and chemical properties, factors affecting wood properties and, finally, properties for different end uses. Much of the recent research has concentrated on wood density variation and on pulp and paper-making properties of the wood but an attempt has been made to deal with its general utilisation as fully as possible in order to provide as much information as possible for the industrial user or for the smaller user of the wood. An effort has also been made to provide information for the silviculturist or tree breeder so that they can incorporate in their activities an element dealing with the improvement in the quality as well as the quantity of the product they are growing.

An attempt has been made to set the quality of the wood in the context of the quality of similar species such as the Southern pines of the United States or in the context of competing products such as pulp and paper made from temperate and other tropical conifers.

Acknowledgements

This monograph is the result of co-operative work by a considerable number of people. In particular, the assistance and co-operation of the New Zealand, Queensland and South African departments of forestry in using previously unpublished information is gratefully acknowledged. Similarly, the Kenyan, Nigerian, Tanzanian, Ugandan and Venezuelan forestry services have assisted in providing test material and permitting publication of the results of research reported originally in restricted reports to the countries themselves.

The writer is indebted to Mr. E.R. Palmer of the Tropical Development and Research Institute, U.K. for checking the pulp and paper section of the monograph and he is also indebted to colleagues, particularly Mr. P. McCarter for the preparation of an annotated bibliography of the wood properties of the species, and Dr. J. Burley, Dr. R.D. Barnes and Mr. J.F. Hughes for making available a number of unpublished and published documents known to them. Particular assistance was afforded by Mr. P.G. Franklin in preparing slides and photographs of the anatomy of the wood and the particle board photographs. Similarly, the assistance of the Tropical Development Research Institute is acknowledged for the photomicrographs of paper made from the species. Mr. P.J. Wood provided several of the photographs for plates and Mr. A. Allen photographed and printed discs from trees shown on the cover and in the text. Miss J. Howse (Assistant Librarian) saved the author many hours by finding the unfindable. The text figures were in many cases redrawn and prepared for printing by Mrs J. Max to whom a great deal is owed for much painstaking work. The typing and preparation of the tables were done by Miss T. Hodgkinson to whom a particular debt of gratitude is owed for bringing what order there is out of chaos. There are others who cannot all be thanked for their contributions but who have contributed in numerous ways, not least some who have encouraged the author when he was weakening or even before he started to weaken. Perhaps the ultimate in self sacrifice has been shown by my colleague Dr. C.G. Goodwin-Bailey who has allowed me to draw extensively on information derived from a project which he has carried out before he has completed the final report.

FIGURE 1. FROM LAMB (1972)

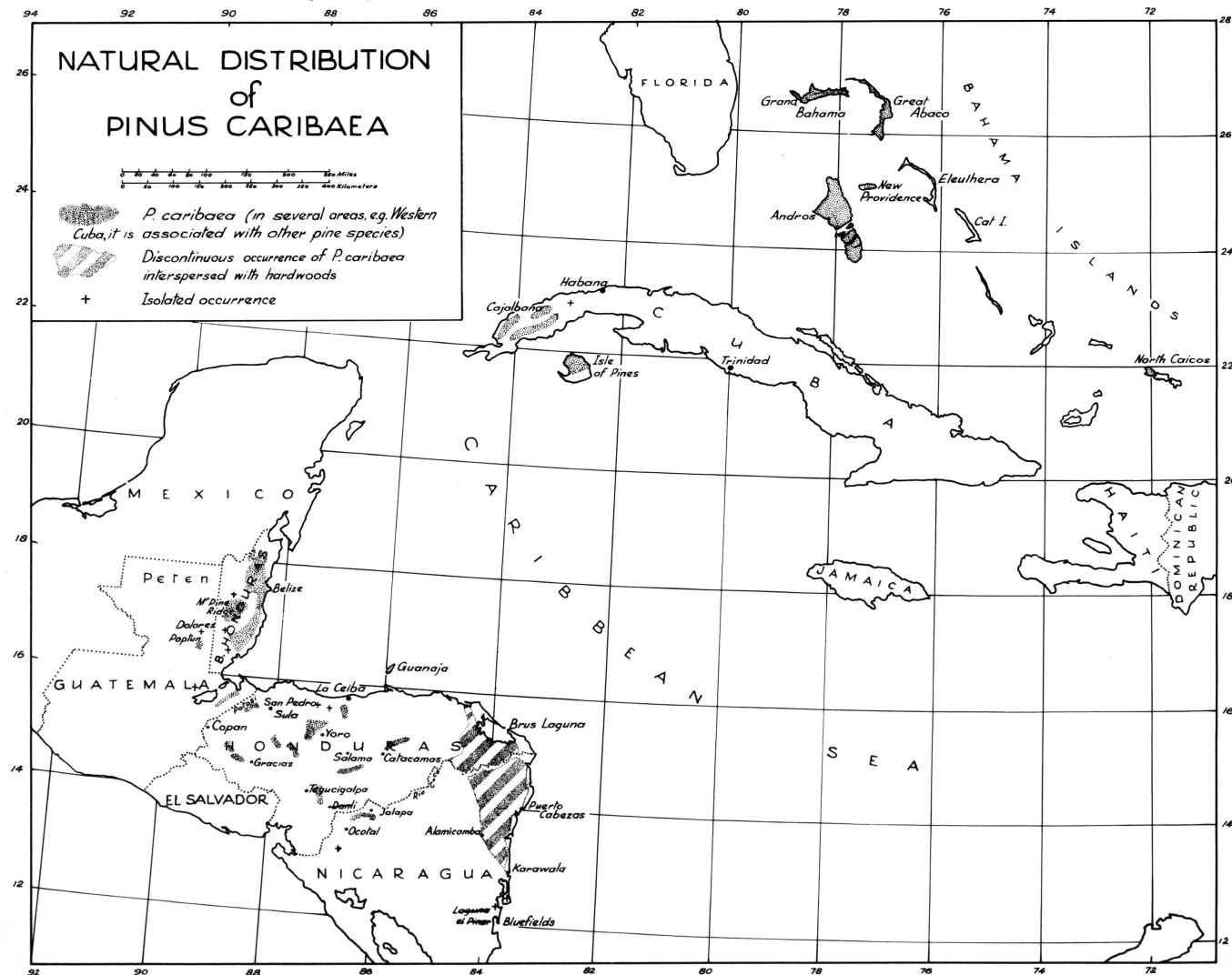
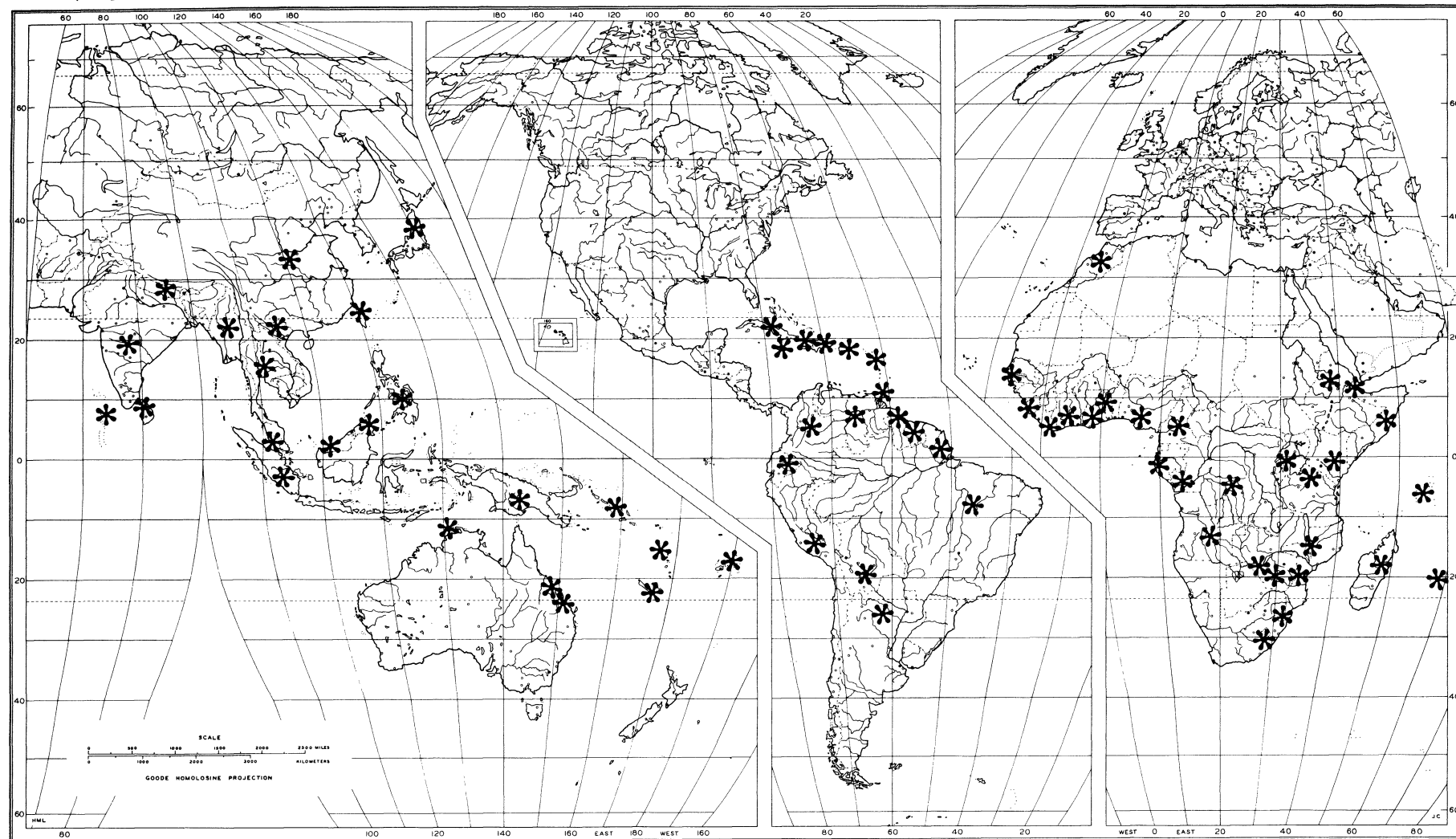


FIGURE 2. MAP OF LOCALITIES OF PROVENANCE TRIALS (co-ordinated by the Commonwealth Forestry Institute)

WORLD (abridged), CONTINENTS

No. 101HA



1.0 General characteristics of the wood

1.1 Naturally grown wood

The picture that emerges from the literature on the wood properties of this species is one of extreme variability from heavy, hard, narrow ringed and resin saturated at one end of the spectrum to soft, light, wide ringed and almost lacking in latewood and resin at the other end.

The majority of the early accounts of the wood come from British Honduras and one of the earliest by a visiting Indian Forest Service forester (Hooper, 1887) describes trees with maximum diameters at breast height of 2-2½ ft diameter but averaging only 10 ins; narrow rings, high wood density and open spaced trees in grassland were common; a sample acre in one of the denser areas contained 101 trees with a tree of 6.6 ins radius having 60 rings. He mentions, however, that "pitch pine of young half grown trees soon rots". In contrast he describes scantlings 3 x 4 ins (75 x 100 cm) in cross section which were taken out of the 80 year old court house in Belize City and were sound enough to be re-used in the building of the new courthouse.

The forest was repeatedly burnt over by Indian hunters. The tree was known to be resinous and resinous pieces of wood were used as torches. In the 1935 Annual Report for the British Honduras Forest Department mention is made of a quarterly court document of 1793 where it states that "at Poor Mans Rest local people were allowed to cut pine free of charge near the settlement".

Hummel (1923 and 1926) a generation later, described a similar situation with pine on the poorer soils on the coastal sands and on sandy pine ridges which had been exploited and burnt over for the previous 200 years. He suggested cattle grazing as a method of keeping down grass and reducing fire damage to the trees. There were, however, large areas of pine of exploitable size and two sawmills to cut them had recently started up. Trees up to 2 ft girth (68 cm diameter) and 102 ft (31 m) height are described with an estimated stocking of 3000 ft³ per acre (214 m³/ha). He estimated annual yield per acre at half a ton (approximately 1.8 m³/ha). Some trees were said to produce a good resin flow and others a poor flow but a resin tapping industry was considered to be a good possibility.

At about the same time Record and Mell (1924) described the wood from Central America as heavier than longleaf pine (Pinus palustris) and containing a greater quantity of resin. They quoted the following account of the wood from F.H. Fischer of Central American Sawmills, Cape Gracias in Nicaragua:

"The pine (Spanish, "pino" or "ocote"; Miskito Indian, "anas") occurs in scattered belts and ridges from the coast to the hills in northern Nicaragua and Honduras. The stand is usually thin and in patches with "bush" land intersecting along all creeks and rivers. No estimate of the stand per acre is available. The logs are rolled into the creeks or hauled with ox teams and 8-wheeled wagons to the rivers, where they are made into rafts and floated to the mill on the coast. Cross-poles of young pine or bamboo are used in making the rafts and the logs are

bound together into cribs of ten or twelve by very long and tough vines which are as good as rope for the purpose. When a certain lot contains many "sinkers" enough "polak" or "balsa" logs are placed in the rafts to keep them afloat. Only timber of good quality is sent to the mill, the minimum diameter of the logs at the small end being 12 ins, and the average length about 18 ft; the mill run is about 135 ft per log. The quality of the timber varies with the locality, but is excellent on the whole, being dense, close-grained, and largely heartwood. Prominent lumbermen of the United States consider it equal to longleaf yellow pine of the South".

Record and Mell then mentioned that although the pine occurs on several West Indian islands it is not of commercial importance.

Fahnestock and Garrett (1938) stated that the sawmills in Nicaragua found trees 30-40 ins diameter and 100 ft tall and occasionally produced sawn timber 45-50 ft long for special purposes. They also mention that extreme variations in strength with the highest bending and compression strengths being two to two and a half times the lowest in natural grown stands. They report less regularity in ring formation and more false rings than in the southern pines of the United States and suggested three quality classes based on the percentage of latewood, (I >30%, II 20-30% and III <20%).

Cox (1939) described the wood from "Honduras" (presumably British Honduras, now Belize) as "dense, hard resinous timber possessing high strength properties. When seasoned it is about 45% harder than commercial pitch pine (P. elliottii of southern USA) and 15% more resistant to shock loads and to splitting".

The sapwood is white to pale yellow in colour and the heartwood a light to medium brown but when strongly resin impregnated it is a deep red-brown. Sapwood varies in thickness according to the rate of growth of the tree but heartwood is seldom formed in the first 10 years of growth and often does not start forming till 15 or 20 years after the wood is laid down. Young plantation-grown trees, therefore, have little or no heartwood and, on the short rotations expected of plantation-grown material, little heartwood can be expected.

The 1920's and 1930's saw the start of a sawmill industry in Nicaragua and Belize (British Honduras) using P. caribaea but the immediate post Second World War period in the 1950's saw a further extension of exploitation for sawnwood; the market for resin seems never to have developed on a large scale in Belize although in the Honduras Republic it was widespread after the war. In Belize timber exploitation on Mountain Pine Ridge lasted from about 1955 till 1970 with a limited introduction of cattle grazing in some areas in the 1960's (Johnson and Chaffey, 1973). In the coastal pine areas exploitation started in 1945 and petered out by about 1966. From 1963-1965 stumps were used for the production of resin near Mango Creek but production was soon discontinued. In 1954 over one million cubic feet of pine were sawn in Belize of which 40% was used locally and the rest exported to the West Indies except for 5% sold outside the area. Timber sent to the United Kingdom was used for special purposes where large sizes were needed or the natural durability of the resinous heartwood was required as in

harbour piling or boat building. Much of the timber shipped outside the West Indies was, therefore, shipped as sawn or hewn baulks 20-25 ft (6-7.5 m) long and 12-14 ins (300-350 mm) square (Rendle, 1969). In Belize this burst of exploitation petered out about 10 years ago with the disappearance of the exploitable timber but regeneration on the Mountain Pine Ridge is now producing another crop which is at the stage of first thinning in some areas. The coastal pine is more sparsely stocked and less protected from fire and other damage.

Rates of growth of natural stands appear to be better and trees reach larger sizes at higher altitudes than by the coast in the Honduras Republic, Longwood (1962), and this would seem to be a trend that is followed in plantations. Pine from the Bahamas grown in natural stands shows about the same rate of growth as in Belize one tree of 15 ins diameter having 112 rings. Cutting for sawn timber is recorded as early as 1905 and a licence to exploit the natural pine for pulpwood was given in 1959 to Owens Illinois of the Bahamas Ltd. Since then large quantities of pulpwood from Abaco have been shipped to the United States at prices of as low as \$0.1 per m³ as compared with prices of 4-10 times that figure charged for P. elliottii in the Southern States (Henry, 1974). Charcoal burning of pine in the Bahamas has been common for some time.

Pine has also been sawn for over 200 years in the Bahamas (Kellogg, 1951) and there was a concession on Abaco in 1900. Sawmills were established on Grand Bahama in 1944 and Andros in 1948 and by 1951 annual production was around 35,000 m³ sawn and sold largely to the United States. The timber is reported to have been of good quality, dense and knot free but only commanding a price of about \$1.0 per cubic metre - insufficient to support a full time forester. Mean annual increment was estimated at 4.5-6.5 m³/ha/an. Pine was being used to produce charcoal but it was considered poor for use in iron smelting, having too much ash, while the wood was considered too resinous for fibre board manufacture.

Commercial utilisation of P. caribaea var. hondurensis and P. oocarpa for sawn timber is now widespread in the Honduras Republic with a large number of sawmills and some four planing mills in operation, including a large new mill of modern Canadian design near Siguatepeque. Sanderman (1953) described the resin industry in the Honduras Republic between 1945 and 1950 and stated that 300,000 trees worth \$4 million as sawn timber were being destroyed each year by destructive methods of tapping and recommended improved tapping methods. Sanchez (1971) suggested further improvements in technique; the resin industry, therefore, has a long history in that country. In Cuba it was estimated (Smith, 1954; Morellet, J., 1968) that at the beginning of the century 50% of the country was covered with forest but by 1954 only 15% cover was left as a result of land clearance mainly for sugar production and fuel and charcoal production. Pines of all kinds covered about 4% of the land area and P. caribaea was found only in small areas at the lower altitudes on seasonally dry soils which do not sustain hardwoods. At that time some 24,000 m³/an of pine timber were produced and stocks were estimated to be capable of lasting another 10 years but by 1980 pine log production from Cuba was around 1,000 m³/an or virtually nil although plantations had been



Plate 1. Variety bahamensis growing on recently burnt area in Grand Bahama

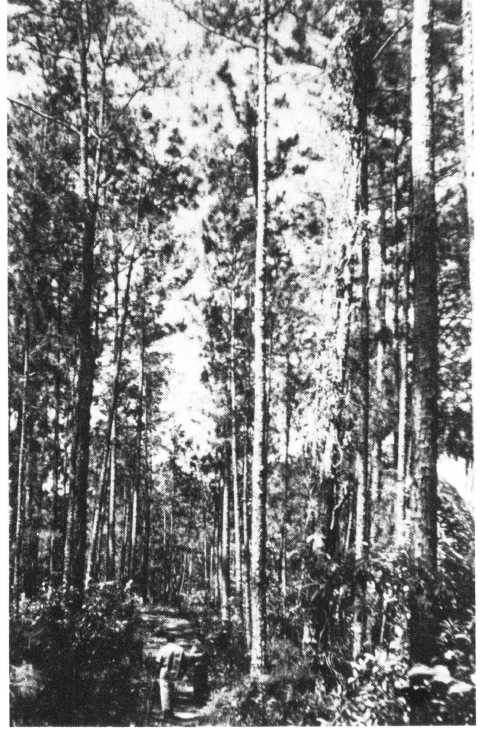


Plate 2. Protected stand of variety caribaea in La Guira National Park, Cuba.

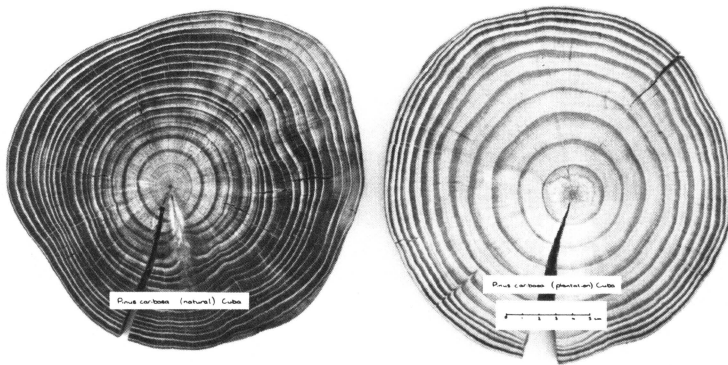


Plate 3. Natural and plantation grown trees of variety caribaea from Cuba (b.h. discs).
(Photographs by P.J. Wood and A. Allen).

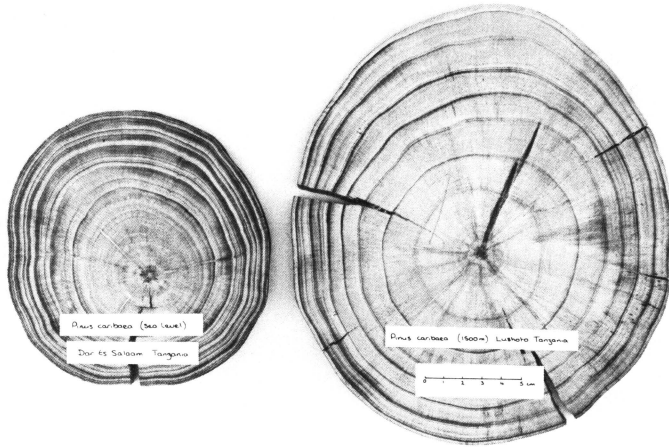


Plate 4. Variety hondurensis planted in a coastal site near Dar es Salaam and at 1500 m at Lushoto (b.h. discs).



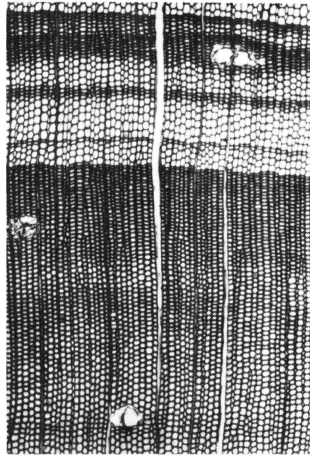
Plate 5. Variety hondurensis, three trees from the same 1 ha plot in Fiji (b.h. discs).
(Photographs A. Allen).

Plate 6. Anatomy of *Pinus caribaea*

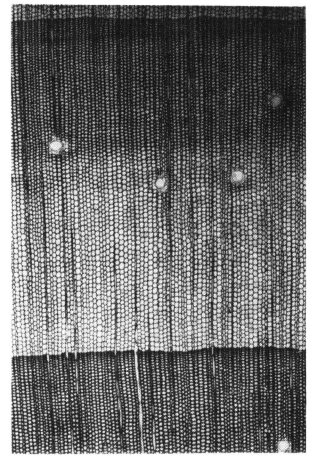
(a) + (b) Transverse sections showing (a) variable ring width and false rings, (b) pronounced annual ring and slow transition from early to latewood.

(c) + (d) tangential longitudinal sections showing (c) fairly high density wood and (d) lower density wood and ray patterns.

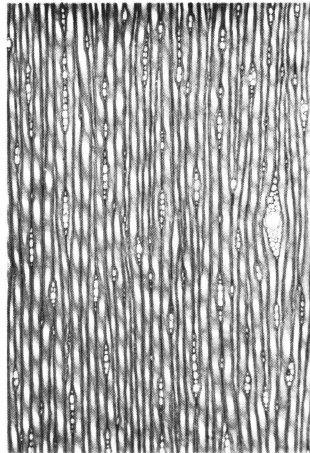
(e), (f) + (g) radial longitudinal sections showing rays and pitting including dentate wall thickening of ray tracheids cross field pits on radial walls of ray parenchyma and bordered pits on wood tracheids radial walls (The size and frequency of the latter vary considerably).



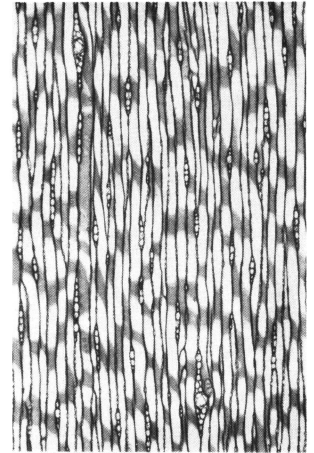
(a) x 25



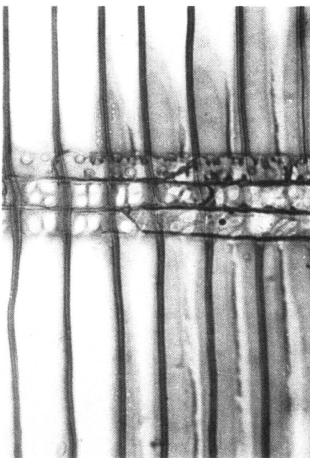
(b) x 25



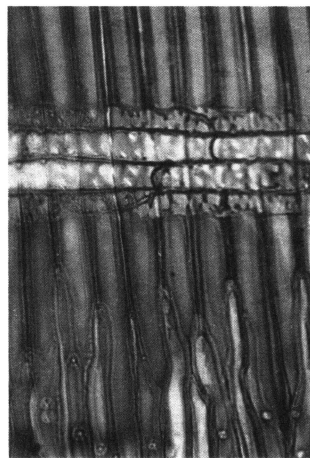
(c) x 25



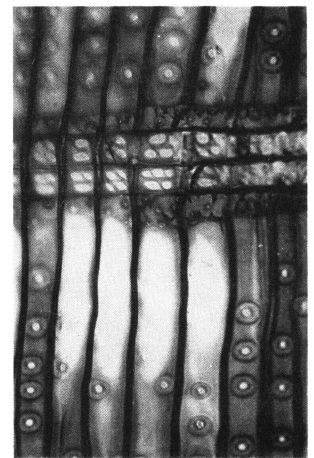
(d) x 60



(e) x 250



(f) x 250



(g) x 250

Photographs P. Franklin

established. Smith recorded that sometimes trees produce two growth rings per year coinciding with two dry and wet seasons but there is very little information available on the use of the timber in Cuba.

Hurricanes of varying intensity have occurred about every 20-30 years in Belize and the Bahamas; "Hattie" in 1961 in Belize was devastating with many trees on Mountain Pine Ridge and much of the coastal pine blown down; a similar hurricane in 1931 was said to have blown down "half the trees on Mountain Pine Ridge" while "Betsy", in 1965 in the Bahamas, flooded large areas of pine with sea water and killed them. Fire-damaged pines appear to be most at risk. The species in its natural environment, therefore, has a hard life and the occasional hurricane in plantations in Fiji must make it feel almost at home.

1.2 General characteristics of plantation grown-wood

Plate 3 shows the differences between the ring patterns in natural and plantation-grown material. The rapid early growth of the plantation material followed by a gradual narrowing of ring width, though not necessarily ring area, with increasing age at a given height in the tree is typical. The same pattern is evident in natural-grown material but the low density central core is much smaller and sometimes almost non-existent. The reasons for this may be severe grass competition, fire, soil compaction or competition from other trees. The low stocking of trees in many places suggests that often the main retarding factor may not be inter-tree competition. The soils on which the pines grow naturally are almost universally poor or they would have been carrying hardwoods and, when plantations are established on good soils with initial cultivation and fire control, growth is very rapid indeed compared with growth in indigenous stands.

Plates 3 and 4 show the more regular ring pattern evident in the P. caribaea var. caribaea than in var. hondurensis. Variation between individual trees of the same variety can be equally striking and throughout the literature the large differences in patterns of growth and wood properties between individual trees grown on the same site are mentioned repeatedly. There appears, therefore, to be considerable scope for breeding to obtain desired wood properties and environment alone accounts for only part of the variation.

1.3 Anatomical features

Anatomically P. caribaea is indistinguishable from other Pitch Pines including P. oocarpa, P. elliottii, P. taeda, P. palustris, P. rigida, P. glabra, P. serotina, P. echinata, P. virginiana, P. banksiana and P. pungens. Koch (1972) gave a detailed account of the anatomy of the southern pines of the United States and maintained that there is no known reliable way of distinguishing one from another on the basis of wood anatomical properties. They are distinguished from other pines principally by having dentate and reticulate ray tracheids and 3-6 elliptical pinoid crossfield pits on the radial walls of ray parenchyma. Very little work has been done on the anatomical characteristics of P. caribaea itself other than measurement of the size and shapes of cells

and cell walls. The brief account that follows, therefore, is largely taken from Koch (1972) but plate 6 shows sections of P. caribaea var. hondurensis in transverse, radial and tangential planes photographed at the Commonwealth Forestry Institute, Oxford.

1.31 Wood elements

Longitudinal elements

Longitudinal tracheids form 90% or more of the volume of the wood. They are arranged in radial files and are radially flattened in latewood but nearly isodiametric in earlywood. As in most other species the tracheid walls are made up of middle lamella, primary wall, S_1 , S_2 and S_3 layers where the middle lamella and the primary wall plus the S_1 wall and S_3 walls are each about $0.3\mu\text{m}$ thick in earlywood and $0.5\mu\text{m}$ thick in latewood while the S_2 layer is $0.5-1.5\mu\text{m}$ in earlywood and $3-7\mu\text{m}$ in latewood. The major difference, therefore, between the two types of wood is in the thickness of the S_2 layer. The tracheid ends are tapered to a point when looking at a tangential wall and in earlywood are rounded but in latewood more pointed when looking at a radial wall. Bordered pits from tracheid to tracheid are largely on radial walls. The middle lamella is composed mainly of lignin, the primary wall has cellulose strands loosely and randomly arranged, the S_1 layer has about 5 laminae of microfibrils at different, fairly large angles, the S_2 has microfibrils in a Z helix with a microfibril angle of about 15° and the S_3 layer has about twelve laminae at different fairly large angles. "Warty" layers are often found in the lumens of tracheids around pit apertures and inside pit chambers. Sporadic spiral thickening is occasionally found mainly in latewood. Also in some latewood transverse thickenings are found bounding bordered pit apertures on radial walls. Pit apertures are often slit-like in latewood but circular and usually surrounded by an inward-bulging dome in earlywood.

Strand tracheids occur occasionally along vertical resin canals outside the parenchyma. They are shorter than the longitudinal tracheids and have small bordered pits along the vertical walls and pitted transverse ends.

Resin canals. These are large and numerous and the vertical canals interconnect with the horizontal canals. They occur in both latewood and earlywood for the first 12 rings from the pith but tend to be more frequent in latewood in older wood. They are lined with thin walled epithelial cells which secrete oleoresins into them. Outside the epithelial cells longitudinal parenchyma cells are found in strands and are slightly longer than the epithelial cells. They are thin walled and have simple pitting. Tapping for resin may increase the frequency of resin canals above the wound by up to 10-fold in new wood laid down. Fast growth also seems to increase the frequency of resin canals.

Horizontal elements. These are all contained in the rays which are uniseriate except for fusiform rays containing horizontal resin canals. Slash pine has about 12% of wood volume in the form of rays (Koch, 1972) and there is some evidence that the nearer the location of the

pine to the equator the higher the ray percentage so P. caribaea could have a higher percentage of rays than P. elliottii.

Ray tracheids are located at the top and bottom of the rays and have complicated "dentate" wall thickening with tooth-like projections viewed radially or in transverse section but tangentially these are seen as irregular, circular or semi-circular ridges going round the cells but not completely closing the lumens. Walls adjacent to ray parenchyma have half bordered pits. The ray tracheids appear not to have distinct S_1 , S_2 and S_3 layers and orientation of microfibrils ranges from 0° to 45° . The pit chambers are smaller in these tracheids than in longitudinal tracheids but are similar in other ways.

Ray parenchyma are located in the central part of the rays. Some are thin walled and unpitted but others are thick walled and show elliptical "pinoid" pits. The wall thickening appears to be associated with heartwood formation to some extent.

Horizontal epithelial cells. These are similar to but smaller than those bordering vertical resin canals. They have lamellar walls which vary in thickness.

2.0 General properties of solid wood

The general wood properties and their variation are dealt with in this section as they affect the performance of wood used in solid forms.

2.1 Sawing - Green

There is little information recorded on the green sawing properties of the species but it has been successfully sawn from very early times (Record and Mell, 1924). The old naturally grown material with high density and resin impregnated wood tends to clog saw teeth with resin and running saws with clogged teeth may result in saw blunting. F.P.R.L. (1957) suggested the use of saws with longer than normal pitch between teeth. Application of diesel oil to the sides of saw blades and the teeth helps to remove resin. No problems have been reported in sawing plantation-grown material.

2.2 Seasoning

2.21 Natural grown material

Early reports on the seasoning properties of the species described a dense resinous wood, heavier and more resinous than the southern pines of the United States. The timber was mainly heartwood and Longwood (1962) recorded that natural grown wood from Belize and Nicaragua with a density of 0.77 g/cm^3 "seasons rather slowly with a tendency for end splitting in the thicker stock and for the sapwood of green lumber to be attacked by sap stain fungi unless it is dried without undue delay. Protection of the ends of flitches and the use of narrow stickers are recommended. Thinner stock air seasons fairly well provided drying is not too rapid although considerable lengthwise bowing may occur in one inch stock if a wide sticker spacing is used. However, the distortion in other directions is not serious. The timber also kiln seasons rather slowly. Considerable care is required for checking and splitting may be severe in the early stages of kiln seasoning, along with a marked tendency for distortion to occur. Kiln Schedule 6 of the Forest Products Research Laboratory in England is recommended".

Cox (1939) recorded that "The timber air seasons slowly and there is a marked tendency towards splitting during the seasoning process especially in the thicker dimensions".

U.K. (1937(b)) recorded that air drying in Britain took six months to dry one inch material from 40% to 18% m.c.

F.P.R.L. (1957) recorded "There is some tendency to split and check in the early stages and a marked tendency to distort later in the drying". Kiln Schedule H is advised (see Table 1 below).

Table 1. Kiln schedule recommended for naturally grown *P. caribaea*

Moist content % of the wettest timber	Temperature dry bulb °C	Temperature wet bulb °C	Relative humidity % (approx.)
Green	57	53	80
50	57	52	75
40	60	52	65
30	65.5	54	55
20	76.5	58	40

(From Stevens and Pratt, 1961).

Using a similar schedule it took 20 days to dry one inch timber from 45% to 10% m.c. (U.K., 1937(b)).

A recent trial of solar drying at Siguatepeque, Honduras Republic in 1981 dried a charge of 25 mm thick naturally grown *P. oocarpa* which was moderately resinous and could be expected to dry at a similar rate to *P. caribaea* from 58% m.c. to 10% m.c. in 26 days. (Unpublished information supplied by A. Bendeck in Honduras.)

2.22 Plantation-grown material

The seasoning properties of plantation grown material differ markedly from the properties of naturally grown material partly because the latter is almost always very much faster grown and partly because it has very little heartwood and normally a smaller percentage of resin.

Air-drying in Fiji

Plantations in Fiji give timber which air dries satisfactorily provided it is under cover, well stacked with closely spaced stickers and weighted to prevent distortion. Drying times of around six weeks are required to dry 30 mm thick timber from green (170% m.c. to 20% m.c.), (Gough, 1977).

Kiln drying in Fiji

Conventional kiln drying of Fiji pine has been successful for both 25 mm and 50 mm thick material and high temperature drying has proved successful for framing sizes (Alston, 1980). A suitable conventional schedule uses a dry bulb temperature of 71°C and a wet bulb temperature of 60°C for the whole drying period ending with a reconditioning treatment (with dry bulb 80°C and wet bulb 79°C) for two hours per 25 mm of thickness. Boards (25 mm thick) take 3-4 days to dry to 12-14% m.c. and planks (50 mm thick) take up to nine days.

High temperature drying with a dry bulb temperature of 115°C and a wet bulb temperature of 70°C is suitable for scantling timber followed by 4 hours reconditioning at DBT 80°C and WBT 79°C. Stack weighting of 1,000 kg per m² of stack is necessary and the process takes 30-36 hours. Re-drying of timber dried and then pressure treated with copper-chrome-arsenate preservatives in an aqueous solution takes about half as long again as drying untreated timber (Alston (1980) quoting Kininmonth (unpublished report)).

Solar drying in Fiji. 30 mm thick P. caribaea dried in a solar kiln in Fiji dried from 145% m.c. to about 12% m.c. in 40 days. The very high initial moisture content requires rapid removal of water from the surface of the wood and air drying followed by solar drying below 30% m.c. would probably be preferable.

Puerto Rico. Flat sawn 25 mm boards cut from 8-10 year old trees were air dried from over 200% m.c. to 18-20% m.c. and then kiln dried to 10% and none of 77 sample boards showed surface checking causing degrade, cup was light in 60% and medium to heavy in 40% of the boards, twist was light in 93% and medium to heavy in 7% while bow was light to medium in all boards (Boone and Chudnoff, 1972). These results were considered promising in view of the high proportion of compression wood in the trees (17.6-19.9%).

South Africa. Poynton (1975) recorded that P. caribaea grown in South Africa seasons easily despite compression wood and the lack of well defined early and latewood bands gives uniformity of texture and therefore stability for mouldings and joinery.

Australia. Siemon (1981) described an experiment in high temperature drying of P. caribaea var. hondurensis treated and untreated with a copper-chrome-arsenate wood preservative. Modulus of rupture was considerably reduced for the treated material but the reduction was non-significant and small for the untreated material.

Jamaica. Van der Slooten, Richter and Cordero (1969) recorded that material from three sites in Jamaica seasoned fast and well without degrade in the 70 mm x 70 mm x 1,000 mm samples. It was thought that thinner and wider boards might have shown more degrade.

The seasoning of plantation grown material, therefore, appears to pose few problems, even where a considerable quantity of compression wood is present. The ease of drying is likely to be related to density, to density gradient from pith to bark, to contrast between density of early and latewood within rings and to radius of curvature of rings in addition to the proportion of compression wood. It is clear, however, that a certain degree of care will be necessary in seasoning plantation-grown material.

2.3 Natural durability

The contrast in natural durability between the slow grown natural material containing heartwood heavily impregnated with resin and the young fast grown plantation material containing only sapwood is as

great as between chalk and cheese. Old growth pitch pine is noted for its durability and its suitability for such uses as building construction, marine piling and boat planking for which it is a prime timber with a reputation similar to teak for decking and oak for knees and beams. Hooper (1887) mentioned the re-use of 80 year old timber taken out of an old courthouse and many wooden boats planked with it have lasted 50-80 years with good maintenance. Longwood (1962) reported that standard graveyard tests in Britain gave a life of 10-15 years in the ground but the heartwood was rated only as moderately resistant to fungal attack on the basis of pure culture tests by the Forest Products Laboratory in U.K.. He further reported that similar tests at Yale University found the wood very durable to white-rot fungus but not durable to brown-rot fungus. Resistance to termites appears largely to be governed by the quantity of resin in the wood. Sapwood is not durable and is susceptible to blue stain, rot and, in log form, to Ambrosia beetles (Anobiids and Bostrychids) in the sapwood, but being a softwood is not attacked by Lyctus (powder post beetles). It can be assumed, therefore, that since heart wood formation does not begin until about 20 years after the wood is laid down most plantation-grown material will never reach the age where trees contain an appreciable amount of heartwood. Since this is the case it can be assumed that all plantation-grown material will require protection against blue-stain, log borers (although the hazard from these is not great), rot of all kinds and termites.

2.4 Preservation

The older standard textbooks state that the sapwood is easy to treat by both pressure and hot and cold dip treatments with creosote while the heartwood is moderately resistant to treatment but can be treated adequately using vacuum pressure methods. Longwood (1962) said that the ease with which the heartwood can be treated depends largely on the amount of resin present. It can, therefore, be assumed that the more durable wood is less well treated and the less durable better treated. Table 1 in Appendix 1 gives the results of graveyard tests in Mississippi using southern pine sapwood, which can be assumed to be almost identical to P. caribaea, using various concentrations of different preservatives. It can be used as a guide for preservative retentions required for external ground contact. Longwood (1962) recommended:

- 20 lb/ft³ (320.4 kg/m³) of coal tar creosote for marine use in coastal waters
- 12 lb/ft³ (192.0 kg/m³) for piling used on land or in fresh water
- 8 lb/ft³ (128.2 kg/m³) for railway sleepers and poles
- 6 lb/ft³ (96.1 kg/m³) for posts, sawn timber and elevated structural timbers

Coetzee (1974) in South Africa reported that small P. caribaea poles treated with copper-chrome-arsenate lasted 12 years with very little degrade as opposed to 1 year's life to failure with untreated poles. He recommended an average of 9.6 kg/m³ of dry salt retention, with a minimum of 8 kg/m³ for satisfactory protection.

In Malaysia Choo and Grewal (1982) found that transmission poles of Pinus caribaea var. hondurensis dried to 22% in 130 days in the open or in a seasoning shed with very little degrade. The outer 50 mm reached 30% in 30 days but when treated by sap displacement with a 3% solution of copper-chrome-arsenate wood preservative they took 55 days to dry. Because of the rapid surface drying it was concluded that sap displacement treatment should be done within two weeks of felling. Even this is probably too long and treatment should be done if possible within a day or two of felling.

Van der Slooten, Richter and Cordero (1972) tested loading and penetration of a copper-chrome-arsenate salt and pentachlorophenol in oil using a variety of processes on wood from a five year old tree. The processes and retentions were as follows:

<u>Preservative</u>	<u>Solvent</u>	<u>Concentration</u>	<u>Treatment Process</u>	<u>Retention (kg/m³)</u>
1. Osmose k33	Water	4%	Lowry process	19
2. Pentachlorophenol	No. 2 fuel oil	5%	" "	444
3. "	"	"	Hot and cold tank process	492
4. "	"	"	Rueping process	133

Treatments 2 and 3 gave three and four times the required retention and in all treatments penetration was complete throughout the pole cross section. The wood density of this tree averaged 0.33 g/cm³. As mentioned above in para 2.22 C.C.A. treatment appears to result in a slight loss in strength particularly if high temperature drying is practical.

Alston (1981) described the treatment requirements for different degrees of hazard in Fiji as follows:

1. Out of ground contact and protected from the weather
2. Out of ground contact and not protected from the weather
3. In ground contact:
 - A - low risk, low value items (fence posts etc.)
 - B - high risk, high value items (house piles etc.)
4. Marine uses

For all these uses he classified Pinus caribaea var. hondurensis grown in plantations in Fiji, as non-durable. He then classified the species as treatable to withstand all these hazards by the "Bethel" or full cell vacuum-pressure treatment process. For treatment hazards 1-3 inclusive he specified the "Q" pressure process as suitable drying pre-treatment before preservation for round pine timber only. In this process green pine poles are steamed under pressure and then the pressure is released and the water evaporates on release of the pressure. There follows a holding period of several days under cover to remove further water this is followed by the normal full cell vacuum-pressure treatment.

By contrast with its ease of treatment by pressure and hot and cold tank processes P. caribaea is not easily treated by diffusion treatment with a hot dip boron-chrome-arsenic formulation (Timber-Tox) or cold dips with a boron-fluoride-chrome-arsenic formulation (Kopper's formula 7). The minimum preservative loadings can only be obtained in timbers of pine up to 50 mm thick during a diffusion period of 6 weeks which was assumed by Alston to be the maximum period which would be economically feasible.

2.5 Woodworking

The timber presents few problems in machining once it is dry except in highly resinous naturally-grown material where the resin tends to clog knives and cutters and gum up tables and fences. Proper drying tends to evaporate the more liquid and volatile resins and reduce this problem and only periodic cleaning of knives and cutters is necessary. Picking up of the grain around knots during planing tends to occur (Longwood, 1962) but can be reduced by careful knife sharpening and setting and by the removal of resin from knife and cutter edges.

The timber is often more uniform within rings and has denser earlywood than some temperate conifers particularly where false rings produce frequent bands of latewood in P. caribaea. This makes for a more uniform material which planes and sands better and gives better screw holding, better finishing and crisper edges than would normally be expected with some temperate conifers. There is also less tendency to splinter and split along weak earlywood planes.

Similar conclusions were reached by Scott (1952) for 19 year old P. caribaea grown in plantations in South Africa where the timber was milder, less knotty and easier to work by hand than P. elliottii.

Poynton (1975) in South Africa also described this uniform nature of wood and its consequent suitability for mouldings and joinery when not over resinous and where high strength is not required. Further confirmation of this comes from Cown et al. (1981) for material grown in Queensland where uniformity of texture in spite of low density made the timber easy to work and more suitable than P. elliottii for general purpose uses.

The sawing, planing, moulding and turning properties of the wood when dry and not excessively resinous are, therefore, better than would be expected of temperate conifers of similar wood density.

The nailing of quarter sawn boards of naturally grown material caused splitting according to U.K. DSIR (1937) but young, lower density material nails easily with little splitting.

The naturally grown timber bends moderately well but resin can cause trouble during steaming (Longwood, 1962). No information has been found on the bending properties of plantation grown material.

3.0 Natural defects in solid wood

These are defects which occur naturally and are not induced by seasoning or other treatments applied to the tree during or after felling.

3.1 Juvenile core

P. caribaea grows very rapidly in plantations, particularly on fertile sites, in the first few years and P. caribaea var. hondurensis tends to grow more vigorously at this stage than other varieties. This rapid growth results in wide rings, a high proportion of early wood and on some sites, very little latewood at all; it also results in shorter tracheids and generally inferior wood. The central core of juvenile wood normally lasts for the first 5-8 years of growth which often coincides with full canopy closure. There is then a gradual transition from juvenile wood to denser, stronger more mature wood. The pattern of juvenile wood formation and transition to more mature wood varies with the genetic make-up of the tree, the site, the climate and the silviculture practised and will be discussed in greater detail below but there is little doubt that it is a very real defect. The lowest density juvenile wood may be only two thirds of the density and half the strength of the mature wood. It is more liable to have severe spiral grain and is more prone to distortion on drying often containing a larger proportion of compression wood than the mature wood. It is, therefore, normally suitable for a totally different and much lower grade use from the mature wood but cannot easily be separated from it by sawing although peeling for plywood may achieve this separation more easily. Normally the juvenile core at the base of the tree in the bottom log (which may account for up to 75% of the tree value) is of poorer quality than further up the tree. By contrast the outer wood at the base of the tree is normally the strongest and most valuable wood in the tree having the most regular ring formation with the least curvature of the rings of any wood in the tree. In saw logs from young plantations much of this outer high value wood is discarded in slabs when the logs are sawn; the large juvenile core, therefore, becomes a serious defect and anything that can be done, to reduce its size is valuable provided that overall tree volume is not seriously reduced.

3.2 Knots

Knots in any pine can be a serious defect particularly if the wood is to be used for a structural purpose. The curvature of grain around live knots and the discontinuity of the grain in dead knots form points of weakness and result in strength reductions. Visual strength grading rules recognise these facts and attempt to allow for reductions in strength for various sizes, shapes and positions of knots in a piece of timber. Mechanical stress grading measures actual strength normally by deflection and measurement of Modulus of Elasticity which is closely correlated to Modulus of Rupture or strength in bending. Normally mechanical stress grading gives a higher grade than visual grading and the actual reduction in strength tends to be less than might be expected because of greater wood density and strength in the knot and the wood around it.

Malan and Toon (1980) reported from South Africa that "The knots in P. caribaea and P. elliottii are generally well distributed and small and in such cases their influence on wood quality is minimal". This is in contrast to P. radiata, P. patula, P. pseudostrobus, P. montezumae and P. kesiya where "Knots are a significant problem".

Besides affecting strength, knots affect workability, appearance, gluing properties and paintability since the changes in grain direction and wood density can affect machining while resin accumulations tend to occur in and around knots. Shrinkage of knots on drying also often causes distortion as a result of grain angle changes and differential shrinkage between different grain axes. From the point of view of appearance, however, sound knots can often be an advantage and knotty pine is often more popular than clear timber for panelling or interior joinery.

There is not much information on knots in P. caribaea other than in Malan and Toon (1980) but in general the species is fairly lightly branched, the branches are well spaced and whorls are not very strongly pronounced or very close together although, on the whole, the whorls are not as widely spaced as in P. radiata except in foxtailed trees where absence of branching is very pronounced. Selection and breeding for uniformity of branching and small branches has been practised in most countries where appreciable quantities of the species are being planted and it can be assumed that in future knot sizes will be reduced. Silvicultural practice influences presence and size of both live and dead knots and this subject is discussed below (para 7.12). With good silvicultural and breeding practice, therefore, knots should prove less of a problem in marketing the timber than in many other pine species.

3.3 Spiral grain

This is a major defect in timber both in the round and sawn forms. In general strength of wood in the round and in normal dimensions of sawnwood is not seriously impaired by grain angles to the axis of less than 4.5° . A grain angle of 4° results in a strength loss of up to 10%, one of 6° about 20% and one of 11° about 45% in standard static bending tests (Modulus of Rupture) while comparable losses in impact bending are, for these angles, 20%, 40% and 60%, whereas for compression strength parallel to the grain they are 0%, 1% and 7% (Koch, 1972). The seriousness of the defect, therefore, depends greatly on the use to which the wood is to be put and the dimensions in which it is used. The requirements for tool handles or sports gear, therefore, need to be much tighter than for timber used in compression as a support.

The variation of grain angle in P. caribaea is described in more detail under physical properties below (para 4.4) but in general the grain angles found have been lower than in some other pines in most sites but in Fiji high grain angles have been found and may prove to be a serious defect in timber there. There are large between-tree differences in grain angle and in breeding it is a character that needs to be considered.

3.4 Resin

All varieties of the species produce considerable quantities of resin which can be a useful commodity if tapped and utilised but it can prove to be a defect. Resin is present in relatively small quantities in both horizontal and vertical resin canals where it is secreted into the canals from epithelial cells. It can, however, be a defect in processed timber where it has accumulated in large quantities. Accumulations are normally the result of damage in the heartwood or around knots. Star shaped resin deposits in and around the pith of plantation grown trees are common and may contain up to 40% by weight of resin.

The resin contributes to durability of heartwood but is a defect where it clogs cutters, prevents sanding and bleeds through paint and other coatings. It is less of a defect if oil based stains and wood preservatives are used instead of paints. Seasoning, particularly high temperature drying, evaporates many of the more volatile resins and makes finishing and painting easier since the residual resin is often hard and crystalline. As with most characteristics some trees appear to be more prone than others to resin infiltration.

Malan and Toon (1980) suggested that resin infiltration into the wood may be due to a variety of forms of damage in the stem:

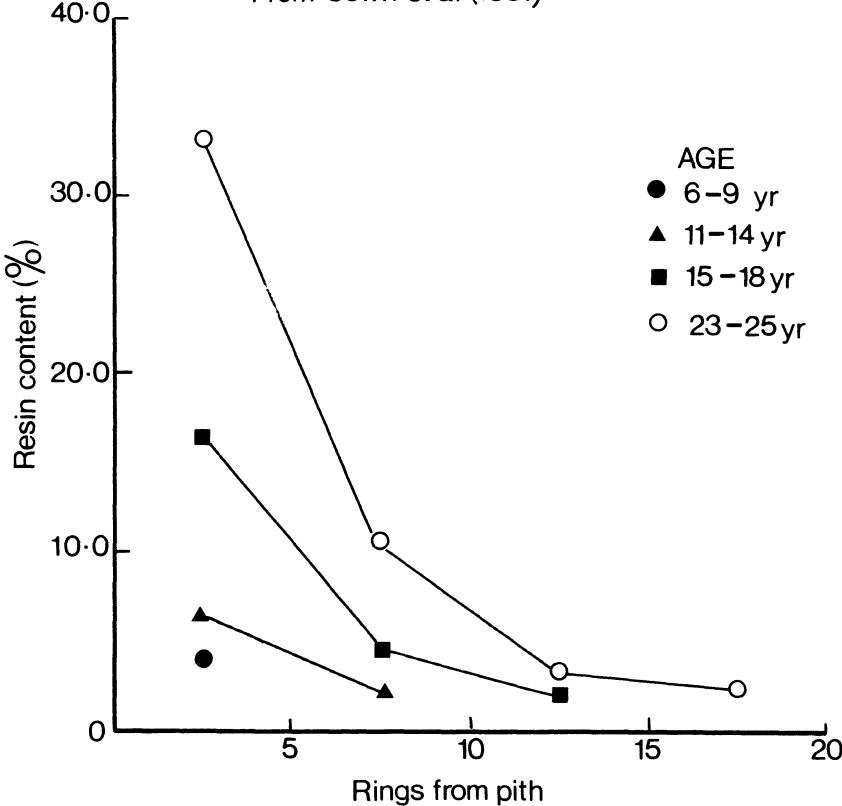
Resin pockets are well defined intercellular cavities containing liquid resin normally confined within a single annual ring, oval or elliptical in cross section or up to 3 mm wide and 10 mm long. They are thought to be caused by wind overstressing the cambial region or by nail or other damage to the cambial area. Although they form small weak points in the wood their main degrading effect is to produce liquid resin which is in itself a defect in sawnwood and veneers.

Resin infiltration. The infiltration of resin into the wood is often associated with checks and splits radiating from the pith or with knots, where wing shaped resin deposits develop along the grain around the knot.

The splits could be caused by wind stressing or by dry periods causing the wood to dry slightly and split around the pith. Severe resin infiltration around the pith can be a serious defect and Banks (1977) examining 24-26 year old trees of P. caribaea var. caribaea and var. hondurensis in South Africa found resin streaks affecting 5% of the var. caribaea timber and 28% of the var. hondurensis timber but the var. caribaea was more seriously infiltrated than the var. hondurensis where infiltration occurred. Bolza and Keating (1972) reported resin infiltration in 27 year old trees in Africa to be so serious that they recommended felling trees at 15 years old. This is probably an over-reaction and only necessary in very limited locations where damage by wind or other agencies is very severe.

In one of the most comprehensive studies done on resin infiltration (Cown et al., 1981), the accumulation of resin in different locations within 15 trees grown in Fiji was measured and is summarised in Figure 3. The results are shown in full in Appendix 2 demonstrate strikingly the progressive accumulation within the wood of resin with time.

FIGURE 3. AVERAGE BREAST HEIGHT RESIN CONTENT TRENDS
From Cown et al (1981)



Whether this is largely the result of hurricane damage or a normal characteristic of the tree is difficult to determine, but experience in Fiji would tend to confirm Bolza and Keating's conclusions.

3.5 Compression wood

Compression wood is characterized by being darker than early wood and often a more pronounced orange-brown colour than the latewood. It blurs the boundaries between early and latewood and normally is associated with wider rings and an eccentricity in the stem. It can be formed in a large block of tissue on the lower side of a leaning stem or, in young trees particularly, it may form in lens shaped areas in one or two rings and then revert to normal wood. These areas may be apparently indiscriminately scattered around the stem and are probably responses to temporary stresses resulting from minor irregularities in the stem.

The cells are thick walled in both early and late formed wood and the tracheids are rounded with intercellular spaces. The wood contains a larger than normal proportion of lignin and galactose in the cell walls and particularly in the S_2 layer. When dry, compression wood is stronger in compression but weaker in other properties than normal wood. The fibre saturation point is lower than for normal wood owing to the inability of the cell wall to hold so much water and the equilibrium moisture content is higher than normal. S_2 microfibril angle and longitudinal shrinkage are much higher; shrinkage can be up to ten times that of normal wood while transverse shrinkage is lower. This can result in severe distortion in pieces of timber containing both types of wood and is probably the main reason why compression wood is a major defect. Finally, the longitudinal permeability of compression wood is lower than for normal wood and can lead to problems in preservative treatment of the wood but this is probably not a limiting factor in P. caribaea where normal permeability is good.

Compression wood appears not only to be associated with stem lean but is also associated with knots and the underside of branches (Koch, 1972) and can be found in apparently straight stems; Boone and Chudnoff (1972) in Puerto Rico reported that boards of P. caribaea kiln dried to 10% m.c. with very little degrade in spite of containing large quantities of compression wood. Brown (1969) reporting on material from Jamaica found that quantity of compression wood was positively correlated with lean and bend in trees and with diameter breast height but negatively with tree height (but these conclusions were based on measurements from only ten trees).

Smith (1978) in Queensland, Australia, found the highest percentages of compression wood in P. caribaea var. caribaea although stems of this variety were straighter than var. bahamensis and var. hondurensis and concluded that the var. caribaea trees have a greater sensitivity to bending and produce compression wood more readily to correct it.

Whiteside (1981) reported low longitudinal shrinkage for P. caribaea var. hondurensis in Fiji in spite of considerable quantities of compression wood.

It appears, therefore, that compression wood, particularly in young trees, may not be as serious a defect as is sometimes feared, particularly if it is present in only a few rings at any one location and does not form solid blocks.

3.6 Brittleheart and brashness

The very low density juvenile cores of some plantation grown P. caribaea are liable to produce "brittleheart" in later life. Brashness can occur anywhere in the wood. Both are associated with compression and slip planes in tracheid walls probably caused by wind or growth stresses and probably exacerbated by the laying down of denser stronger wood outside the central core which has different properties and is more capable of withstanding the growth stresses. The effect of brittleheart, therefore, makes weak wood even weaker. No surveys of brittleheart and brashness have been recorded for P. caribaea but they are likely to account for some of the instances of very weak wood taken from juvenile cores.

3.7 Other minor defects

Other less frequent or less serious defects occur such as wandering pith where the tree was sinuous when young and later became straighter. Timber cut through the pith is of lower quality than normal. P. caribaea var. hondurensis grown on good soils in old high forest areas often exhibits very rapid growth and sinuous form which leads to this condition. Nodal swellings can occur and result in low recovery but they are more common in P. patula and infrequent in P. caribaea. Needle traces are often included within the wood of P. caribaea particularly if foxtailed in early life and may be regarded as a defect but can be regarded as decorative. Canker and other damage caused to the bark result in knobs, irregular grain, resin infiltration and sometimes rot, which all reduce the value of the timber. Thinning, felling, bad pruning and animal damage can all contribute to this.

4.0 Physical properties

4.1 Cell dimensions

There have been numerous studies dealing with P. caribaea cell and particularly tracheid dimensions, both in cross-section and in length. Many of the studies have also attempted to relate cell dimensions to end-use properties.

In general the earlywood tracheids of P. caribaea are rather larger in cross section and thicker walled than those of temperate pines such as P. sylvestris. The cells also appear more round and less rectangular in cross section. The latewood also has less flattened cells. The whole structure is larger and coarser and lumens, cell walls and pits are all larger in dimensions.

The length of tracheids is important in imparting strength to timber and paper made from the wood but it is now recognised that this is only critical below a length of 2 mm and most P. caribaea tracheids are longer than this. Probably more important for paper making are the cross-sectional measurements of the cells and cell walls which determine the collapsibility and conformity of the cells and the burst and breaking length of paper made from them. The strength and rigidity of the individual fibres is important in determining tear strength and this is normally high for P. caribaea whereas burst and breaking length are normally less good.

Methods of preparing material for measurement of tracheid dimensions vary; wood anatomists normally macerate wood for tracheid length measurement using hydrogen peroxide and acetic acid while paper makers often measure fibres produced from sulphate pulping or acid chlorite pulping. Cross-sectional dimensions are measured on solid wood or on sections by wood anatomists. While all these methods will give reasonably similar results for tracheid length they do not do so for all cross-sectional measurements and sulphate pulp may give a 50% greater measurement than chlorite pulp for cell width (Palmer and Gibbs, 1968). It is, therefore, essential to compare like with like.

4.11 Tracheid length

Tracheid length increases from pith to bark in a linear or quadratic fashion within a tree varying from about 2 mm length near the pith to about 6 mm at 14-20 years old and, thereafter, decreasing slowly or remaining level. Garcia de Leon (1982) found that minimum tracheid length increased faster than maximum tracheid indicating that tracheids not only become longer in older wood but more uniform in length. Patterns of variation up and down the tree at a given ring number from the pith are much less pronounced and are liable to be quite different in different trees. The trend however is for an increase in length from the base to 30-50% of the height of the tree and thereafter a reduction in length (Vivekanandan and Chandraratne, 1978, and Brown 1969). Lengths and cross-sectional dimensions of cells also vary markedly from tree to tree but the radial pattern is always there. Within rings, recent research suggests there is a tendency for latewood

to have longer tracheids than earlywood (Hoffman et al. (1978), Barrichelo et al., (1979), Resch and Bastendorff (1978) and Bayne (1960)) but a few earlier authorities claim there is little variation within rings, (Inchbold Stevens, 1959).

Table 2 gives fibre dimensions of different P. caribaea varieties collected for pulping trials from various locations. The main fibre characters were measured from sulphate pulp and are comparable. Since the ages of the trees are included comparisons of variety, age and site are possible but should be viewed critically since variation between trees is large and often relatively small numbers of trees were sampled.

The radial gradient of tracheid length at breast height expressed as a mean of 360 radii from 180 trees from 18 sites in Fiji is given below:

Ring No.	2	5	10	15	20
Tracheid length mm	3.4	4.4	4.8	5.1	4.8

(from Cown et al. (1981))

4.12 Cell cross-sectional dimensions and cell wall thickness

Cell widths are shown in Table 2 as discussed above but are not comparable with measurements made on solid wood which are much smaller (15-18 μ as measured by Garcia de Leon, 1982). Both radial and tangential cell widths vary considerably between trees and there is a significant but not very pronounced increase in cell widths radially from the pith to about ring 4 and then a slow decrease (Ong, 1978). On average, radial and tangential measurements are similar (radial 15.3-18.0 μ and tangential 14.8-17.0 μ according to Garcia de Leon (1982)), although radial flattening may occur in some latewood. Average cell wall thickness shows a slow, steady increase from the pith outwards according to Garcia de Leon (1982) but Ong (1978) found no consistent variation.

4.13 Site and provenance differences

Paraskevopoulou (1973) found significant differences for tracheid length but not for cross-sectional dimensions between natural and plantation-grown material of var. caribaea in Cuba while significant but not very large differences between provenances planted on the same site were found by Dyson (1971) for cell length. Similar differences were found for cell length and cell tangential and radial diameters by Garcia de Leon (1982). Smith (1973 and 1978) reported that P. caribaea growing in Queensland has longer tracheids than P. elliottii or P. taeda and that variation in tracheid length between varieties bahamensis and hondurensis were non-significant although significant at 90% confidence level in the 10th ring (representing growth outside the juvenile core).

There appear to be no significant differences in tracheid dimensions between foxtailed and non-foxtailed trees (Hoffman et al., 1978).

Table 2. Comparison of tracheid dimensions of *P. caribaea* (by ages, locations and varieties)

Location	Age (years)	L (mm)	D (u)	e (u)	$\frac{L}{D}$	$\frac{d}{D}$	$\frac{2e}{D}$
<u><i>P. caribaea</i> var. <i>hondurensis</i></u>							
Jamaica	10	3.65	56.9	7.0	64	0.76	0.34
	11	4.18	54.9	7.5	77	0.73	0.38
	15	4.20	58.3	6.5	72	0.77	0.30
Trinidad (5)	5	2.55	39.1	6.0	66	0.69	0.45
	10	3.94	53.2	5.8	74	0.78	0.28
	14	3.77	48.9	6.3	77	0.74	0.35
	17	3.91	43.3	7.3	92	0.67	0.50
Venezuela (2)	5	2.62	41.3	5.9	64	0.72	0.40
Sabah (3) (8)	5	2.57	46.5	4.3	55	0.81	0.23
	9	2.90	52.0	5.1	56	0.90	0.20
Honduras (1)	10	-	50.0	7.0	-	0.72	0.39
	11	-	50.5	9.1	-	0.64	0.56
	12	-	47.3	8.0	-	0.66	0.51
	13	-	47.3	7.0	-	0.70	0.42
	17	-	42.4	9.4	-	0.56	0.80
	19	3.05	43.4	9.5	70	0.56	0.54
	24	-	42.5	12.0	-	0.44	1.29
Congo (6)	7	2.66	40.0	-	-	-	-
Fiji (4) (9)	9	3.38	38.8	4.5	87	0.77	0.30
	10	2.93	38.4	4.1	76	0.79	0.27
	10	2.67	37.9	4.2	70	0.78	0.28
	15	3.10	44.9	5.7	69	0.64	0.25
Malaysia (7)		3.09	61.0	14.2	51	0.78	0.47
Sri Lanka (10)	9	2.31	30.5	5.1	76	0.83	0.33
	20	2.85	30.1	5.6	95	0.81	0.37
	22	2.87	38.0	5.5	60	0.86	0.29
<u><i>P. caribaea</i> var. <i>bahamensis</i></u>							
Bahamas (11)	30-50 Natural grown	2.7	41.0	7.5	66	0.82	0.37
<u><i>P. caribaea</i> var. <i>caribaea</i></u>							
Cuba (12)	Natural grown	3.61	44.7	6.74	81	0.85	0.30
		3.11	52.0	5.04	60	0.90	0.19

Legend: L = Length $2e/D$ = Runkel factor
D = Diameter L/D = Flexibility factor
e = Wall thickness d/D = Relative wall thickness
d = Lumen

() Literature reference

- (1) Chittenden and Palmer (1959)
- (2) Fairest, R.W. (1967)
- (3) Palmer and Gibbs (1967)
- (4) Palmer and Gibbs (1968)
- (5) Palmer and Gibbs (1969)
- (6) Tissot (1968)
- (7) Palmer and Peh (1966)
- (8) Palmer and Gibbs (1970a)
- (9) Palmer and Gibbs (1972)
- (10) Palmer and Ganguli (1982)
- (11) Palmer and Gibbs (1970)
- (12) Palmer and Gibbs (1975)

4.14 Predictability of tracheid dimensions

Morphological characters were found not to be correlated in any significant way with tracheid dimensions but Garcia de Leon (1982) and Ong (1978) both recorded good correlations between 5% height and whole tree values for tracheid dimensions indicating that cores or discs taken at about breast height give good predictions of whole tree values once the relationship between the two is known.

4.15 Correlations between tracheid dimensions and paper properties

In general correlations between tracheid dimensions and paper made from matched wood samples are not very good. Tear strength is moderately well correlated with tracheid length and density but correlations are not good enough to predict the quality of paper obtainable from anatomical or physical properties measured on wood samples. (See paragraph 8.311 below.)

4.16 Conclusions, cell dimensions

Methods of measuring cell dimensions have improved over the years but are still slow, tedious, incapable of measuring adequate samples of the very large number of tissues and cells in wood, or of giving very accurate measurements of such things as wall thickness. Image analysers hold out possibilities for improvements in future. P. caribaea is however known to have large tracheids with thick walls which have an influence on the properties of paper made from it and affect its strength for other uses. The large between-tree variations and relatively smaller between-provenance and between-variety differences suggest that within provenance genetic variation and site variations have a strong influence on the type of wood produced. Further work on breeding and the application of silvicultural techniques to improve certain desired characteristics should yield considerable gains.

4.2 Micellar angle

This tends to be inversely related to cell length and, therefore, decreases as wood becomes more mature from the pith outwards at any given height in the tree. P. caribaea var. hondurensis has mean values normally below 25° from pith to bark despite considerable variation between trees. P. elliottii and P. taeda (Smith, 1978) have higher micellar angles than P. caribaea.

4.3 Shrinkage and movement

Shrinkage and movement of the wood of the species are sufficiently different between naturally grown and plantation-grown material for them to be considered separately.

4.31 Naturally grown material

Shrinkage of naturally grown P. caribaea has been measured by a number of investigators and the results are given in Table 3 below. Since some measurements are made from green to air dry (normally 10-12% m.c.) and others are made from green to oven dry it is necessary to distinguish between the two. Shrinkage to the oven dry condition often involves collapse and severe distortion of the cells of the wood and since wood is never dried to zero moisture content in practice it is a somewhat artificial value.

Table 3. Shrinkage of naturally grown Pinus caribaea

Location, variety and authority	Shrinkage							
	Tangential		Radial		Longitudinal		Volumetric	
	Green to 12%	Green to OD	Green to 12%	Green to OD	Green to 12%	Green to OD	Green to 12%	Green to OD
Guatemala, (1972) var. <u>hondurensis</u>		8.0		6.3		0.3		13.1
Belize, Longwood (1962) var. <u>hondurensis</u>		7.8		6.3				12.9
Belize, Stevens & Pratt (1961) var. <u>hondurensis</u>	6.0		2.5					
Belize, UK DSIRO (1937) var. <u>hondurensis</u>	3.9		3.1					

4.32 Plantation-grown material

The information available on plantation-grown material is more comprehensive and interesting. The most intensive study has been done by Cown et al. (1972) on Fiji grown P. caribaea var. hondurensis and Table 4 below summarises the information obtained and compares it with shrinkage values for P. radiata.

Table 4 Comparative Shrinkage Data for Fiji Pine and Radiata Pine

Dimension	Shrinkage (%)			
	Green to air-dry		Green to oven-dry	
	Fiji Pine	Radiata	Fiji Pine	Radiata
Longitudinal	+0.07	0.02	0.09	0.25
Radial	2.5	2.0	4.5	3.4
Tangential	3.9	4.0	6.4	7.0
Volumetric	7.3	6.2	11.6	10.4

Note: positive values indicate expansion (from Cown et al., 1972).

Appendix 3, Table 1, shows a table of shrinkage in the 15 trees sampled in Fiji by ring group from the pith and by height in the stem. It shows a trend to increase from pith to bark for radial and tangential shrinkage but, for longitudinal shrinkage, no trend is apparent. The trend up the tree is slight but radial and tangential shrinkage are slightly lower at positions higher in the tree than at the base. This trend is also noticeable for longitudinal shrinkage from green to oven-dry but not from green to air-dry. It is interesting that longitudinal expansion rather than shrinkage has occurred in drying to air-dry and this could possibly be explained in part by tensions within the stem and partly by forces set up by radial and tangential shrinkage. No statistical tests appear to have been applied to these trends although trends of density variation have been analysed. Appendix 3, Table 2, presents the same information in the form of tree means of shrinkage and shows the wide between-tree variation.

Boone and Chudnoff (1972) in Puerto Rico compared the occurrence of compression wood with shrinkage in *P. caribaea*. Table 5 below gives their findings and demonstrates the increase in longitudinal shrinkage and reduction in radial and tangential shrinkage with increased percentages of compression wood.

Table 5 Specific gravity and shrinkage values for plantation-grown *Pinus caribaea* from Puerto Rico with several levels of compression wood

Levels of compression wood	Sample size	Basic ^{1/} specific gravity	Shrinkage (green to oven-dry)			
			Radial	Tangential	Longitudinal	Volumetric
<u>pct.</u>	<u>No.</u>	<u>pct.</u>	<u>pct.</u>	<u>pct.</u>	<u>pct.</u>	<u>pct.</u>
CUBUY PLANTATION						
0-10	37	.35	2.8	5.5	.15	8.1
11-30	13	.36	2.4	5.4	.24	7.7
31-50	15	.37	2.2	4.2	.52	7.1
51+	6	.37	1.4	3.3	.88	6.0

1/ Based on oven-dry weight/green volume, (from Boone and Chudnoff, 1972).

4.33

Varietal differences

Banks (1979) compared varietal differences in shrinkage of *P. caribaea* in 20-24 year old plantations at Kwa-Mbonambi in South Africa and obtained the following figures:

Variety/Species	Shrinkage (green to oven-dry)		
	Tangential	Radial	Volumetric
<u>P. caribaea</u> var. <u>caribaea</u>	6.7	3.2	10.3
<u>P. caribaea</u> var. <u>hondurensis</u>	5.7	2.9	8.6
<u>P. elliottii</u>	6.7	4.0	10.5

They indicate fairly minor differences between the two P. caribaea varieties with generally lower shrinkage for var. hondurensis, but the differential between radial and tangential shrinkage was greater than for P. elliottii. The Fiji figures quoted above show less differential.

4.34 Site differences

In a study of variation in P. caribaea var. hondurensis planted in Jamaica sampling 10 trees per site, Van den Slooten (1969) found small differences between sites in total shrinkage values, but larger ratios of tangential to radial shrinkage (2.4 instead of 2.0) on two of the sites. These did not result in any serious seasoning defects.

The shrinkage properties of P. caribaea are, therefore, fairly similar to those of P. elliottii and other similar pines although longitudinal shrinkage may be higher. The presence of quite large quantities of compression wood affects longitudinal shrinkage but has not resulted in severe seasoning defect in most places where the species is grown. Similarly, a sometimes high ratio of tangential to radial shrinkage does not seem to have affected the seasoning properties very seriously.

4.4 Grain angle

Spiral grain as a timber defect has already been discussed in paragraph 3.3 but its variation was not dealt with there in detail. Hughes (1970) measured grain angle of naturally grown P. caribaea var. hondurensis grown at Mountain Pine Ridge and found mean tree angles varying from 0.6° to 13° illustrating the large between-tree differences found for this property.

Cown et al. (1981) studied grain angle in detail on P. caribaea var. hondurensis planted in Fiji. They quoted an unpublished report by Wiggins (1979) as stating that trees on ferruginous latosols (the poorer soil types) had mean grain angles of 4.3° compared to 3.2° on humic latosols. This difference was statistically highly significant. Cown, McConchie and Young (1981) used the same measurement techniques as Wiggins on breast height discs from 180 trees and also at 5 m, 10 m and 15 m levels in 25 trees. Measurements were made ring by ring from pith to bark. They drew the following conclusions from the information obtained:

- (1) 79% of all angles measured were left handed spirals;
- (2) 28% of all angles exceeded 5° and 3% exceeded 10° ;
- (3) No consistent radial trend was apparent at any stem level and no relationships with tree age could be expected.
- (4) While there were large differences between stems at any one stem

level correspondence between levels within stems was not good. Some trees maintained similar angles at all heights others varied at different heights. The Nausori Highlands grain angles were significantly lower than at the lower altitude site of Lololo and Seagaga and were only just over half their value at breast height and for whole trees.

(5) Breast height grain angles were on average higher than whole tree values.

These conclusions are interesting to compare with those of Dyson (1971) who found average grain angles of 3.73° for a Belize coastal plain provenance of var. hondurensis and 2.0° for a Mountain Pine Ridge provenance both planted at Muguga arboretum (over 2000 m altitude). It appears, therefore, that not only do higher altitudes give lower grain angles but also possibly provenances from higher altitudes tend also to have lower angles; however Dysons differences were not significant at the 95% level because of large between-tree differences of angle.

Falkenhagen (1979) found no significant differences between grain angles of the three varieties of P. caribaea 16-17 years old, grown in the Transvaal and Zululand in South Africa and most trees had mean values below 2° possibly reflecting the effect of high latitude rather than high altitude.

In Australia, Schmidt and Smith (1961) found low grain angles in five plus trees of P. caribaea probably var. caribaea, 26 years old in Queensland. More detailed investigations carried out by Smith (1973) comparing 15 year old trees of var. bahamensis and var. hondurensis at Beerburum in Queensland found variety grain angle means of 2.77° and 2.25° respectively. Although relatively small, these differences were significant at the 95% level. In a 35 year old plantation at Imbil var. bahamensis had a mean grain angle of 1.5° . Thirty nine ten year old Queensland plus trees of var. hondurensis had a mean grain angle of 2.6° with a range from 0.8° - 5.3° for the means.

Hawkins et al. (1978) found that a fast growing F_1 hybrid of P. caribaea var. hondurensis and P. elliottii aged 13 had lower grain angles than either parental species.

In summary then, grain angles over 5° are a serious defect and over 10° are near to disastrous. In general P. caribaea grain angles are low but they have been found to be unusually high in Fiji where low altitude and more difficult soil or climatic conditions appear to give higher angles. Large differences between trees indicate that the trait is genetically controlled to a considerable extent so that with correct breeding and silviculture it should be possible to reduce the occurrence of high grain angles. There is little indication that age of tree significantly affects the mean grain angle of the tree.

4.5

Wood density

Wood density is one of the most important wood properties since it affects so many other properties and thus the performance of the wood for many uses. Since the density of wood substance does not vary

greatly wood density is a measure of the quantity of cell wall and the quantity of lumen which vary from tissue to tissue, from earlywood to latewood, radially and axially within trees, between trees, between sites, between silvicultural treatments and between different progeny, provenances, varieties and species. It is not surprising, therefore, that density has been the most widely studied property of P. caribaea particularly since it is easy to measure compared with most other properties. In order to measure the relative importance of these many sources of variation of the property it is necessary to measure density accurately on a very large number of wood samples and besides a variety of gravimetric methods, x-ray and beta-ray methods have been developed which measure density changes over small areas and can determine, rapidly, density variation within rings. For the more detailed investigations of density patterns within trees and their response to external factors these techniques are now widely used. Substances other than the wood substance, however, are found in wood and of these by far the most important in P. caribaea is resin which can, as has been seen in paragraph 3.4, account for up to 40% of the weight of a piece of the wood. It contributes only slightly to the strength of the wood and most other important properties except durability and permeability and consequently if the density of the structural wood substance is to be found in resinous wood it is necessary to extract the resin; this is normally done with a mixture of benzine and alcohol.

As mentioned in the introduction to the general properties of the wood, general wood density varies within the species from over 1.0 g/cm³ for sinker logs naturally grown and saturated with resin to material with a density of below 0.3 g/cm³. If within-ring density variation is considered even wider density ranges can be found.

4.51 Methods of measuring and expressing density

There are several ways of measuring wood density and expressing it and density measured in different ways is not necessarily comparable. An account of different methods of measuring the property is given in Elliott (1970), but it is worth recording the main methods of expressing it here:

Basic density is density expressed as:

$$\frac{\text{oven dry weight}}{\text{green wood volume}}$$

Oven-dry density is:

$$\frac{\text{oven dry weight}}{\text{oven dry volume}}$$

Air-dry density Air dry is normally taken as 12% m.c. (occasionally as 10%) and is:

$$\frac{\text{weight at 12\% m.c.}}{\text{volume at 12\% m.c.}}$$

Green density is:

$$\frac{\text{weight green}}{\text{volume green}}$$

Green density varies according to the moisture content and the latter needs to be stated when quoting green density.

Before one form of density can be converted to another (for instance basic to oven-dry density) it is often necessary to know the volumetric shrinkage of the wood from one moisture content to another (green to oven dry for basic and oven dry density).

The variation of wood density within the species will be considered under a number of headings.

4.52 Density of naturally grown material

Even the earliest authorities recorded a timber that varied considerably in its density. Record and Mell (1924) mentioned that some pine logs in Nicaragua were sinkers and had to be lashed to Balsa logs to keep them afloat while being transported down rivers. F.P.R.L., Princes Risborough in an early series of tests on the wood recorded (UK DSIR, 1937) a mean basic density for the timber of var. hondurensis of 0.71 g/cm^3 (44 lbs/ft^3); this figure was repeated by Cox (1939) and F.P.R.L. (1957). Fahnestock and Garratt (1938) acknowledging the variability of the timber suggested grading it into three grades by percentage of latewood ($>30\%$, $20-30\%$ and $<20\%$) as a method of getting different structural strengths. Later writers give wide ranges of variation between trees ($0.34-0.68 \text{ g/cm}^3$ oven dry density, Chudnoff (1979)). Lantican (1979) in a doctoral study with 30 year old naturally grown trees found tree means for basic density varying between 0.381 and 0.522 g/cm^3 while Hughes (1970) found, for material from Belize, within-tree 2 cm compression strength test samples varied in density from 0.3 to 1.1 g/cm^3 air dry density; the heaviest site mean was 0.641 g/cm^3 and was a coastal site, while the least dense site was a high altitude one on the Mountain Pine Ridge with an average of 0.493 g/cm^3 . Guatemala (1972) recorded a mean of 0.67 g/cm^3 for density at 12% m.c. and 0.59 g/cm^3 for oven dry density of material of P. caribaea var. hondurensis in Guatemala and Houkal (1981) sampling seven different sites in the Honduras Republic found a mean basic density of 0.525 g/cm^3 . He also found significant differences in wood density between sites and moderate correlations between site altitude and extracted basic density ($r = 0.596$).

4.53 Density of plantation-grown material

There are over 80 publications dealing with wood density in planted P. caribaea and no attempt is made here to quote all of them but all those found and considered to be of significance are included in the bibliography. Variation has been found between varieties, between provenances, between trees, within provenances and within trees and these sources of variation will firstly be considered under separate headings and then the effect of various factors upon density.

4.531 Variation between varieties and provenances

P. caribaea var. hondurensis has been more widely studied than var. caribaea or var. bahamensis. It was planted earlier and more widely since it is on the whole more vigorous and faster growing. Table 6 summarises the varietal and provenance mean densities measured in various parts of the world. The trials have been established in different sites and climates at different altitudes and at different latitudes. To complicate matters further different methods of measuring density have been used which are non-convertible without a knowledge of shrinkage. If it is assumed that volumetric shrinkage from 12% to oven dry is 5% and from green to oven dry is 12% then an oven dry density of 0.5 g/cm³ becomes a basic density of 0.446 g/cm³ or 89% of the O.D. density and 12% m.c. density is $\frac{0.5 \times 1.12}{1.05} = 0.533\text{g/cm}^3$ or 106.6% of the oven dry figure.

It is unwise, therefore, to compare directly the figures for one trial to another too slavishly but there are indications that on the whole varieties caribaea and bahamensis produce a lower volume of slightly denser wood than the faster growing var. hondurensis. The latter tends also to be more prone to produce false rings and have a less regular annual growth.

The differences between provenances are in most cases non-significant if averaged over several sites and if they are significant they normally only account for a small percentage of total variance but within a given site the differences can be quite large and highly significant. It is still, therefore, normally necessary to grow a particular provenance in a particular site to determine the density of the wood which will be produced because of the large site-by-provenance interaction. One or two provenances, however, stand out as having a higher than average density on most sites and Guanaja provenance is outstanding in this respect in var. hondurensis. Figure 4 taken from Barnes et al. (1980) shows provenance by site interaction.

4.532 Variation of density with site

That site affects both rate of growth and wood density is clear from Table 6 and Figure 4. Components of variation are normally higher for site than they are for provenance or even variety. (Barnes et al., 1980; Andrew and Plumptre, 1973, and Plumptre, 1978).

Appendix 4 and Tables 7 and 8 below show the site means for breast height cores from 10 trees from each of 18 plantation sites in East Africa and demonstrates the large between-site differences in rate of growth and mean density.

Table 6. Varietal and provenance differences in multivarietal trials

Author and Country	Age years	Provenance	Altitude m	mean density g/cm ³			
				var. <u>hondurensis</u> b.h. whole tree	var. <u>caribaea</u> b.h. whole tree	var. <u>bahamensis</u> b.h. whole tree	
Bailey (1982) Uganda, Katugo	11 14 9		1100 1100 1100	0.431 ⁽¹²⁾ 0.460 ⁽¹²⁾	0.422 ⁽¹²⁾ 0.452 ⁽¹²⁾		0.379 ⁽¹²⁾
Banks (1979) Kwambonambi, South Africa	24-26		55-60	0.471 ^(B)	0.53 ^(B)		
Barnes et al. (1977) Zimbabwe	5	Belize 1892 Mountain Pine Ridge 2023 British Honduras 20281 Great Abaco Island 1961 Grand Bahama 2025 Cuba 2026 Cuba 2027	698 -1850 5 sites replicated	0.347 ^(B) -0.349 ^(B) 0.346 ^(B)		0.340 ^(B) 0.356 ^(B)	
					0.339 ^(B) 0.348 ^(B)		
Barnes et al. (1980)	6-7	Guanaja Poptun Rio Coco Alamicamba Brus Lagoon	Mean of 8 sites (Jari, Brazil, Bukit Papah, Malaysia, Puerto Rico, Cardwell, Melville Is., Huey Bong, Thailand)	0.427 ^(B12) 0.410 0.400 0.400 0.391			
Dyson (1971) Muguga, Kenya	5	Belize, Mountain Pine Ridge Belize Coastal Plain	2300	0.33 ^(B) 0.34 ^(B)			
Falkenhagen (1979) South Africa (means of 3 sites)	16-17	Grand Bahama Pinar del Rio Cuba Mountain Pine Ridge	30-870	0.437 ^(OD)	0.450 ^(OD)	0.480 ^(OD)	
Garcia de Leon (1982)	6-7	Guanaja Melinda Poptun Mountain Pine Ridge Santos Brus Lagoon Alamicamba	mean of 3 sites Jari, Cardwell and Melville Island	0.465 ⁽¹²⁾ 0.445 0.445 0.442 0.438 0.428 0.418			
(Note: Provenance differences significant at the 5% level but account for only 2-3% of total variance)							
Guth (1973) Argentina	12			0.355 ^(OD)	0.379 ^(OD)	0.375 ^(OD)	
Hawkins et al. (1978) Beerburum, Australia	12-19			0.460 ^(B)		0.430 ^(B)	
Kromhout (1978) South Africa	26			0.467 ⁽¹²⁾	0.546 ⁽¹²⁾		
Plumptre (1979) South Africa Kwambonambi	16-18	Grand Bahama Bahamas (Abaco?) Cuba Mountain Pine Ridge Guanaja Stann Creek Santa Barbara		0.551 ⁽¹²⁾ 0.516 ⁽¹²⁾ 0.498 ⁽¹²⁾ 0.459 ⁽¹²⁾	0.557 ⁽¹²⁾	0.629 ⁽¹²⁾ 0.562 ⁽¹²⁾	
(Note: only Grand Bahama and Santa Barbara are significantly different at the P = 0.05 level)							
Plumptre (1979a) Mubende, Uganda	10	Andros Bahamas var. <u>caribaea</u> and hybrid with <u>P. elliottii</u> Great Abaco Belize	1300	0.404 ⁽¹²⁾	0.433 ⁽¹²⁾	0.470 ⁽¹²⁾ 0.414 ⁽¹²⁾	
Plumptre (1977) Jubiya, Uganda	12	var. <u>hondurensis</u> var. <u>bahamensis</u>	1150 m	0.465 ⁽¹²⁾		0.447 ⁽¹²⁾	
(Note: No significant difference between varieties)							
Smith (1973)	34-36	var. <u>bahamensis</u> var. <u>caribaea</u>			0.49 ^(B)	0.50 ^(B)	
Smith (1978) Queensland at Beerburum (Be) and Byfield (By)	12	var. <u>caribaea</u> var. <u>bahamensis</u> Republic of Honduras Mountain Pine Ridge Woree School N. Queensland Coastal Plain, Belize Byfield improved	Both sites at low altitude Beerburum 26°58' South Byfield 22°58' South	Be0.397 ^(B) Be0.426 Be0.426 Be0.416 Be0.413	By0.416 ^(B) By0.442 By0.464 By0.458 By0.455	Be0.434 ^(B) By0.471 ^(B) Be0.430 ^(B) By0.477 ^(B)	
(Note: the two sites are significantly different, provenances within sites are not)							

Note: (12) = density at 12% m.c. (volume and weight)
(B) = basic density (green volume oven dry weight)
(OD) = oven dry density (oven dry volume and weight)
(B12) = green volume weight at 12% m.c.

FIGURE 4. ANALYSIS OF WOOD DENSITY (AT 12% MOISTURE CONTENT) FOR 17 PROVENANCES OF *PINUS CARIBAEA* VAR *HONDURENSIS* OVER 8 LOCALITIES. From Barnes *et al* (1980)

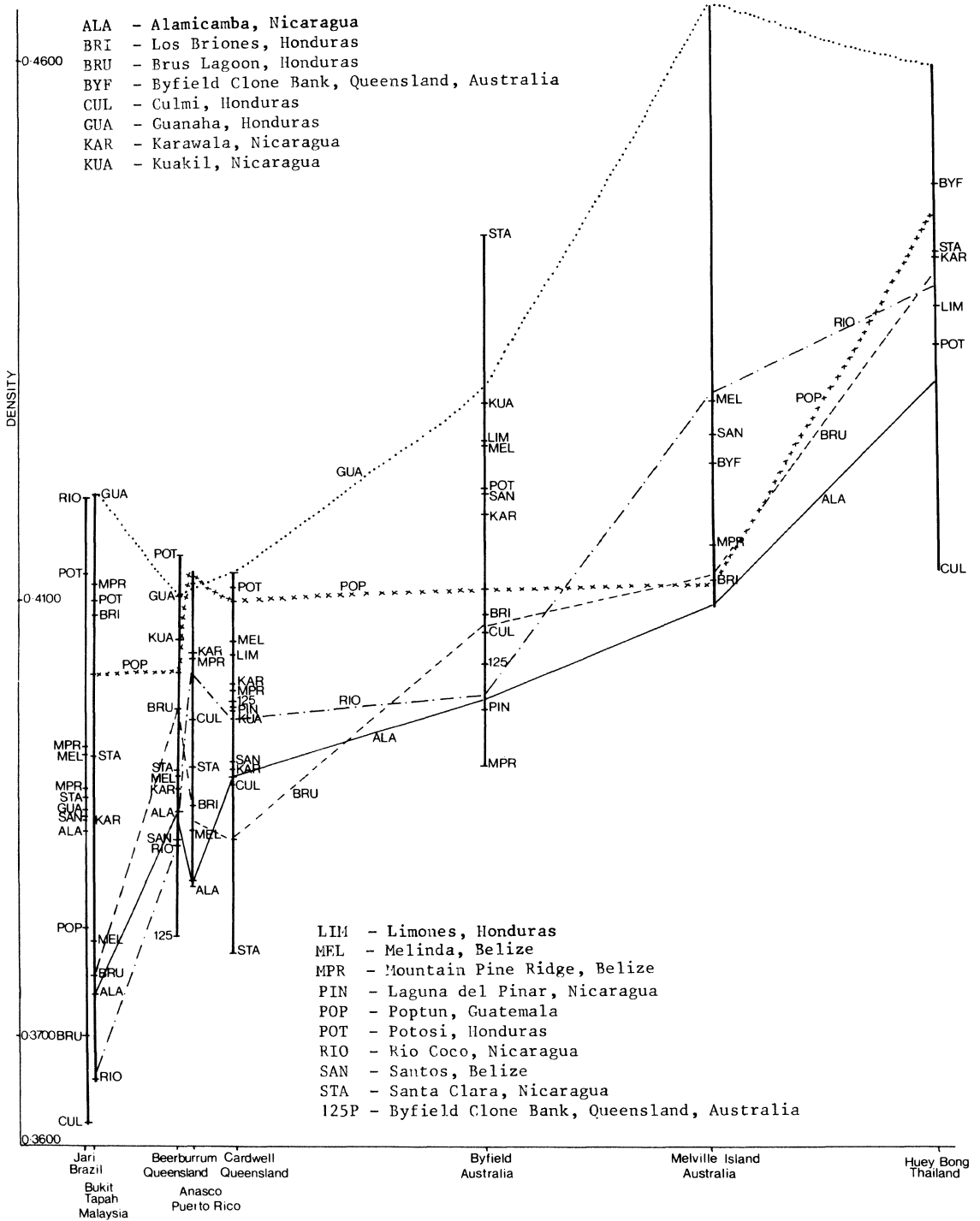


Table 7

Cross-sectional area under bark, (cm²). Inner eight rings
Analysis of variance

Source	df	MS	F	VC%
Between sites	17	46821	7.3 ***	39.5
Within sites	155	6446		60.5

Note: *** indicates statistical significance,
P<0.001

Table of site means

<u>Site</u>	<u>Area, cm²</u>
Lushoto	359
Opit	248
Kafu	244
Kei	204
Bana Cpt 1	185
Abera	181
Singo	168
Bana 553	167
Kwale 3A	140
Kazimzuumbwe	139
Vikundo	133
Katugo	130
Msumbugwe	125
Kachung	117
Longuza	117
Kwamalukanga	100
Kwale 1A	92
Kwale 5A	60

Standard error of a site mean = $\pm 26 \text{ cm}^2$

Coefficient of variation = 16.3%

Note: Vertical bars span means which do not differ significantly,
P<0.05

From Andrew and Plumptre (1973).

Table 8

Weighted mean density, g/cm³. Inner eight rings
Analyses of variance

Source	df	MS	F	VC%
Between sites	17	0.03556	8.3 ***	43.3
Within sites	155	0.00426		56.7

Note: *** indicates statistical significance, P<0.001

Table of site means

<u>Site</u>	<u>Density, g/cc</u>
Kwale 3A	0.640
Kwale 1A	0.598
Kwale 5A	0.573
Longuza	0.571
Kei	0.561
Vikundu	0.551
Kafu	0.548
Abera	0.521
Singo	0.517
Opit	0.514
Kazimzumbwe	0.505
Maumbugwe	0.481
Kachung	0.473
Kwamalukanga	0.472
Bana 553	0.470
Katugo	0.452
Lushoto	0.437
Bana Cpt 1	0.411

Standard error of a site

mean = ± 0.021 g/cc

Coefficient of variation = 4.1%

Note: Vertical bars span means which do not differ significantly, P<0.05

From Andrew and Plumptre (1973).

Causes of variation of density between sites

Various attempts have been made to correlate site characteristics such as temperature, rainfall, altitude and latitude to wood density and rate of growth. Plumptre (1978) found no significant correlations between altitude and rainfall and density but a multiple regression of altitude, rainfall, and maximum and mean temperatures against density gave a coefficient of multiple determination (R^2) of 40%. For a limited number of sites for which figures were available for moisture deficit the following simple linear regressions were calculated:

Dry matter = $24.71 - 0.0254$ moisture deficit ($r^2 = 76.7\%$)

Wood density (12%) = $0.667 - 0.00259$ moisture deficit ($r^2 = 51.6\%$)

Barnes et al. (1977) reported a very high degree of correlation ($r^2 = 88\%$) between density and soil moisture deficit in Zimbabwe.

Cown et al. (1981) in Fiji found quite high correlations ($r^2 = 65.6\%$) between wood density and altitude (see Figure 5). In a multiple regression of altitude and soil moisture they found the r^2 improved to 77%. Cown et al. (1981) also found that if tree age were included in the regression for ages of tree from 8 to 25 years the value of r^2 was 85%.

Harris (1978) found an inverse correlation between latitude and wood density indicating that if the species is grown near the equator it produces denser wood than at greater latitudes.

There appears, therefore, to be a tendency for the species to have higher density at lower altitudes and latitudes and with higher moisture deficits, or in climates where there is a pronounced dry season. Plate 4 shows two breast height discs one from a tree grown at low altitude at Dar es Salaam and the other at Lushoto at about 1500 m altitude.

4.533 Density variation between trees

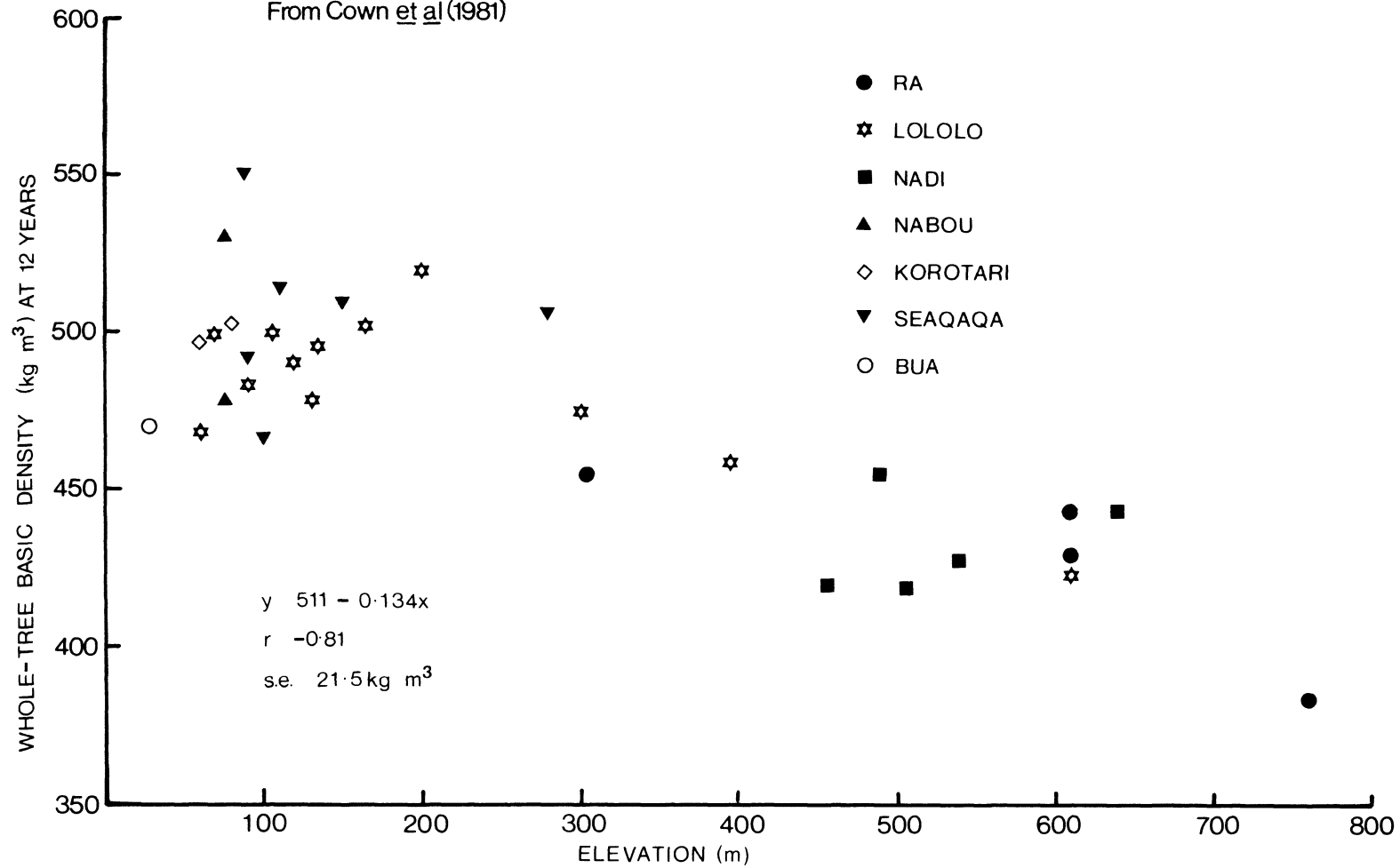
In almost all of the many studies made of density variation the between-tree variation component is large in relation to others; this is one of the most constant characteristics of density variation. Plate 5 shows breast height discs taken from three trees in the same plot in Fiji; the differences in the amount of latewood formed and the pattern of its formation are striking. Table 9 shows density variation between 20 trees grown in 4 sites in Fiji (Ong, 1978).

Various researchers have tried to relate rate of growth to density but, in general, correlations of the tree mean densities and rates of growth are poor and so are correlations of ring width and density pooled between several trees.

Ong (1978), for instance, found that with P. caribaea var. hondurensis in Fiji a simple linear regression of ring width on density, for 20 trees covering four sites gave an r^2 of 23%. Within each of the four

FIGURE 5. INFLUENCE OF ELEVATION ON DENSITY OF 12-YEAR-OLD TREES

From Cown *et al* (1981)



sites the r^2 's were 33%, 34%, 37% and 36%. Within individual trees the correlations would be higher. The influence of between tree variation even within a single site, whether it is caused by the genetic make-up of the tree or the "micro-environment" within which the tree lives, is strong and suggests the possibility of increasing mean tree density without serious loss in rate of growth.

Table 9 Ranking order of trees from Fiji, tree statistical interrelationships and ranges of between tree variation (weighted density)

Studentized range test P.05

Tree number Density (g/cc)

12	0.7212	
19	0.6405	
4	0.6339	
2	0.6258	
20	0.5755	
3	0.5684	
11	0.5649	
10	0.5643	
9	0.5576	
18	0.5543	
7	0.5539	
16	0.5536	
17	0.5350	
1	0.5221	
8	0.5070	
14	0.4921	
13	0.4796	
5	0.4416	
6	0.4413	
15	0.4383	

Highest mean value: 0.72 g/cc

Lowest mean value: 0.44 g/cc

Range: 0.28 g/cc

Standard error of a mean = 0.0089

Numbers subtended by the same vertical line refer to the trees whose mean are not significantly different from each other, from Ong (1978).

4.534 Within-tree variation in density

Between ring variation

Certain patterns of mean ring density variation in P. caribaea are well established of which the most constant and universal is the radial increase in density from pith to bark at any given height in the tree. Trends up and down the tree are less pronounced and can vary very considerably from tree to tree; they are much influenced by the growth conditions at different stages in the trees life, particularly

competition, thinning and pruning and also the depth and moisture, retention capabilities of the soil. Figures 6 to 9 from Kromhout and Toon (1978) show within-tree radial and axial density gradients of different provenances and varieties on two sites while Figure 10 from Plumptre (1979a) shows radial density, ring width and ring area gradients from pith to bark. Figures 1 to 5 in Appendix 4 taken from Ong (1978) show computer drawn contours of density plotted around mean ring density figures measured by x-ray densitometry of radii at 5%, 15%, 25%, 35%, 45%, 55%, 65% and 75% of tree height. The crosses represent the centres of rings along the radii and the figures on the diagram give mean ring density. The contours are plotted around these points. The trees shown in these figures are the same trees whose tree mean densities are given in Table 9. While only approximate the contours give a picture of density variation both vertically and radially within the stem and looking at the figures the following deductions can be made with some degree of confidence:

Figure 1 (Tree 1) Appendix 4: A relatively short squat tree with very rapid early diameter growth and low density followed in later life by much slower growth and higher density. This accounts for an increase in density up the tree and high density near the bark.

Figure 2 (Tree 6) Appendix 4: A large fast growing tree with a decrease outward from the pith for about 75 mm and then an increase. Density is low and almost uniform up the tree. It is probably dominant and has suffered very little from competition.

Figure 3 (Tree 9) Appendix 4: A tall but relatively narrow tree with fairly uniformly low density central core and thereafter a fairly steep density gradient near the base of the tree but less gradient further up. Growth has increased in the last 2-3 years possibly as a result of thinning and this has resulted in a levelling off of density.

Figure 4 (Tree 12) Appendix 4: A tall, thin, high density tree with steep radial density gradient at the base of the tree but less steep gradient further up the tree.

Figure 5 (Tree 19) Appendix 4: A relatively tall tree with small low density central core at the base of the tree followed by a radial increase in density at all heights leading to an axial density increase up the tree. It probably suffered competition after the first 3-4 years but has maintained dominance in spite of this.

If contours of ring width or ring area are plotted and superimposed on density contours it is sometimes possible to match areas of rapid growth and low density and vice-versa within specific areas in trees indicating that within these areas rate of growth and density of wood are quite strongly linked (Plumptre, 1978a). The tendency therefore, is to develop wide ringed low density wood within the living crown of the tree and narrower ringed higher density wood lower down the tree. The further the cambium is from the living crown the narrower the rings and the higher the density. This is shown also in Plate 7 where discs from four heights in a *P. caribaea* var. *hondurensis* tree are shown. The tree is of low average density but the dense ring about 3 rings in from the bark can be seen to move into the

FIGURE 6. RADIAL DENSITY GRADIENTS (as measured at 2.4m height) OF THE MPATE PROVENANCES. From Kromhout and Toon(1978)

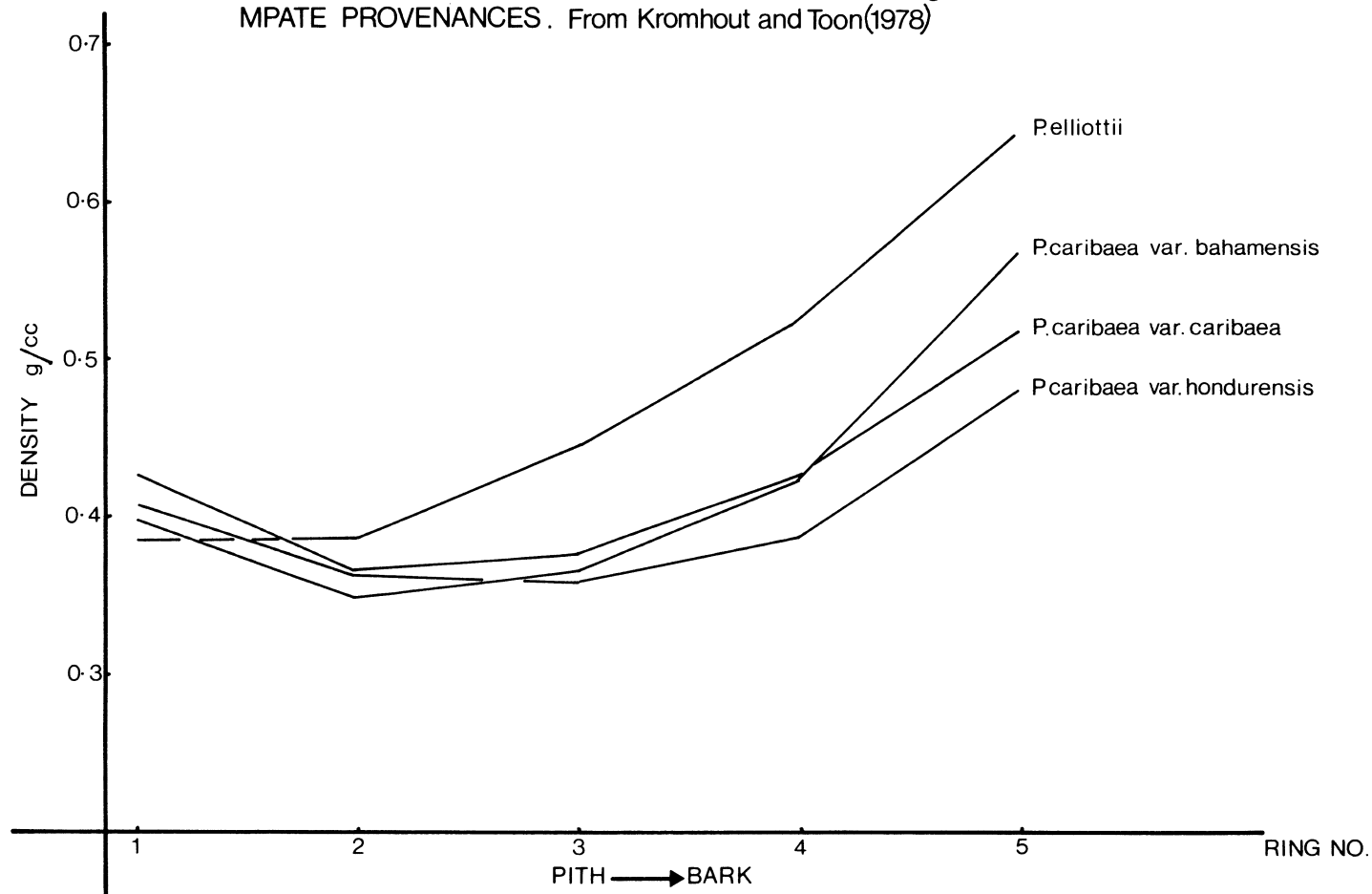


FIGURE 7. RADIAL DENSITY GRADIENTS (as measured at 2.4 m height) OF THE WILGEBOOM
PROVENANCES. From Kromhout and Toon (1978)

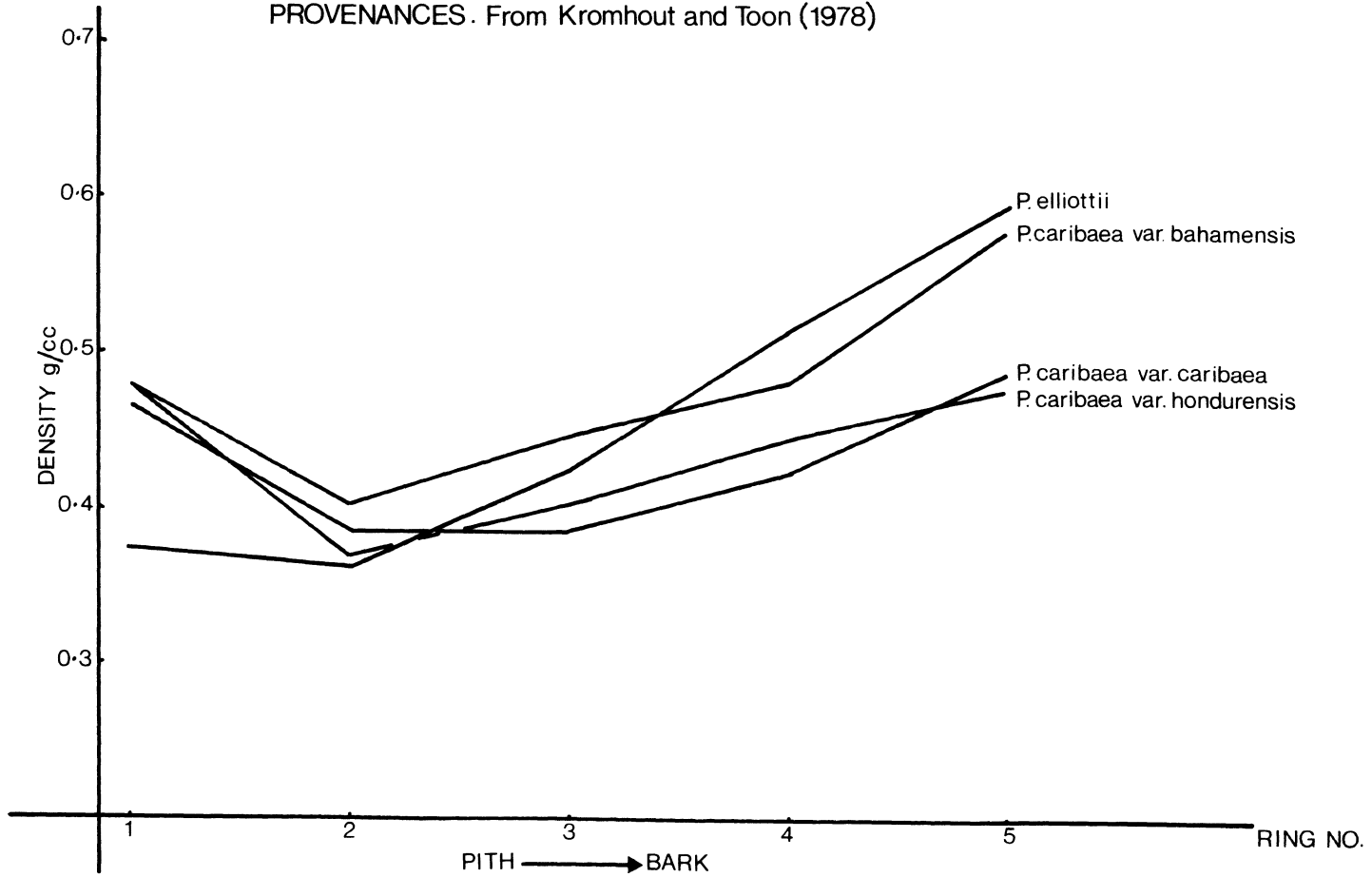


FIGURE 8. VERTICAL DENSITY GRADIENTS : MPATE. From Kromhout and Toon (1978)

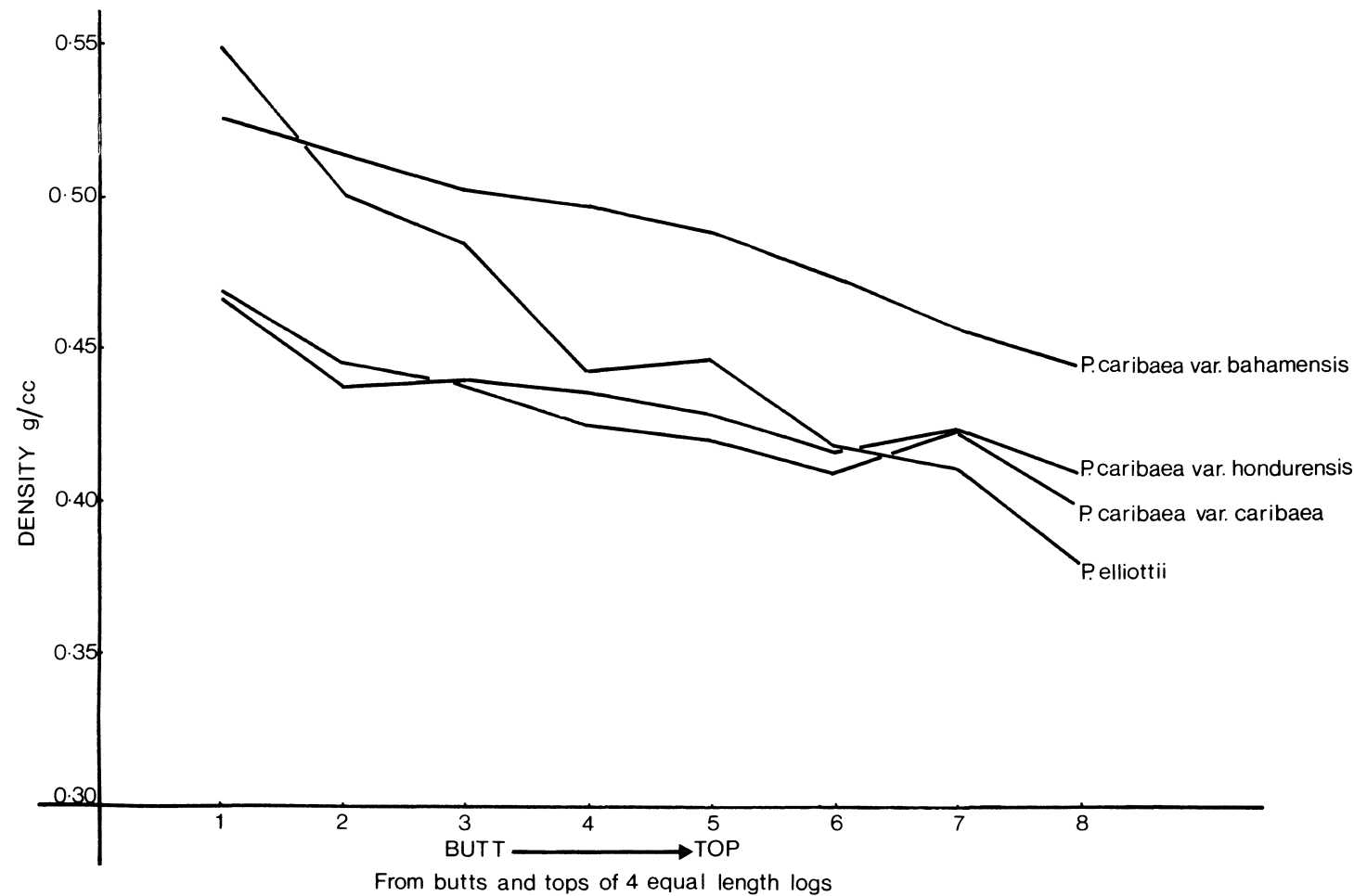


FIGURE 9. VERTICAL DENSITY GRADIENTS: WILGEBOOM. From Kromhout and Toon (1978)

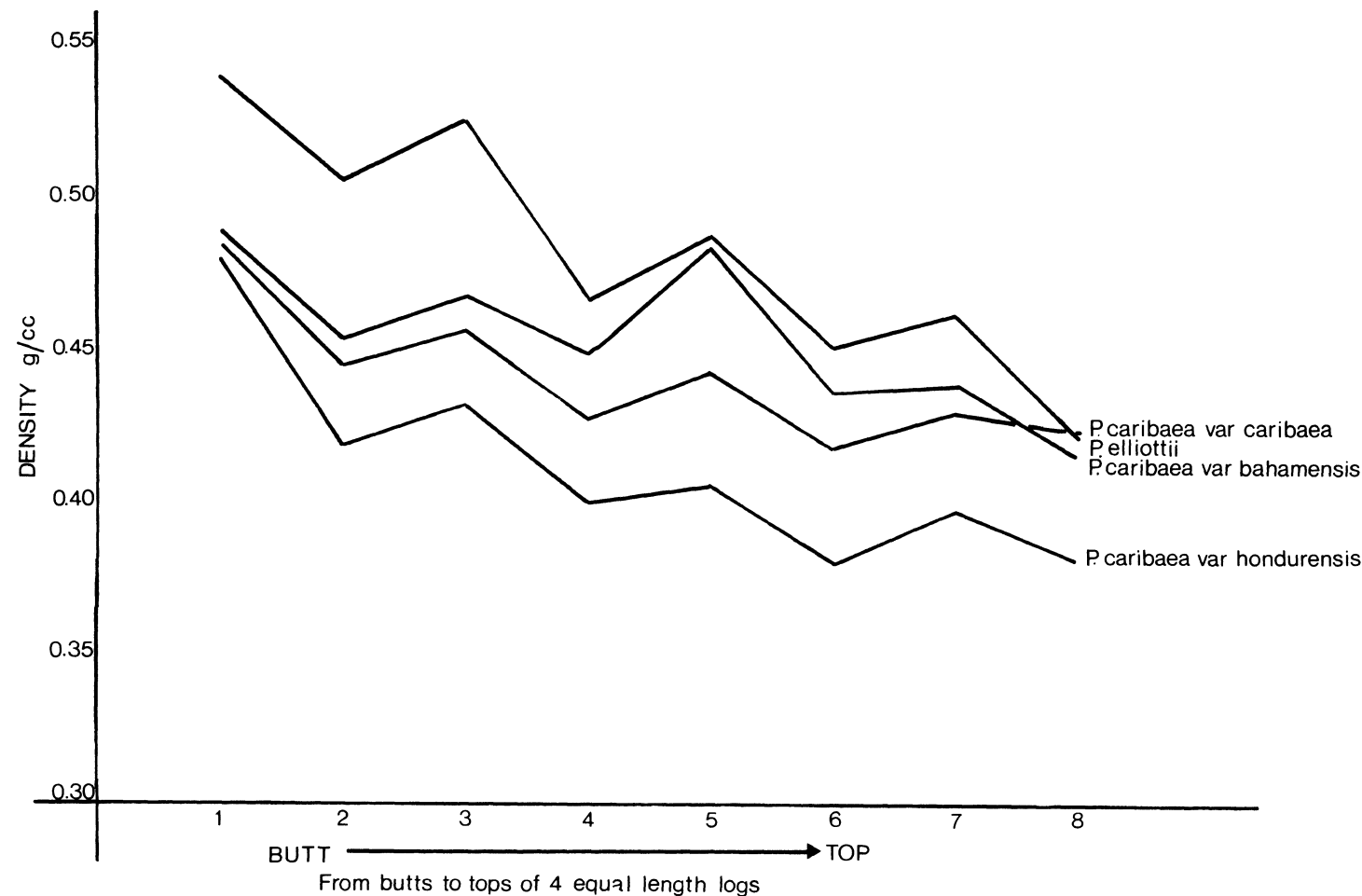
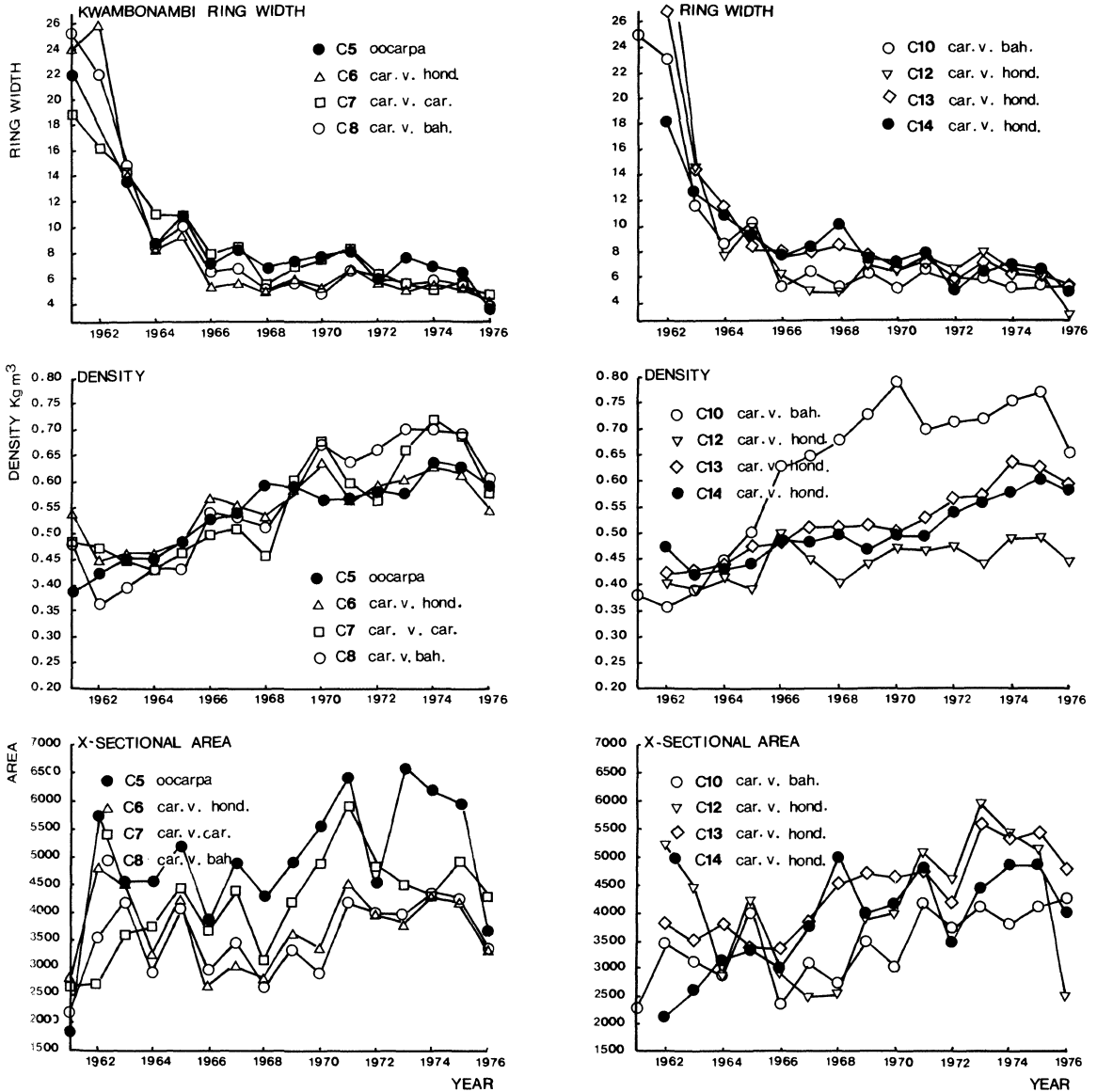


FIGURE 10 RADIAL VARIATION OF RING WIDTH, DENSITY AND X-SECTIONAL AREA AT KWAMBONAMBI FROM X RAY DENSITOMETRY . From Plumtree (1979)

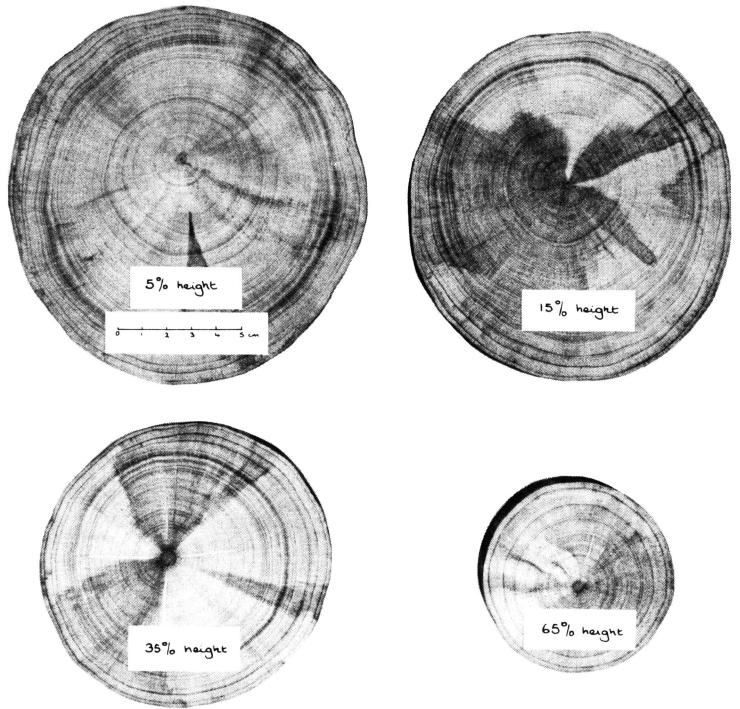


(N.B. The 1976 ring may only represent half a ring)

- C5 = P. oocarpa (ex Honduras Republic)
 C6 = P. caribaea var. hondurensis (Mountain Pine Ridge)
 C7 = P. caribaea var. caribaea
 C8 = P. caribaea var. bahamensis
 C10= P. caribaea var. bahamensis (Grand Bahama)
 C12= P. caribaea var. hondurensis (Santa Barbara)
 C13= P. caribaea var. hondurensis (Guanaja)
 C14= P. caribaea var. hondurensis (Stann Creek)

PLATE 7

Discs taken at 5, 15, 35 and 65% height from low density tree of variety hondurensis from Uganda



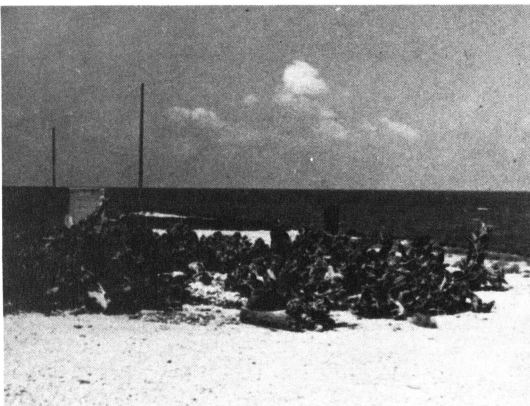
(Photograph A. Allen)

PLATE 9

Seed trees and pulpwood at Andros, Bahamas

PLATE 8

Pine roots for export for resin extraction lying on the beach Grand Bahama



(Photograph P.J. Wood)



(Photograph P.J. Wood)

stem from 5% to 35% height and almost disappears in the crown at 65% height.

Figure 6 Appendix 4: Percentages of wood in different density classes are shown by different trees in different sites in Fiji (Ong, 1978).

The pattern varies from tree to tree illustrating that denser trees have larger amounts of wood in the higher density classes. The amounts of wood in different density classes can correlate highly with pulp and paper properties (see Tables 29 and 30 and Burley et al., 1976).

Prediction of whole tree wood density from measurement of density at the base of the tree

In spite of the clear response of trees to environment and treatments it has been found by an increasing number of workers that density measured at breast height or in the lower part of the bole is highly correlated with mean density of the whole tree; with a sample of six 27 year old trees of P. caribaea var. hondurensis in South Africa, Van der Sijde (1979) found good correlations between wedges and cores taken at breast height and whole tree density measured gravimetrically (r^2 of 98.6% for wedges and 81.7% for cores).

Ong (1978) obtained similar results from 20 trees of P. caribaea var. hondurensis in Fiji and Table 10 below shows the result of his x-ray density correlations between density at different heights in the tree and whole tree weighted density also measured by x-ray densitometry and weighted assuming a stem of circular cross section and constant ring width around it.

Table 10 Simple linear regressions of whole tree on percentage densities at various heights

% height	$r^2\%$	a	b
5	78.8	-0.0075	1.122
15	90.6	-0.0396	1.114
25	90.5	0.0086	0.982
35	87.5	0.0791	0.828
45	81.7	-0.0069	0.928
55	72.9	0.0151	0.891
65	58.2	0.0404	0.817
75	65.3	0.0671	0.758

y = whole tree weighted density

x = weighted density at the percentage heights

(From Ong, 1978.)

Figures 11, 12 and 13 from Cown et al. (1981) show correlations between breast height core segments and whole tree density for about 120 trees

FIGURE 11. RELATIONSHIPS BETWEEN CORE SEGMENT DENSITIES (EXTRACTED) AND WHOLE-TREE DENSITIES
BY TREE AGE CLASSES. From Cown *et al* (1981)

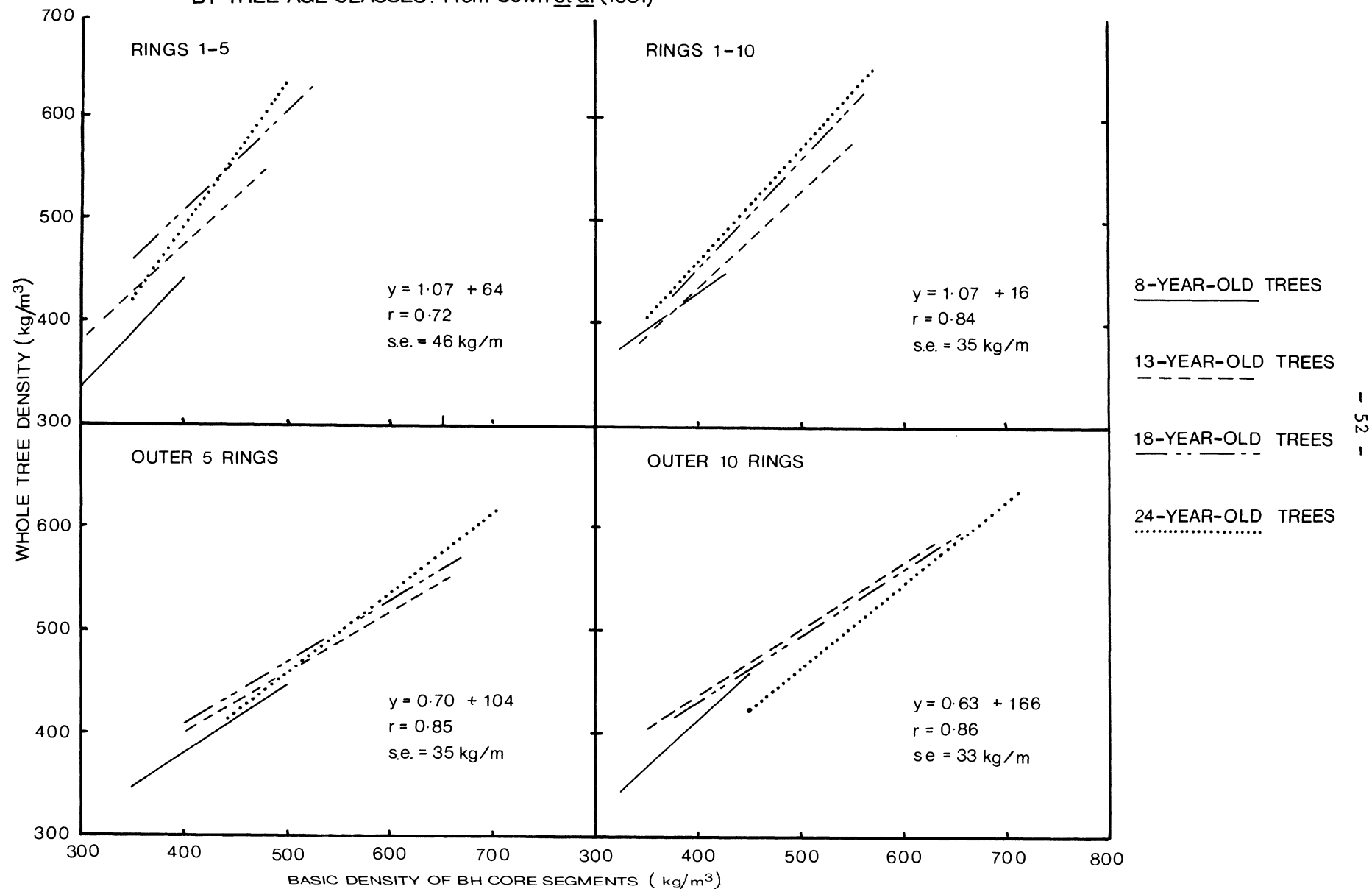


FIGURE 12. RELATIONSHIP BETWEEN OUTER 5 RINGS AT BREAST HEIGHT AND
WHOLE-TREE DENSITY. From Cown et al (1981) INDIVIDUAL TREES

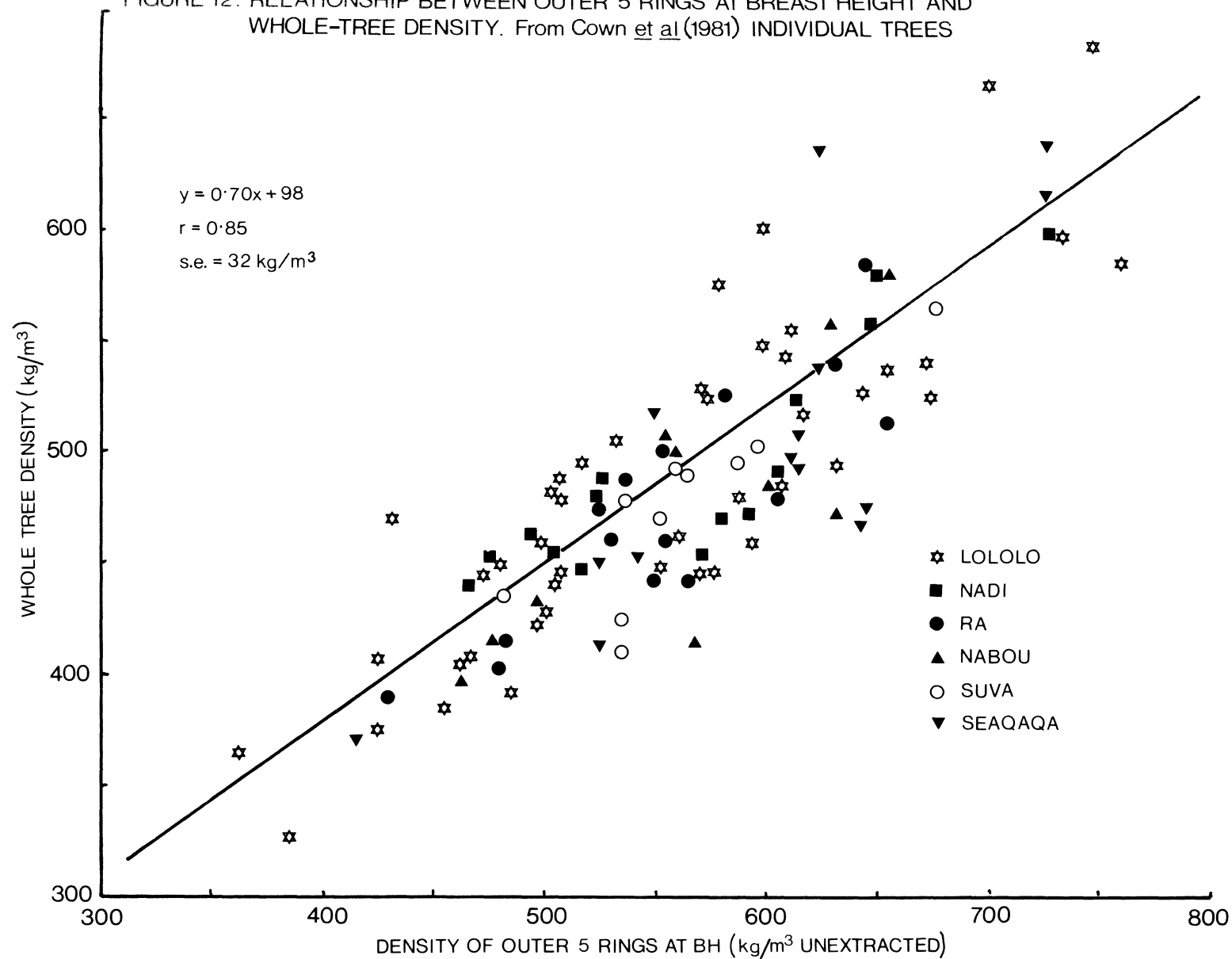
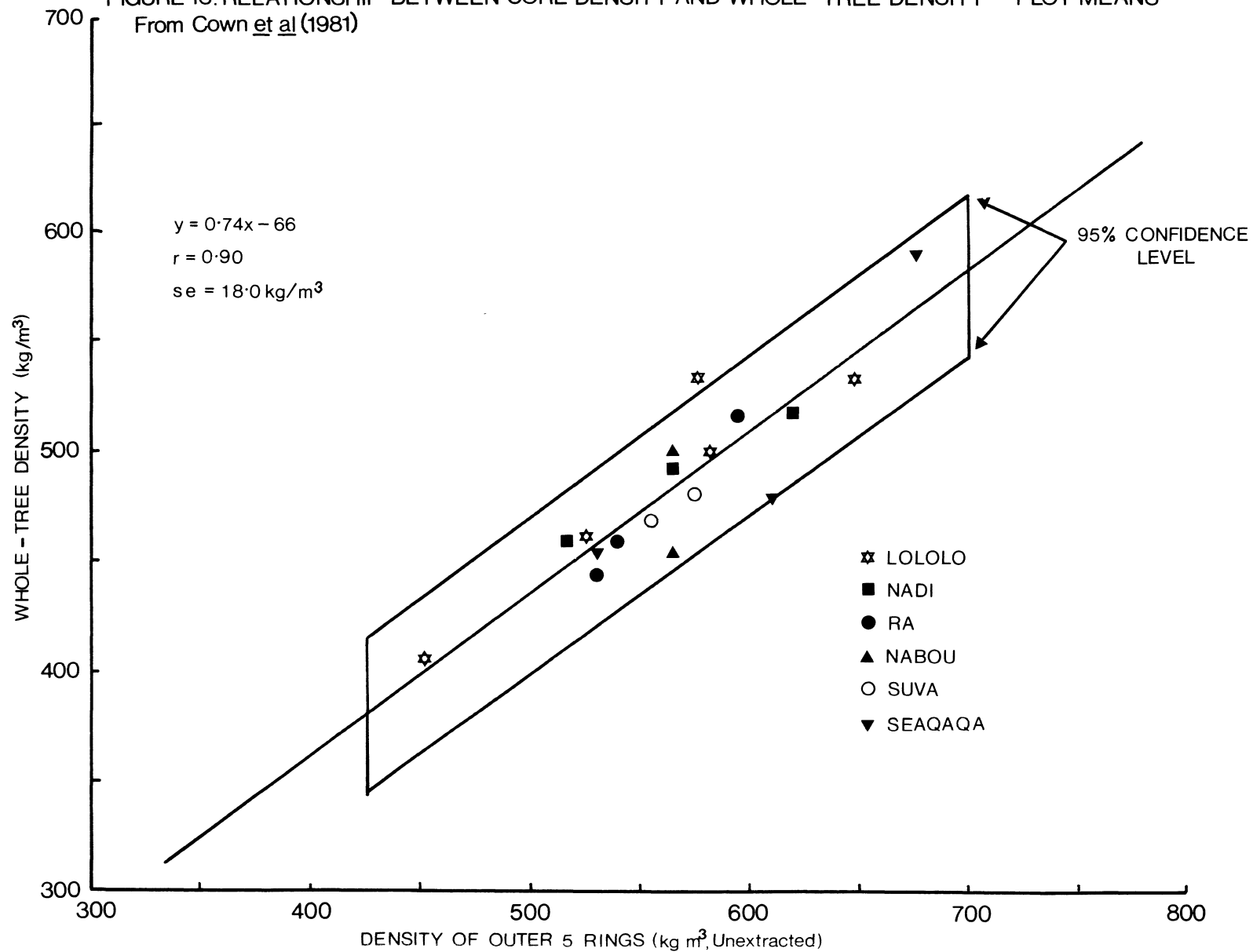


FIGURE 13. RELATIONSHIP BETWEEN CORE DENSITY AND WHOLE-TREE DENSITY - PLOT MEANS

From Cown et al (1981)



from Fiji and demonstrate that good estimates can be obtained of whole tree density by sampling only the outer five rings at breast height. Similarly, a moderate estimate of density of trees of 8-24 years old can be obtained by measuring the breast height density of the trees when they are 5 years old.

Goodwin-bailey (1982) with twenty 11-year-old trees of P. caribaea var. hondurensis from Uganda, twenty 13-year-old trees of P. caribaea var. hondurensis from Tanzania and ten 13-year-old trees of P. oocarpa from Uganda obtained the results in Table 11 below.

Table 11 Prediction of whole tree density from whole breast height cores (coefficients of determination r^2 in percent)

	Sample points breast height	Within tree: 15% height	Breast ht + 15% ht
<u>P. caribaea</u> var. <u>hondurensis</u> , Uganda	77%	58%	85%
<u>P. caribaea</u> var. <u>hondurensis</u> , Tanzania	74%	-	-
<u>P. oocarpa</u> , Uganda	85%	86%	92%

(from Bailey (1982)) determined by x-ray densitometry from discs.

In order to obtain an estimate how early in life it is possible to estimate whole tree density, Bailey (1982) carried out a further set of regressions ring by ring as shown on Table 12 below.

Table 12 Correlations of breast height to whole tree density by rings from pith (P. caribaea var. hondurensis)

	Years from planting										
	1	2	3	4	5	6	7	8	9	10	11
a	25	41	57	69	69	70	72	76	82	85	83
b	97	81	80	82	85	82	82	82	83	83	83

Coefficients of determination ($r^2\%$) for regressions between

a) Breast height mean density accumulated for successive years growth and whole tree mean density at maturity.
Fitted function: $y = a + b + cx^2$

b) Breast height mean density (accumulated) and whole tree mean density for the same number of years of growth.
Fitted function: $y = a + bx$

Source of material - P. caribaea var. hondurensis from Uganda.

From Goodwin Bailey (1982).

The "a" figures in Table 12 are a measure of the closeness of correlation between the density of a breast height core measured at successive ages from 1-11 years old with whole tree density at 11 years old (1st year is ring density for that year, 2nd year is weighted average b.h. density for the two years, 3rd year is weighted average b.h. density for 1st 3 years of growth etc. regressed against whole tree density at 11 years).

The "b" figures are a measure of the closeness of correlation of the whole b.h. core with the whole tree density at different ages in the trees' life up to 11 years (2nd year is weighted average of b.h. density for 1st two rings regressed against the weighted average of the whole tree at that age etc.). The "a" figures are, therefore, an indication of how soon it is possible to predict from a b.h. core what the density of the whole tree will be at 11 years and it can be seen that by the 4th year a reasonable prediction can be made ($r^2 = 69\%$).

The "b" figures indicate how accurate breast height cores are likely to be in predicting whole tree density at different tree ages. It can be seen that it is very high in the first year, after that it drops slightly but remains remarkably constant.

It can be assumed, therefore, that in normal conditions of growth whole tree density can be predicted quite accurately from breast height cores and that even breast height cores from young trees can give a good indication of what whole tree density will be like in later years. Similarly, by measuring the density of only the last five years of growth quite good estimates can be obtained for whole tree density.

For this reason the "Pilodyn", an instrument with a spring loaded plunger which is driven into the tree and the depth of penetration measured, has given quite accurate measurements of tree density used on P. caribaea.

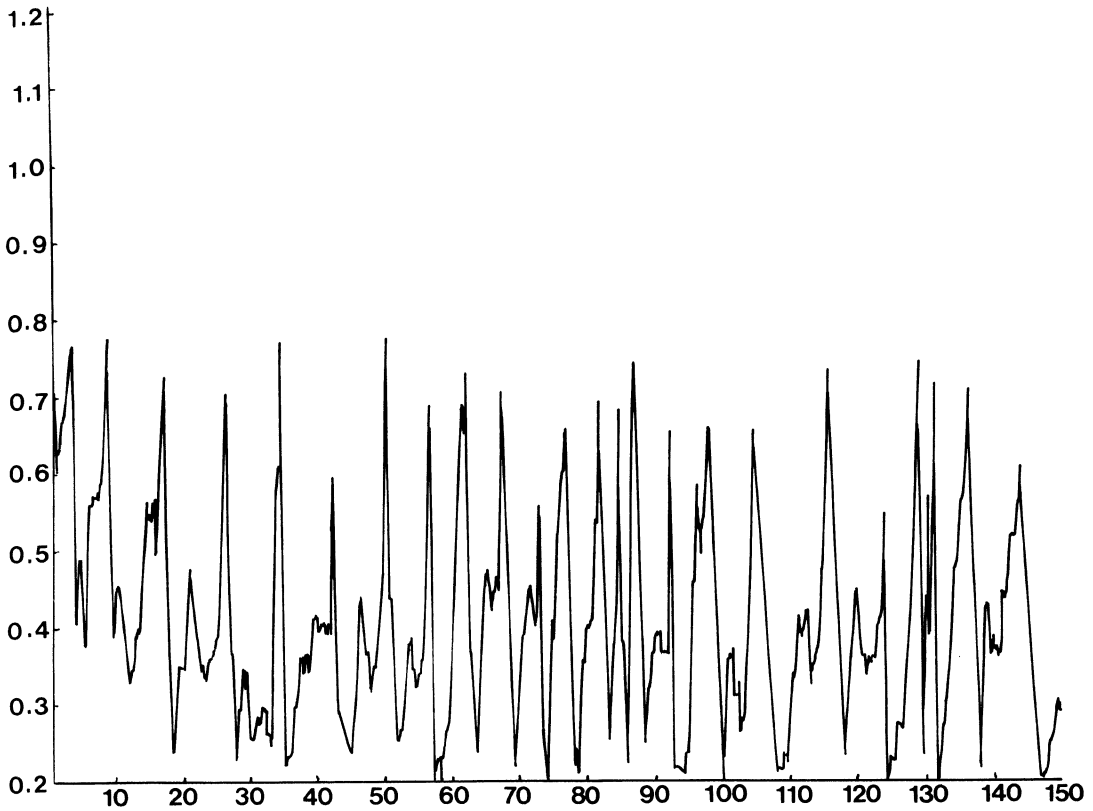
4.535 Within-ring variation in density

Poynton (1975) and Scott (1952) remarked on the uniform texture and ease of finishing of the wood of P. caribaea due to the large number of false rings and lack of extreme contrasts between early and latewood. Cown et al. (1981) also confirmed this uniformity of wood texture. Figure 14 shows x-ray densitometric traces for P. caribaea var. hondurensis and Picea sitchensis (Sitka Spruce) a temperate conifer performing a similar function in the United Kingdom to P. caribaea in tropical countries as a general purpose softwood. Borgin (1972) has pointed out that in weathering of wood much of the deterioration is due to the wood tearing itself apart through repeated movement and extreme contrast between early and latewood speeds up this process greatly.

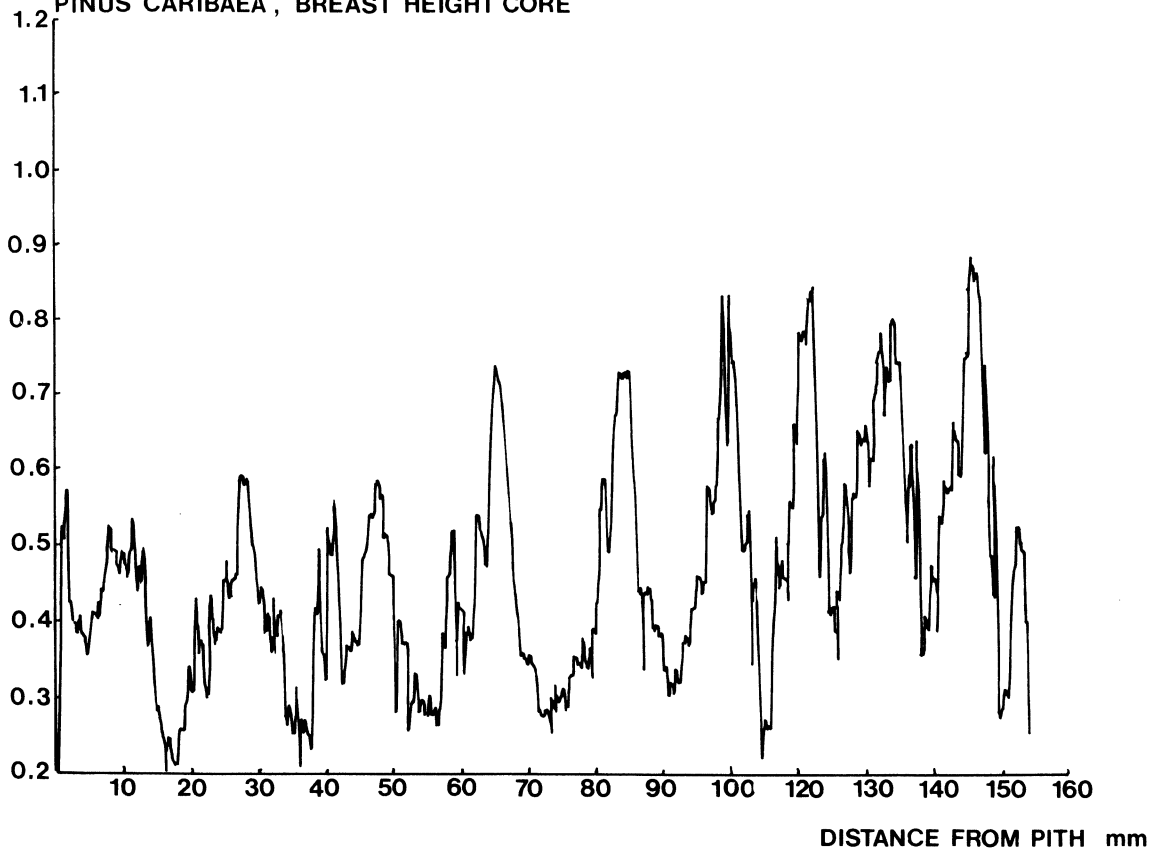
It can be seen from Figure 14 that the earlywood density of the Sitka Spruce is lower than in the P. caribaea and the very steep drop from latewood to earlywood of the following year in the Spruce is not found in the pine where there is a more gradual transition from one type of wood to the other. The Spruce does not, however, have the low density juvenile core found in the pines generally but the tropical pines in particular.

FIGURE 14. DENSITOMETER TRACES

PICEA SITCHENSIS, BREAST HEIGHT CORE



PINUS CARIBAEA, BREAST HEIGHT CORE



5.0 Mechanical properties

Mechanical properties are not as easy to measure as wood density since they require larger pieces of wood for carrying out the tests and careful conditioning and preparation. For these reasons wood strength of P. caribaea has been less widely measured than density. Information on methods of testing clear specimens are given in Lavers (1969). The clear specimens give the strength of the wood without knots and other visible defects and for strength grading for timber to be used for structural purposes allowances have to be made for defects and the effects of long term rather than short term loading. Tests on small clear specimens do, however, give useful information for comparing different species, varieties, sites, treatments, etc. Wood strength measured in this way is a much more accurate measure than density of what forces structural members made of that timber will stand since, although correlations with density are normally high for most strength properties except cleavage, there are still quite wide variations of specific strength between and within trees.

Strength varies very considerably according to moisture content of timber below fibre saturation point (approx. 30% m.c.) and tests must be done either green or at a standard moisture content to be comparable with other tests; 12% m.c. is normally taken as "air dry" moisture content at which almost all tests, other than green tests, are done. The green and dry values of strength are very different. In general green timber is more flexible and less rigid green than dry. Its modulus of rupture, modulus of elasticity, compression strength, hardness, shear and cleavage are much higher dry than green but resistance to impact and toughness are as high or higher green than dry.

Table 13 summarises most of the published standard strength tests done on the species and separates natural material from plantation material; other common softwood species are included for comparison.

5.1 Variation between species

Examination of Table 13 indicates that at the same wood density P. caribaea is slightly less strong in most strength properties than P. radiata but the differences are small. Alston (1980) in Fiji stated that Fiji-grown var. hondurensis is slightly stronger in modulus of rupture than P. radiata but weaker in modulus of elasticity. Similarly, it is slightly weaker than temperate pines and considerably weaker than Sitka Spruce of the same density but it has very considerable advantages over the latter in having a more uniform textured wood. It has to be remembered, however, that P. caribaea is on average a denser wood than any of these species at a given tree age on most sites and therefore if one compares wood of the same density in different species it is likely to come from more juvenile wood in P. caribaea than in other species.

In Fiji Whiteside (1976) stress graded 100 x 50 mm timbers and found the differences shown in Table 14 below between species. (Modulus of elasticity is measured by stress grading).

Table 13. Mechanical properties of *P. caribaea* in different locations

Source and variety	Origin and age	No. of trees sampled	Moisture content at test	Density		Static bending centre load				Impact maximum drop of hammer	Compression maximum compression strength parallel to grain	Hardness resistance to indentation on side grain	Shear maximum shearing strength parallel to grain	Cleavage	
				Green or 50% mc	Basic	Maximum bending strength MOR	Stiffness MOE	Energy consumed						Resistance to splitting	
								To max load	To total fracture						radial
				%	kg/m ³	kg/m ³	N/mm ²	N/mm ²	mmN/mm ³	mmN/mm ³	m	N/mm ²	N	N/mm ²	N/mm width
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A Natural grown material															
Cox (1939)	Belize	-	41	-	-	65	10376	-	0.34	1.04	34.0	3200	9.2	9.2	10.1
var. <i>hondurensis</i>		-	12	-	-	106	12568	-	0.25	0.91	56.0	4982	14.3	12.2	13.3
Armstrong (1960)	Nicaragua	5	29	977	-	87	10635	0.17	0.44	1.07	39.0	4177	11.3	-	-
var. <i>hondurensis</i>															
Longwood (1962)	Nicaragua	-	-	-	610	52	10312	0.06	-	-	29.0	3470	-	-	-
var. <i>hondurensis</i>	Belize	-	41	-	650	65	10377	0.09	-	-	33.0	3203	8.10	-	-
	Belize	-	35	-	680	81	11921	0.09	-	-	35.0	4359	8.07	-	9.6 mean of rad. 9.6
LWers (1969)	Nicaragua	5	29	977	660	83	11400	0.135	0.352	0.99	37.4	4180	9.9	8.6	11.0
var. <i>hondurensis</i>	Belize	10	41	977	600	66	10400	0.091	0.338	1.04	33.0	3200	9.2	9.3	10.0
		10	12	-	620	107	12600	0.125	0.253	0.91	56.1	4980	14.3	12.1	13.3
Guatemala (1972)	Guatemala (Poptun)	5	air-dry	670	590	46	11177	-	-	-	32.0	3384	-	-	-
var. <i>hondurensis</i>															
Hughes (1970)	Belize	50	12	-	-	-	-	-	-	-	26.1-73.6	-	-	-	-
var. <i>hondurensis</i>															
B Plantation grown material															
Banks (1954)	South Africa	-	12	-	458	65	7967	-	-	-	33.8	2370	7.7	-	-
var. <i>hondurensis</i>			12	-	467	73	8436	-	-	-	40.5	2682	10.0	-	-
Lee & Chu (1965)	Malaysia	14	188	1.07	370	27	3274	0.060	0.185	0.51	14.2	1968	6.6	8.7	9.4
var. <i>hondurensis</i>															
Banks (1979)	South Africa	-	12	-	546*	85	9162	-	-	-	41.4	3433	11.1	-	-
var. <i>caribaea</i>	24-														
(Kwambonambi)															
var. <i>hondurensis</i>	26	-	12	-	471*	73	8372	-	-	-	40.3	2637	10.0	-	-
(Dukuduku)	years														
var. <i>hondurensis</i>	old	-	12	-	437*	74	8631	-	-	-	40.3	2799	9.9	-	-
(Kwambonambi)															
Bolza & Kloot (1972)	Fiji	12	Green	-	415	34	4551	-	-	-	16.0	-	-	-	-
var. <i>hondurensis</i> ?	12 years old		12	-	503*	64	6276	-	-	-	33.6	-	-	-	-
Resch & Bastendorff (1978)	Brazil														
var. <i>hondurensis</i>	Bugre														
5 years		13	12	-	360	33	3724	-	-	-	-	-	-	-	-
Freudenberg	4 years	5	12	-	360	36	3586	-	-	-	-	-	-	-	-
Freudenberg	10 years	15	12	-	380	48	5034	-	-	-	-	-	-	-	-
Freudenberg	17 years	21	12	-	440	75	8620	-	-	-	-	-	-	-	-
Viscosa	5 years	-	12	-	350	33	3655	-	-	-	-	-	-	-	-
Puerto Rico	10 years	-	12	-	380	61	6345	-	-	-	-	-	-	-	-
Central America	Natural	-	12	-	680	105	14000	-	-	-	-	-	-	-	-
Siemon et al. (1976)	Queensland	3	Green	-	-	-	-	-	-	-	20.1	-	-	-	-
var. <i>hondurensis</i>	Australia		12	-	-	-	-	-	-	-	40.3	-	-	-	-
Hughes (1967)	South Africa	-	12	-	-	-	-	-	-	-	30.6	-	-	-	-
var. <i>hondurensis</i>															
Wood Handbook (1955)	Jamaica	-	12	-	390	52	6792	0.044	-	-	-	2716	-	-	-
var. <i>hondurensis</i>															
C Comparable species															
<i>Pinus sylvestris</i>	U.K.	61	89	625	420	46	7300	0.070	0.214	0.69	21.9	2220	5.9	8.2	9.5
(Scots Pine)		61	12	-	460	89	10000	0.103	0.134	0.71	47.4	2980	12.7	10.3	13.0
<i>Pinus radiata</i>	Kenya	4	88	641	430	41	7700	0.059	0.123	0.46	19.1	2180	5.8	7.5	9.1
		4	12	-	460	85	9000	0.112	0.147	0.58	48.1	3830	12.8	16.1	13.0
<i>Picea sitchensis</i>	U.K.	105	69	481	330	34	5900	0.058	0.170	0.56	16.1	1560	4.5	5.8	7.2
(Sitka Spruce)		104	12	-	340	67	8100	0.079	0.125	0.51	36.1	2140	8.7	7.7	10.0

Notes: 1. *Volume at test and weight at 12% mc
2. One Newton/mm² is the same as one Megapascal (Mpa) quoted by some authorities.

Table 14 Stress graded strengths of pines in New Zealand

	Mean basic density	Mean E (N/mm ²)	
		Green timber	Dry timber
<u>P. elliotii</u> - Fiji	0.486	6,050	7,450
<u>P. caribaea</u> - Fiji	0.445	5,350	6,630
<u>P. radiata</u> - Kaingaroa	0.423	4,690	6,600
<u>P. taeda</u> - New Zealand	0.386	4,700	5,540
<u>P. palustris</u> - New Zealand	0.422	4,600	-
<u>P. elliotii</u> - New Zealand	0.343	4,160	4,800

From Whiteside (1976).

The superiority of the P. caribaea over the New Zealand pines was attributed by Whiteside to smaller knots and other defects in the Fiji timber. This indicates that any inferiority in strength of clear timber may be made up by having fewer, smaller defects.

5.2 Variation between varieties and provenances

Very few strength tests have been done on varieties caribaea and bahamensis but both varieties produce denser timber on most sites than var. hondurensis and consequently stronger timber. There are insufficient figures available to determine whether specific strength (strength for a given wood density) is higher or lower than for var. hondurensis. Little or no information is available on the strengths of different provenances other than some work done by R.D. Barnes using a "Pilodyn" which forces a small plunger into the outer rings of a tree and measures penetration and hence hardness of the wood or a property similar to it. These tests have been carried out on different provenances and significant differences have been found between provenances and good correlations with density measurement on matched cores (personal communication).

5.3 Variation between trees

This is very large indeed reflecting often the age of trees rather than anything else. This is demonstrated by the different densities and strengths of trees of different ages as shown by Resch and Battendorff (1978) (see Table 13).

Bower et al. (1976) showed that the strength properties vary more than density and that 5 year old trees have 25-27% of the modulus of elasticity, 31-39% of the modulus of rupture and 52-62% of the density of the wood of mature naturally grown P. caribaea.

As early as 1938 Fahnestock and Garratt showed that the lowest compression strengths found were only 40% of the highest.

De Villiers (1974), however, found little difference in strengths between 19 and 30 year old trees in South Africa (64.3 N/mm^2 and 66.1 N/mm^2 for modulus of rupture). It is, therefore, in the juvenile stages of growth that the very low strengths are found, but it is important to note that, although density and strength are closely correlated, the increase in strength with increase in density is very much greater than the increase in density and relatively small density differences may give quite large strength differences. This is reflected in specific strength differences (see below para, 5.8).

5.4 Variation between sites

There is not a great deal of information on variation of strength from site to site but Table 15 below from Van der Slooten et al. (1969) shows variation between three sites in Jamaica.

Table 15. Mechanical properties of Pinus caribaea from Jamaica

	SPECIFIC GRAVITY weight oven dry Volume green	STATIC BENDING			HARDNESS	
		Modulus of Rupture N/mm^2	Modulus of Elasticity N/mm^2	Work to Max. load mmN/mm^3	End N	Side N
SITE J (JOPPA)	0.39	47.7	6176	0.45	3236	2099
SITE D (ADAM BRANDON)	0.42	55.2	7843	0.45	3452	2324
SITE E (LANCASTER)	0.36	46.8	6373	0.41	2795	1657
AVERAGE	0.39	49.9	6764	0.42	3158	2050

(From Slooten van der et al., 1969)

Differences in strength between sites were small and components of variation also below 10%.

Table 16 shows strength variation from different Fiji sites as tested by stress grading of 100 mm x 50 mm timber.

Table 16 Strengths of stress graded timber from different sites in Fiji

<u>Fijian timbers</u>	Mean E (N/mm ²)	
	Green	Dry
<u>P. caribaea</u> - Nausori Highlands	4,850	6,150
<u>P. caribaea</u> - Drasa-Lololo	5,580	7,080
<u>P. caribaea</u> - Seaqaqa	5,630	6,650
<u>P. caribaea</u> - All sites	5,350	6,630
<u>P. elliottii</u> - Nadarivatu	6,050	7,450

(From Whiteside, 1976).

No statistical tests of significance were carried out on these figures.

The differences between sites for strength, therefore, are likely to be similar to those for density.

5.5 Variation within trees

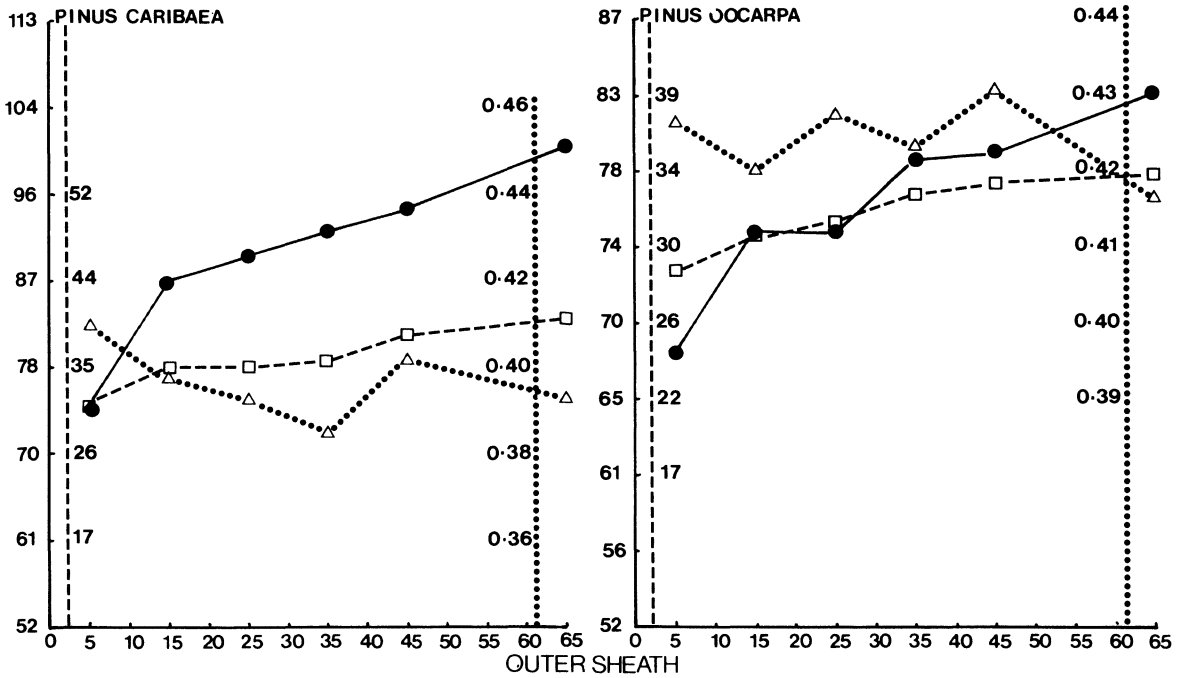
Not many studies have been done on strength variation within trees of P. caribaea but Goodwin-Bailey (1982) has made a study of within tree axial compression strength variation in 20 trees of 12 year old P. caribaea var. hondurensis and 20 trees of P. oocarpa in Uganda where samples were taken at six heights up the tree and contiguous samples were taken from pith to bark at these heights. Figure 15 shows plots of mean strengths, densities and specific strengths up the trees for the inner test samples near the pith and for the outer "sheath" of samples nearest the bark. It shows trends up the tree but also if examined carefully it shows radial gradients at the six heights between the innermost and outermost sample at that height. It shows a very slight decrease of density up the tree near the pith but at the same time a slight increase in compression strength and thus a considerable increase in specific strength.

In the outer sheath there was a strong decrease in density up the tree as would be expected, a similar but slightly smaller decrease in compression strength but an increase in specific strength in the middle of the trees length at 15-45% height suggesting that the wood may be more "strength efficient" in this region of the tree.

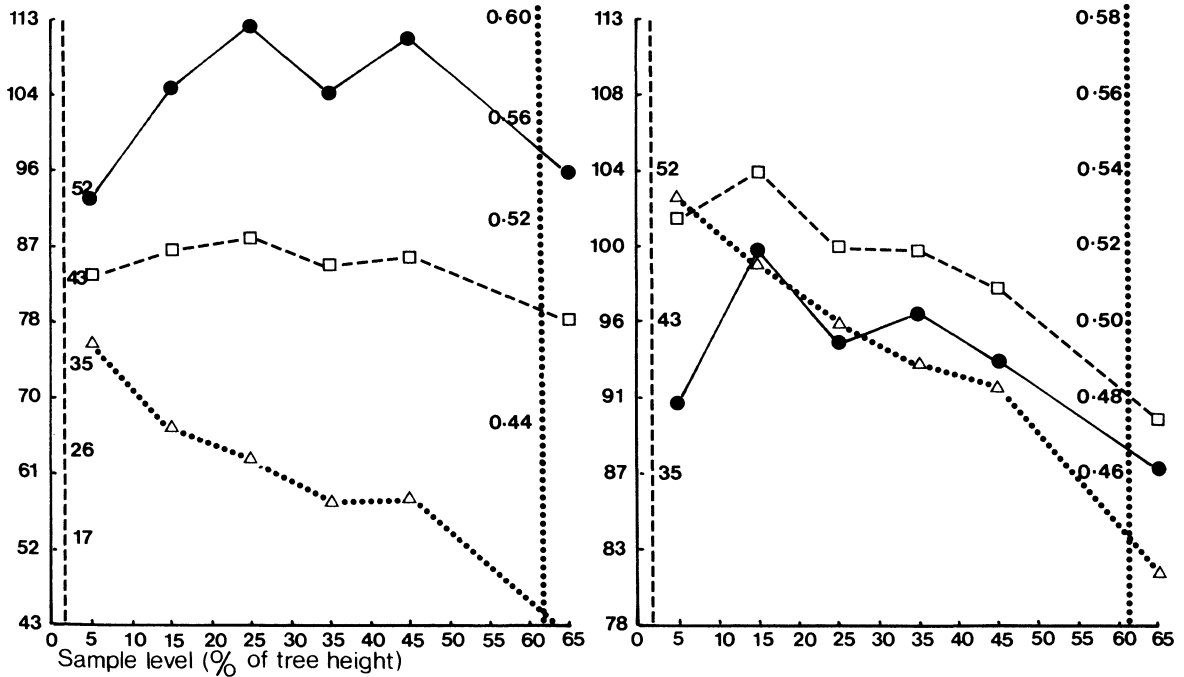
Resch and Bastendorff (1978) found modulus of elasticity increased up the tree and with distance from pith and modulus of rupture also increased with distance from pith as did compression strength.

FIGURE 15. Effect of sample position on the compression strength, specific strength and true gravimetric density of wood of *P. caribaea* var. *hondurensis* and *P. oocarpa* from adjacent plots at Katugo, Uganda. From Goodwin - Bailey(1982)

INNER CORE SAMPLES



OUTER SHEATH



- Specific strength
- Compression strength (N/mm²)
- △.....△ Gravimetric density (g/cc)

5.6 Correlations between strength and density

Resch and Bastendorff (1978) also investigated correlations between strength properties and density and found the following linear coefficients of determination (r^2) of strengths against density.

Modulus of elasticity	51%
Modulus of rupture	63%
Compression strength parallel to the grain	57%

Goodwin-Bailey (1982) found that correlations between compression strength and density were as follows:

<u>P. caribaea</u>	48%
<u>P. oocarpa</u>	79%

The better r^2 for P. oocarpa reflected test samples with fewer defects and less compression wood.

These findings agree with the classical relationship between strength and density described by Lavers (1969) and the relatively low figures of r^2 probably reflect the relatively small range in strength and density measurements in young plantation-grown trees and the occurrence of compression wood, leaf traces and other minor defects in the strength test samples.

5.7 Correlations between breast height and whole tree strength

Goodwin-Bailey (1982) correlated tree mean breast height compression strength with whole tree compression strength and found the following values of r^2 for the two species:

<u>P. caribaea</u>	55%
<u>P. oocarpa</u>	83%

For breast height x-ray density against whole tree compression strength r^2 values were as follows:

<u>P. caribaea</u>	23%
<u>P. oocarpa</u>	25%

It appears, therefore, that breast height compression strength is moderately closely related to whole tree strength but poorly related to x-ray density at breast height for that study but for trees with a greater range of density and strength the correlations would probably have been better.

Simeon et al. (1976) comparing axial compression strength with wood density of 14-16 year old P. caribaea found high correlations of strength with basic density and latewood percentage ($R^2 = 84\%$) and of either variable alone ($r^2 = 79\%$ and 77% respectively). These higher correlations probably reflect a greater tree age and density range than in Goodwin-Baileys' study, (Note: r^2 is coefficient of determination for simple regression, R^2 is coefficient of multiple determination for multiple regression).

5.8 Specific strength

Specific strength has been mentioned above but deserves some attention on its own. It is a measure of the strength of the wood per unit of wood density or the strength:weight ratio or the efficiency of the wood in terms of strength for a given density. In spite of the general relationships between strength and density, the physical arrangement of the wood and possibly also the chemical composition result in some wood being more efficient than other wood. The following specific strengths for instance can be calculated from Table 13.

Table 17 Specific strengths of *P. caribaea* and other species

Species and location	Basic density g/cm ³	MOR S Strength	MOE S Strength x 10 ⁻³	Compression S Strength	Total Work S Strength
Natural <i>P. caribaea</i> var. <i>hondurensis</i> Belize (Lavers, 1969)	0.620	173	20.32	90.5	0.408
5 year old <i>P. caribaea</i> var. <i>hondurensis</i> Brazil (Resch & Bastendorff (1978))	0.350	94	10.44	-	-
Scots Pine (Lavers, 1969)	0.460	184	19.57	103	0.29
Sitka Spruce (Lavers, 1969)	0.340	197	23.82	106	1.50

The Sitka Spruce, therefore, for MOR and MOE has double the efficiency of the young plantation-grown *P. caribaea* while the denser mature *P. caribaea* is not much less efficient.

Goodwin-Bailey's work mentioned above also suggests that with increased density and maturity, coinciding with longer tracheid length and probably lower micellar angles the specific strength increases. Plumptre's work with *P. patula* (Plumptre, 1974) suggests that there may be considerable between-tree differences in specific strength in tropical pines.

5.9 Effect of compression wood on strength

Boone and Chudnoff (1972) in an extensive study on the effect of different quantities of compression wood on three strength properties in 8-10 year old *P. caribaea* from Cubuy plantation in Puerto Rico found that compression wood did not affect density or modulus of rupture a great deal but modulus of elasticity was reduced (see Table 18 below).

Table 18. Static bending strength of plantation-grown Pinus caribaea with several levels of compression wood

Levels of compression wood	Sample size	Basic density	Static bending (12% m.c.)					
			Modulus of				Work to maximum load	Work to max. load SS
			rupture	MOR SS	elasticity	MOE SS $\times 10^{-3}$		
pct.	No.		N/mm^2		N/mm^2		$mNmm^3$	
CUBUY PLANTATION								
0-10	49	.38	60.9	160	6345	16.70	0.077	0.20
11-30	38	.39	58.6	150	6069	15.56	0.068	0.17
31-50	24	.41	59.8	146	5655	13.79	0.071	0.17
50+	15	.41	60.3	147	4828	11.77	0.083	0.20

From Boone and Chudnoff (1972).

5.10 Effect of treatment with copper-chrome-arsenate wood preservative and high temperature drying on strength

Simeon (1981) using twenty five matched pieces of timber per trial from logs from a 21 year old stand of *P. caribaea* var. *hondurensis* at Beerburum in Queensland tested the effect of high temperature drying and CCA treatment on the modulus of rupture and modulus of elasticity of the wood. The results of the trial are shown in Tables 19 and 20 below.

Table 19 Mean values and coefficients of variation for MOR and MOE (N/mm^2) by drying method and preservative treatment

Treatment*	Number of samples	MOR		MOE	
		Mean	C.V.%**	Mean	C.V.%
C.C.A./HTD	25	71.9	18.4	8962	24.3
U/HTD	25	78.3	32.7	9515	28.4
C.C.A./AD	25	79.9	21.0	8853	29.0
U/AD	25	85.8	18.1	9275	26.2

* C.C.A. preservative treated
U untreated
HTD high-temperature-dried
AD air-dried

** Coefficient of variation

Differences between treatments, expressed as percentage of the means, are shown in Table 20.

From Simeon (1981).

Table 20 Statistical significance of absolute differences in Table 19 data by drying and preservative treatment

	MOR	MOE
Matched pairs		
HTD: C.C.A. vs U	*	*
AS: C.C.A. vs U	**	**
Unmatched pairs		
C.C.A.: HTD vs AD	*	NS
U: HTD vs AD	NS	NS

* significant at the 5% level

** significant at the 1% level

Abbreviations as for Table 19

From Simeon (1981).

The comparisons of CCA treated versus untreated samples were based on matched pairs but the high temperature drying versus air drying was not on matched pairs and may affect the significance of the results but CCA treatment appears to cause a slight but significant loss of strength while the effect of high temperature drying, although apparently appreciable, was not significant except for MOR and after treatment.

5.11 Strength of *P. caribaea* poles

Kromhout (1978) reporting on low density young material in South Africa suggested the low density and wide inner rings make for weak poles. By contrast Wong and Shakari (1980) tested 9 poles from 15 year old trees in Malaysia for use as transmission poles. All passed the lower limit of strength of 5340 N and most were 2-3 times this strength.

Walford (1980) tested 36 CCA treated poles from 15-17 year old trees in Fiji; he found modulus of rupture for the poles was lower than for small clear specimens but modulus of elasticity was higher for wet poles. MOR was 66 N/mm² and MOE was 11,700 N/mm².

It appears, therefore, that poles from very young trees grown in sites which are high in altitude or latitude may prove to be weak but older trees will probably produce quite satisfactory poles from any site and certainly the more tropical and lower altitude sites.

6.0 Chemical properties

The chemical composition of the wood of P. caribaea is similar to that of many pines in general characteristics. The structure of the wood consists of between 58-76% of holocellulose, 37-45% of α -cellulose and 25-35% lignin as a percentage of weight of oven dry wood. Barrichelo et al. (1979) found that latewood of P. caribaea contained more holocellulose and less lignin than earlywood. Besides the structural material in plantation-grown trees extractives vary from 1.5 to 7.0% while in natural grown trees with mature heartwood they can amount to up to 50% of the weight of the dry wood. The wood structural components are used extensively for paper making after chemical or mechanical separation of the cells or a combination of both. The extractives in the form of resin are used to manufacture turpentine and rosin by distillation of the resin.

Paper making will be dealt with separately in paragraph 8.311 below but extractives and their use are considered here.

6.1 The resin

Resin from P. caribaea has been successfully used for a long period of time to produce rosin and turpentine. As far back as 1923 Hummel was pointing out that the tree produced a useable resin. Hummel (1926) also stated that some trees produced a good flow of resin while others did not.

Record and Mell (1924) also mentioned the growing importance of the species (also including P. elliottii at that time) in producing turpentine and rosin.

The resin is collected either by wounding and tapping living trees, by extraction from stumps or various resin products are obtained as by-products from sulphate pulping. Figure 16 from Greenhalgh (1982) shows the various processes involved and the products obtainable while Plate 8 shows pine stumps on a beach in the Bahamas awaiting collection for exporting for resin production. Resin yields vary from site to site and tree to tree but du Ploy and Male (1977) from South Africa reported that var. hondurensis produced twice the quantity of resin of the other two varieties.

6.11 Resin properties

Oleoresin from P. caribaea produces about 70% of rosin and 10-20% of turpentine.

Rosin uses

The rosin is used to provide adhesives for paper size, additives to adhesives, additives to printing inks to provide adhesion and gloss, in rubber processing in natural and synthetic rubbers and in paints and surface coatings. Figure 16 gives the various products obtained from resin.

FIGURE 16. NAVAL STORES PRODUCTION PROCESSES. From Greenhalgh (1982)

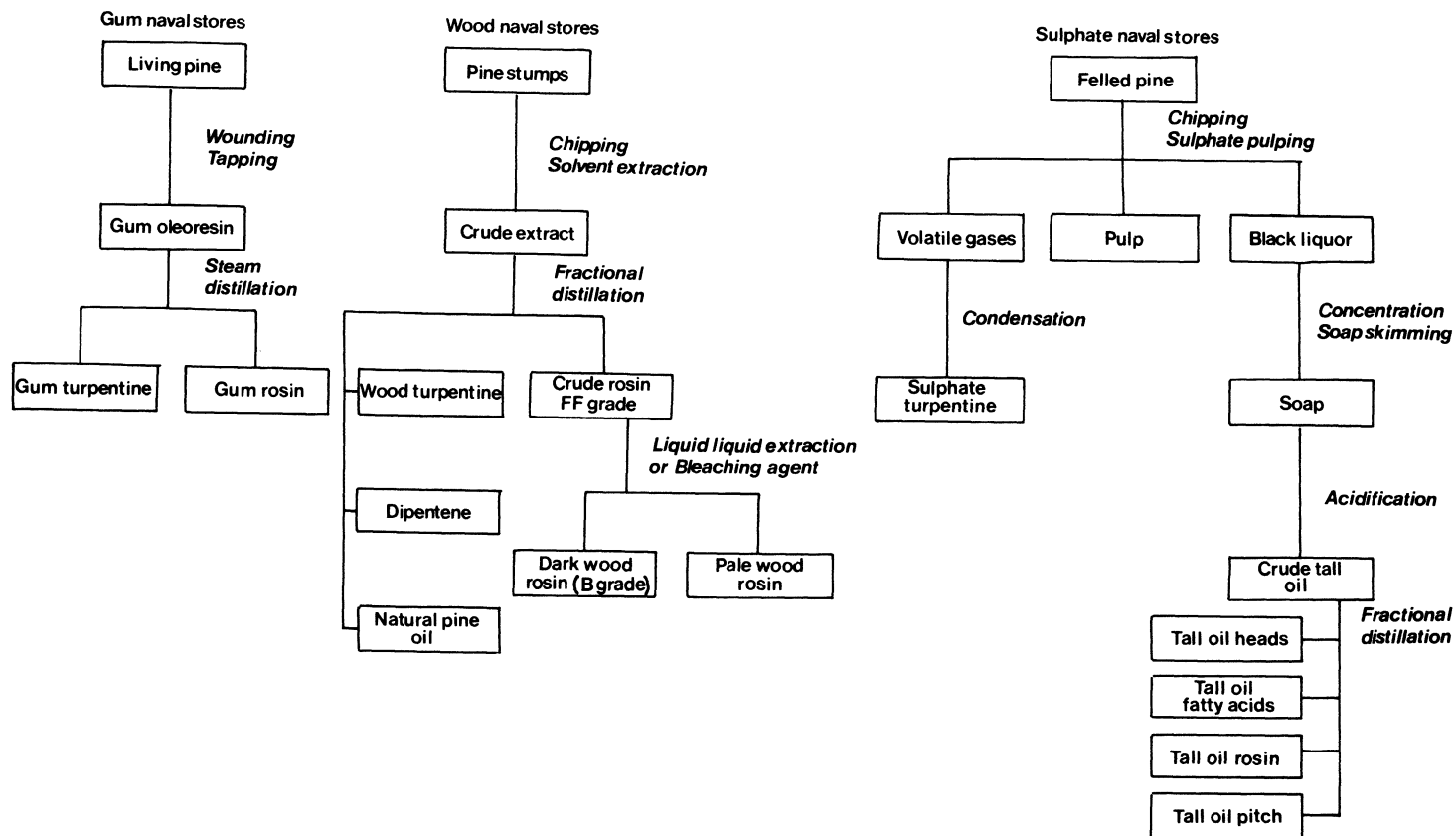
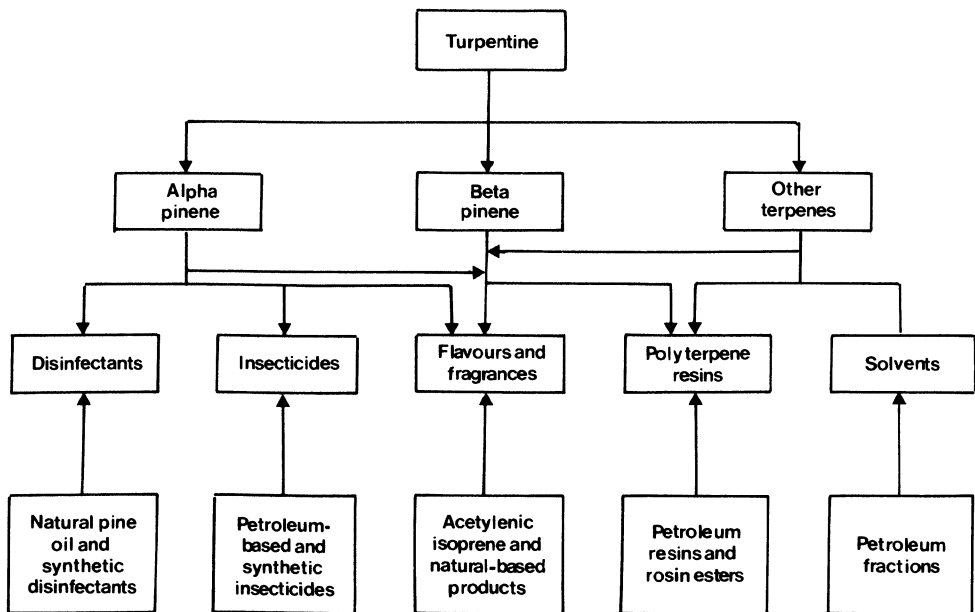


FIGURE 17. TURPENTINE: USES AND COMPETITORS
From Greenhalgh (1982)



Turpentine

Reports of turpentine yields from P. caribaea resin vary but commercially produced have been around 18% (Islip and Matthews, 1950) and Coventry, 1954), while Janz (1980) reported yields varying from 9-27% from different trees in a sample of 17 trees from Sri Lanka.

A Tropical Products Institute Report (UK T.P.I., 1959) reports a clear and pale turpentine from Belize containing the following quantities of products:- 70% alpha-pinene, 5% beta-pinene and small quantities of myrcene and beta-phellandrene.

Smith (1975) reporting on material from var. hondurensis in Fiji gave the following quantities:- alpha-pinene 66%, beta-pinene 7%, beta-phellandrene 22% and estragole 5%.

Table 21 from Green et al. (1975) gives the results of analyses done for different provenances and varieties of P. caribaea and P. oocarpa while Table 22 shows the very wide range of variation between trees within provenances of P. caribaea and the possibilities for selection and breeding. Of the P. caribaea provenances only the Grand Bahama provenance (var. bahamensis) was considered to produce a commercially non-utilisable resin.

Uses of turpentine products

Figure 17 from Greenhalgh (1982) shows the products derived from turpentine. Beta-pinene being more reactive is used more in high value fragrance and flavour compounds. The prices obtainable for beta-pinene are about 30% above the alpha-pinene prices while "perfume" grades of the products have about ten times the value of the unrefined product. There is therefore a need for high quality in production and processing.

Resin collection

Resin has been collected and processed in the Honduras Republic for a long period of time. An attempt was made to establish an industry in Belize, between 1963 and 1965 (Johnson and Chaffey, 1974) but failed. Flowers (1980) however, mentioned a recent agreement to export stumps. Nicaragua produced resin in some quantities in the 1960s and 1970s but production ceased in 1980 when political problems intervened. Stumps have been sold for export from the Bahamas since 1950.

Methods of tapping have changed and Howes (1949), Sanderman (1953) and Sanchez (1971) all wrote reports suggesting better methods of tapping while Sanderman claimed that 300,000 trees a year were being destroyed in Honduras through destructive tapping methods. Little, if any, commercial tapping of plantation-grown trees has taken place.

Stephan and Betancourt (1981) found in Cuba with var. caribaea that the production of resin per metre of face streaks cut on the tree was not significantly different from year to year and estimated that maximum yield per hectare would be greatest from 20 cm diameter trees but greater yield per man would be obtained with larger trees. Brito

Table 21. Summary of mean turpentine composition by provenance

Species	Provenance	No. of trees sampled	Average % yield of turps from oleoresin (v/w)	Av. % composition of the turpentine		Major components of the turpentine (abundance >10%)				
				Mono-terpenes	Sesqui-terpenes	Alpha-pinene	Beta-pinene	Delta-3-carene	Beta-phellandrene	Longi-folene
<i>P. oocarpa</i> (Natural stands)	Honduras									
	San Juan	27	27.3	85.4	14.6	71.6	*	*	*	11.5
	Pimientilla	21	27.9	88.5	11.5	63.7	15.5	*	*	*
	Nicaragua									
	Yucul	29	26.3	86.0	13.5	18.3	11.3	51.7	*	*
	Las Mangas	30	27.9	84.8	15.1	43.9	*	23.4	*	11.3
<i>P. oocarpa</i> (Natural stands)	Belize									
	Mountain Pine Ridge	23	28.0	93.3	6.7	85.3	*	*	*	*
	Belize									
	Mountain Pine Ridge	20	28.6	93.8	6.1	83.5	*	*	*	*
	Guatemala									
	La Cumbre	21	30.2	86.7	12.4	80.4	*	*	*	*
	La Lagunilla	27	28.1	80.9	18.4	19.9	*	52.0	*	13.9
	Honduras									
	El Zamorano (K86 area)	26	28.9	84.9	14.3	69.9	*	*	*	*
	El Zamorano (K88 area)	34	29.5	84.8	14.2	70.6	*	*	*	10.5
<i>P. caribaea</i> (Natural stands)	Villa Santa	19	29.4	85.5	13.8	71.3	*	*	*	10.2
	Nicaragua									
	Alamicamba	30	30.5	93.2	6.8	68.4	*	*	17.5	*
	Belize									
	Melinda	30	28.8	95.4	4.4	63.2	*	*	25.3	*
	Las Lomitas	29	20.3	94.9	4.8	66.0	*	*	16.7	*
<i>P. caribaea</i> (Natural stands)	Grand Bahama									
	High Rock	28	25.7	98.0	1.6	36.4	*	*	54.0	*
	Honduras									
	Los Limones	11	31.3	89.4	10.2	56.5	*	*	25.5	*
	Nicaragua									
	Santa Clara	12	29.0	92.2	7.6	66.9	*	*	14.3	*
<i>P. caribaea</i> (Natural stands)	Laguna el Pinar	8	29.1	90.3	9.2	53.5	*	*	22.2	*

* = less than 10%

From Green, Keeble and Burley (1975).

Table 22. *Pinus caribaea* - turpentine compositions of individual trees selected to show the range of types

Provenance	% abundance of selected constituents				
	Alpha-pinene	Beta-pinene	Delta-3-carene	Beta-phellandrene	Longi-folene
Alamicamba, Nicaragua	86.7	5.7	1.0	1.0	2.6
	40.0	2.2	1.2	42.7	9.6
Melinda, Belize	89.9	5.0	0.8	0.7	1.5
	46.9	3.4	1.6	45.8	Trace
Las Lomitas, Belize	88.9	6.2	1.1	1.3	Trace
	60.2	19.5	1.3	10.0	4.2
	34.5	2.5	1.6	35.9	12.5
High Rock, Grand Bahama	64.1	2.8	1.1	28.5	Trace
	13.6	1.5	1.6	78.1	0.1
	14.2	2.0	26.4	51.4	0.2

From Green, Keeble and Burley (1975).

(1978a) during trials of tapping with var. bahamensis in a 10 year old plantation in Brazil found that neither temperature nor rainfall had much effect on resin production and tapping could be done throughout the year. Coventry (1954) found that acid treatment of faces producing resin had little effect on the quality of resin produced.

7.0 Factors affecting wood development and properties

The factors which influence the type of wood produced by a particular tree in any particular location can be divided into genetic and environmental factors.

7.1 Environmental factors

The factors of the environment of a tree can be subdivided into those which are fixed or virtually fixed such as climate, soils and topography and those which can be altered by silviculture or other treatments.

7.11 Fixed environmental factors

Climate is affected by altitude, latitude and topography and these will be considered together with soils in their effect on wood properties and growth rate of the species. The variation of wood density between and within trees is discussed in paragraphs 4.533 and 4.534 while variation of density with site has been discussed in paragraph 4.532.

Plate 5 shows breast height discs of three trees grown in a single plot in Fiji, the rates of growth are similar but the patterns of early and latewood formation are quite different. The differences could be due to genetic factors or the immediate environment of the individual trees but cannot be due to climate or general topography.

Plate 4 shows the differences between different trees grown on different sites at different altitudes and the contrast between slow growth and high density and rapid growth and low density can be seen which in this case coincide with low and high altitude respectively; high or low altitude per se do not necessarily influence wood properties but appear to do so by affecting the moisture available to the tree at different periods of the time during the year.

The response of P. caribaea is different from that of P. taeda or P. elliottii to climatic variation. There is a much greater tendency to produce false rings with minor climatic changes during the year than with the more temperate species and var. hondurensis shows this trait to a greater extent than var. caribaea or var. bahamensis which are more similar to the Southern pines of the United States. (Smith, 1978a).

Harris (1978) suggested that wood density varies inversely with altitude and latitude and this agrees well with Cown (1981) in Fiji who found close correlations between wood density and age and site altitude.

Barnes et al. (1978) in Zimbabwe and Plumptre (1978) in East Africa found close correlations between wood density and soil moisture deficit but the latter found little correlation between wood density and altitude in East Africa. Hughes (1970 and 1973) suggested that moisture availability and formation of latewood and earlywood were

closely connected. Goodwin-Bailey (1982) found that with var. hondurensis although rates of growth were not significantly different between a coastal site in Tanzania and a seasonally dry site at 1100 m altitude in Uganda the average density was significantly higher in the coastal site but only by 0.03 g/cm³ while the mean maximum density within rings was much higher (0.703 as opposed to 0.500) and the mean minimum density was the same or slightly lower.

Okoro (1980) at Ibadan in Nigeria studying 8 year old trees found var. hondurensis exhibited periods of fast and slow growth; fast growth was initiated when rainfall exceeded 150 mm/month and slow growth was initiated when rainfall dropped below 100 mm per month while potted, 1 year old layered material in a greenhouse, irrigated continuously, grew continuously.

Smith (1973, 1978 and 1978a) found in Queensland that the higher quality sites with rapid growth gave lower density wood; ring width increased and density decreased with altitude while latitude had no effect on density. He also found that fast grown, dominant trees had higher spiral grain angles than normal. He found that growth ceased below 12°C but that periods of rapid growth and earlywood formation were associated with high sunshine and monthly evaporation of over 120 mm while slower growth and latewood formation were associated with low sunshine, peak rainfall and lower evaporation in mid to late summer or early autumn.

It appears that these results conflict with the findings elsewhere but the delay in soil moisture replenishment after rain has begun to fall and decreasing temperatures may have an effect in higher latitudes such as Queensland.

It appears, therefore, that water availability and, where limiting, sunshine and temperature have an effect on production of earlywood and latewood particularly in var. hondurensis and less in var. bahamensis and var. caribaea but the exact methods by which these factors act are imperfectly known.

Soils

Little work has been done to compare soils directly with wood properties but it is reasonable to assume that, provided adequate trace elements are available, the availability of the main nutrient elements are important in determining the rate of growth; the depth of soil and its water retaining and yielding properties are important in determining the amount of early and latewood produced. It is possible, for instance, that the different developments of early and latewood shown in Plate 5 could be due to the depth and porosity of the soil around each of the three trees rather than to genetic differences.

Wind

According to Slee and Nikles (1968) and Slee (1971) the wind firmness of var. hondurensis is less than var. bahamensis but increases with tree size. Young foxtailed trees appeared to ride cyclones in Fiji better than more branched trees. Trees grown in the tropics appear to be less tapered than those grown at higher latitudes.

7.12 Alterable environmental factors

These are factors which can be altered by silviculture and include methods of establishment, spacing, pruning and fertiliser application. Establishment has little effect on wood properties other than to determine whether the tree starts growing rapidly and overcomes weed competition quickly; spacing, pruning and fertiliser application, however, can radically affect wood properties.

Spacing

Considering the extensive literature on P. caribaea there is little information on the effect of spacing on wood properties of the species but Cown (1981) found in Fiji spacing trials that wider spacing gave more rapid growth per tree and lower wood density. In contrast Whitmore and Liegel (1980) in Puerto Rico found that trees 11.5-13.6 years old triangularly spaced at 5, 7, 10 and 14 ft spacing had lower density at the 5 ft spacing than at the 14 ft spacing (0.44 g/cm^3 as opposed to 0.52 g/cm^3).

Pruning

The effects of pruning on wood properties are of particular interest in that pruning can have a considerable effect on wood quality both in producing clear wood and in altering taper and wood density.

Luckoff (1949) in a study on the effects of pruning on three pine species (P. caribaea, P. patula and P. taeda) found that:

- pruning reduced diameter increment more than height increment
- recovery from even quite severe prunings took only 2 years; if there was no competition from surrounding unpruned trees an absolute recovery of increment was considered possible
- pruning of 25% of tree crown had no effect on diameter or height growth
- pruning 50% of crown had an influence on diameter increment but none on crown increment
- between 4 and 8 years of age, rate of recovery from pruning was in inverse proportion to tree age
- P. caribaea was the quickest of the three pines to recover from pruning
- recovery from pruning was quicker on poor sites than on good ones
- pruning reduces taper except in the upper crown and at the extreme base of the tree.

Vel (1975) in Surinam carried out a series of pruning trials with P. caribaea on the basis of which he recommended pruning when the tree was 10.5 cm in diameter to obtain a knot affected core of 15 cm and estimated that it would be economic to prune on a 30 year rotation at 7% interest rate.

Gerischer and de Villiers (1963) showed with P. patula that severe pruning not only decreased taper in the merchantable bole but also increased wood density and Plumptre (1978, 1978a and 1979) also with P. patula, found very considerable density increases in the lower stem as a result of severe pruning with rapid recovery of growth rate in the

crown following pruning but a permanent increase of density in the bottom log of the tree. There appears, therefore, to be scope for reducing the size of the juvenile core by severe early pruning of at least the bottom log of the tree with very little if any permanent loss of increment, in a reduction in radial gradient of density in the lower bole, a reduction of taper and the production of knot free timber outside the knotty core. This, as far as is known, has not yet been fully tested but could provide a far more sensitive way of controlling the low density juvenile core than by closer spacing. Trials would need to test prunings on very young trees, pruning to between 50% and 75% of tree height. It is essential to allow trees space to recover from the prunings and to prevent competition from surrounding unpruned trees.

In most cases the juvenile core of a tropical pine is laid down in the first 5-7 years of its growth. Prunings need to be during this period to control the core. Numerous pruning studies in New Zealand and elsewhere show that the maximum benefit from pruning is obtainable in the bottom log of the tree for the following reasons:

- a smaller knotty core is possible because the tree crown is smaller when it is young
- the bottom log is the most valuable
- the bottom log is the largest and therefore more clear wood after pruning is obtainable
- the most rapid diameter growth and lowest wood density is often found in this log
- the most dense and strongest wood is often near the bark at the base of the tree.
- For this reason there is often the largest gradient of strength and wood density from pith to bark if no control of juvenile core is exercised.
- The tree recovers better from pruning when young, and therefore, permanent loss of increment is less likely than later in life
- low pruning to 5 or 6 metres or so is much easier and cheaper to do than high pruning.

Fertiliser application

There appears to be little or no information about the effects of fertiliser application on the wood properties of *P. caribaea*. Fertilisers can, in the right circumstances, greatly increase growth rate which may reduce wood density but experience with other conifers suggests that this is not necessarily the case and that very little if any decrease in density will occur; much depends on other environmental factors such as existing soil nutrients, moisture availability, competition with other trees and other factors affecting the general rate of growth of the tree.

7.2 Influence of tree morphology on wood properties

Attempts to predict wood properties from morphological properties of trees have largely failed so far. Correlations have normally proved to be low: Brown (1969) found low correlations between crown form, tree

height and d.b.h. and wood density for P. caribaea while Ong (1978) found the low correlations between various morphological characters and wood density given below:

Table 23 Coefficients of determination % for regressions of tree morphological characters on wood density

<u>Character</u>	<u>Value of r^2 per cent</u>	<u>Significance</u>
Tree height	+0.46%	NS
Tree volume	-17.7%	NS
D.b.h.	-17.1%	NS
Crown width	- 1.4%	NS
Crown length	- 3.4%	NS
Age	+ 2.4%	NS

From Ong (1978).

Plumptre (1974) also found low correlations with P. patula between density and morphology, the highest correlation being a positive one between crown diameter and wood density with an r^2 of 20% (better than crown volume (12%%)).

Lean and stem irregularity affects the quantity of compression wood and tends to be greater in var. hondurensis than in var. caribaea or var. bahamensis. Fertile soils and high rainfall also appear to increase stem irregularity, spiral grain and foxtailing (Wiersum (1973) in Costa Rica).

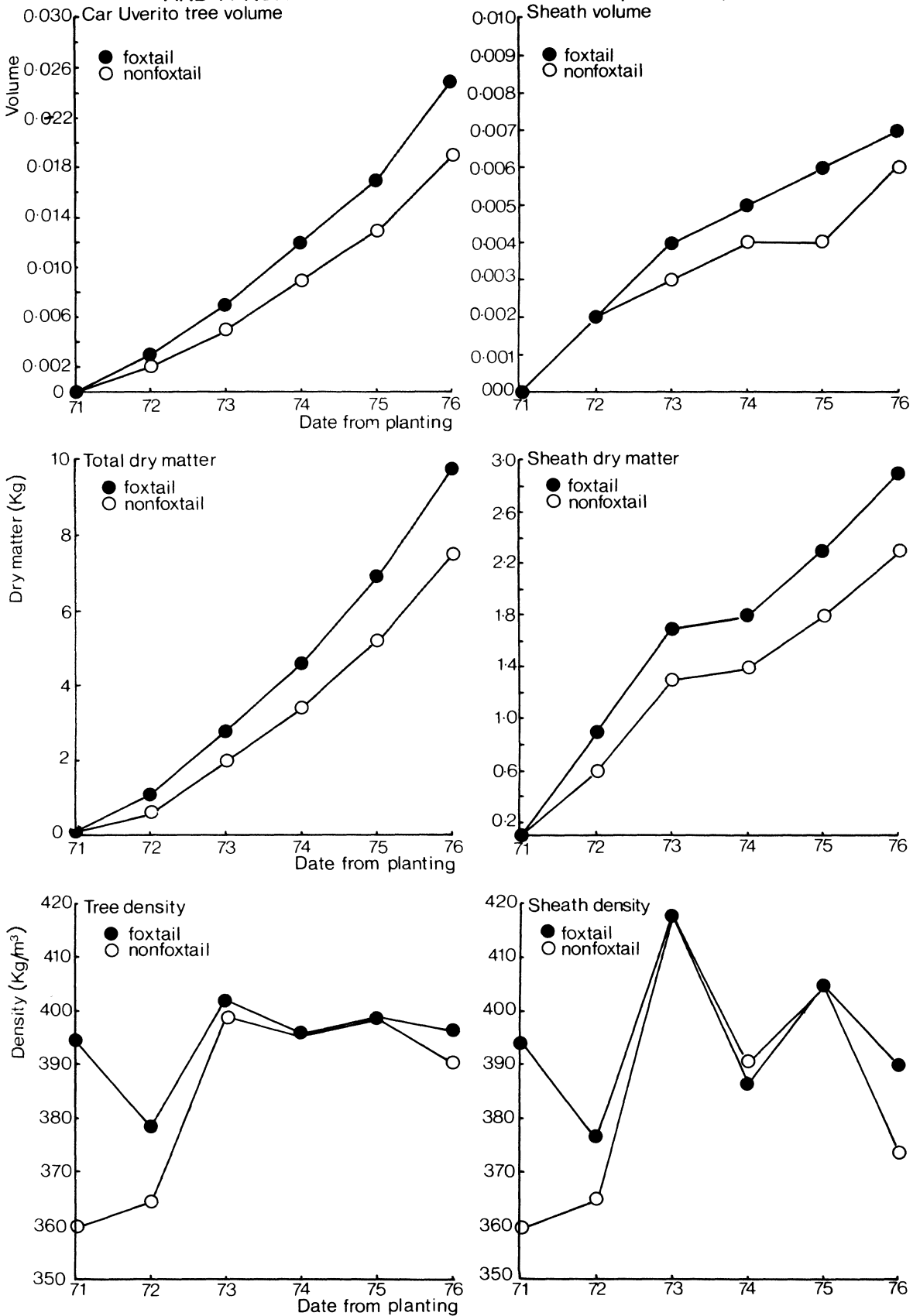
7.21 Foxtailing

A number of studies have been carried out on the effects of foxtailing on wood properties. Plumptre (1980) in a study on 20 foxtailed and 20 non-foxtailed trees, 6 years old, of var. hondurensis in Venezuela found no significant differences in mean tree density between foxtailed and non-foxtailed trees. No tree was completely without branches and some foxtailed trees were more foxtailed than others. Photographs of the original trees standing were compared with contour diagrams of density within trees and analysis of density within successive growth sheaths for all 40 trees. The foxtailed trees were taller with a mean height of 7.6 metres as opposed to 6.5 m for non-foxtailed trees but d.b.h. was non-significantly different. Figure 18 gives plots of annual and accumulated annual growth in volume, dry matter production and wood density for the foxtailed and non-foxtailed trees. The density plots suggest that the gradient of density from pith to bark (at all heights in the tree) is less for the foxtailed than the non-foxtailed trees.

Whyte et al. (1981) also found foxtailed trees to be 7-20% taller and straighter without any significant difference in mean wood density between foxtailed and non-foxtailed trees.

Woods et al. (1979) again with 24 pairs of foxtailed and non-foxtailed trees from Venezuelan grown var. hondurensis found no significant

FIGURE 18. ANNUAL GROWTH SHEATH PLOTS FOR MEANS OF 14 FOXTAILED AND 14 NON-FOXTAILED TREES. From Plumtre (1980)



differences between density at breast height in foxtailed and non-foxtailed trees but at five metres height the foxtailed trees were significantly less dense. They were also significantly taller and d.b.h. at breast height was significantly smaller but not at 5 m.

The conclusions, therefore, are that foxtailed trees are taller and slimmer than non-foxtailed but are not significantly lower in mean density than branched trees. The density seems to be slightly lower in the area of foxtailing and the gradient of density from pith to bark may be lower. Foxtailing, therefore, tends to have a beneficial rather than a detrimental effect on wood properties at any rate in the early life of the tree. Further studies are needed on what happens when this tree grows out of its foxtailed stage.

7.3 Breeding for improved wood properties

The great variation in rates of growth and wood properties of the species suggest that a considerable quantity of the variation must be genetically controlled and that comparable gains in productivity and in wood quality can be obtained by breeding.

Extensive provenance trials of the species have now been set up throughout the tropics and these will provide a good basis for a breeding programme.

Determination of heritability

The gain obtainable from breeding clearly depends on the heritability for any particular property.

Few studies of heritability of wood properties of P. caribaea have been done but a number of studies on the Southern pines indicate that for several wood properties they are quite high. Smith (1967) with P. taeda found narrow sense heritabilities for micellar angle, tracheid cross-sectional dimensions and tracheid length of 0.28-0.97. He emphasised the need to beware of the systematic trends of variation within trees in calculating heritabilities.

Nuevo (1982) and Burley et al. (1983) calculated narrow sense heritabilities from breast height increment cores for P. caribaea var. hondurensis in open pollinated progeny tests in Fiji and Queensland, Australia. Using x-ray densitometry radial growth rate, mean, maximum and minimum density were calculated on a single tree and on a family mean basis. Family variance accounted for 4-16% and variance between individual trees within families 36-73% of the total suggesting that individual tree selection was preferable; heritabilities in Queensland were approximately 0.7 for mean density, 0.5 for maximum density and 0.5 for minimum density with standard errors of 0.2 to 0.5 of the heritability estimates.

Hybridisation

Smith (1973 and 1978) and Hawkins et al. (1978) report on an F₁ hybrid of P. elliotii and P. caribaea var. hondurensis which at 13

years old produced 54% more in dry weight per hectare than either parent and wood density lower than the P. *elliottii* parent but slightly higher than the P. *caribaea* parent.

Selection of trees for breeding

It is clearly necessary in any breeding programme to decide on the weight to be given to different properties in the selection process and this will depend on the importance of the property and its heritability. Van der Sijde and Denison (1969) described a selection system for plus trees operated in South Africa. Properties considered included:

- height
- volume
- straightness of stem
- resin yield
- resin composition
- spiral grain
- wood density
- tracheid length
- branch size
- branch angle

Properties were grouped into external characters and internal (wood quality) characters and equal weight was given for each (i.e. 50 percentage points). For wood quality 20 were given for spiral grain quality, 12 for wood density and 18 for fibre length. Clearly the weighting should differ in different countries or locations; spiral grain for instance may not be such a critical property in some areas.

The decisions on which properties to select and breed for are, therefore, complicated, differ from place to place and may be crucial in achieving breeding programmes which effectively improve wood quality. The possible gains, however, are very great with a species as variable as P. *caribaea*.

8.0 Suitability of *P. caribaea* for different end uses

The general properties of the timber of the species and past usage of the timber are discussed in paragraphs 2.11 and 2.22; this section will deal with the suitability now, and in the future, of the wood for a series of end uses. Paper making properties are considered here rather than under paragraphs on wood properties but uses of the wood in its solid form have, in part, already been dealt with under sections dealing with physical and mechanical properties of the wood and consequently are dealt with in less detail here.

8.1 Fuel and charcoal

Henry (1974) mentions the use of *P. caribaea* for the production of charcoal in the Bahamas and Kellogg (1951) again referring to the Bahamas mentioned that pine charcoal is not good for smelting. Hummel (1926) referred to the resin impregnated timber being used as torches. Harker et al. (1982) gives a value of 20,298 kJ/kg for the gross calorific value (dry basis) of the species which compares with a softwood mean of 20,817 and a hardwood mean of 19,734. It is likely, however, that the value would vary considerably according to the quantity of resin in the wood and much of the resin and combustibles are removed in oven drying.

The wood is likely to be fast-burning and liable to send out sparks as with many pines; similarly a fairly light-weight, fast-burning charcoal is produced with a relatively high ash content but provided it is marketed at a price which reflects this there is no reason why it should not be suitable for domestic use or possibly an industrial use, such as cement manufacture, where it is powdered and used in a jet in a similar way to liquid fuel.

For the production of gas and liquid fuels there are no reasons why *P. caribaea* should not prove suitable although no trials have been made yet with the species.

8.2 Poles and posts

Poles and posts of the species take preservatives easily and preservative penetration of the tissues is such that long term protection is obtained with relatively small loadings of preservative. Coetzee (1974) in South Africa for instance found 10-12.5 cm (4-5 inch) diameter posts completely treated with 9.6 kg/m^3 (0.6 lbs/ft^3) of copper-chrome-arsenate salt were quite sound after 12 years exposure. Kromhout (1978) considered some posts in South Africa to be too low in density and too weak to make good poles but Fiji Forest Department (1969), Alston (1981b) and Coetzee (1974) all consider the species suitable for posts while tests of strength on poles in Fiji (Walford (1980)) and Malaysia (Wong and Shukari (1980)), indicate that transmission poles of *P. caribaea* var. *hondurensis* pass the necessary French and British Standards for strength of transmission poles. It is possible, therefore, that in sites producing very low density wood, lack of strength may be a problem but the regularity and smallness of

branching may give greater strength than would be expected from density measurement alone.

The poles dry quite rapidly (100% m.c. to 22% m.c. in the outer 55 mm of poles took 55 days in Malaysia, (Choo and Grewal, 1982), and do so with relatively little checking or splitting. The latter authors stated that blue stain and slight beetle attack occurred during drying but can be prevented by spraying poles before drying with a solution of sodium pentachlorophenate, BHC and boric acid in water.

8.3 Uses as sawnwood

Sawnwood is used for a variety of uses and these will be considered separately.

8.31 Structural uses

Paragraph 2.5 described the variation in strength of the timber from natural to plantation grown material, from site to site and within and between trees. Timber can be used "structurally" but require very little real strength as in single storey house construction in tropical countries where roofs or walls are supported by timber but the timber is never subjected to great stress. In these conditions there is no great need for rigorous grading but for engineered structures the variation in wood density and strength is so great, particularly the variation within a single tree or log between corewood and peripheral wood that some form of stress grading is necessary. Mechanical stress grading is ideal but not necessarily available and other methods of stress grading will be necessary if it is not.

For a species as variable as P. caribaea a method of stress grading which includes density, latewood percentage, ring width or some method of assessing the inherent "background" strength of the wood as well as strength-reducing defects is required to give an accurate visual form of stress grading. Any method, such as pruning, of controlling the growth of the juvenile core to reduce variation within trees would be extremely valuable for timber to be used structurally.

8.32 Joinery, cladding and flooring

The prime requirements for good joinery are good machining characteristics, good finishing characteristics, reasonable hardness, uniformity of grain and reasonable stability. Webster (1978) gave detailed lists of preferred and acceptable levels for various joinery uses. For external joinery durability is required.

P. caribaea, provided it is of reasonable density (not below 450 kg/m³ at 12% m.c. for Webster's preferred level for windows or 370 kg/m³ for the acceptable level), satisfies all the requirements specified by Webster except durability which can be imparted by preservative treatment. The relatively high earlywood density, the frequent false rings (in var. hondurensis) and the gradual transitions

into and out of the latewood make the wood particularly even in texture and suitable for joinery.

Since density is likely to be a limiting factor, Webster's minimum density figures are worth listing below in Table 24.

Table 24 Minimum densities for softwoods specified by Webster (1978) for joinery and other uses.

<u>Use</u>	<u>Preferred₃</u> <u>level kg/m</u>	<u>Acceptable₃</u> <u>level kg/m</u>
Windows	450	370
External door frames and panel doors	450	400
Door thresholds	600	600
Flush doors (external) (internal wooden members) not critical if no screw holding involved)		
Door frames and panel doors internal	510 (for public usage)	400 (for domestic usage)
Door panels internal	450	350 (light duty domestic)
Flush doors (internal) (interior wooden members) not critical if no screw holding involved		
Cladding (external walls of permanent buildings)	370	370
Cladding (external walls of temporary buildings)	370	370
Flooring - Industrial, heavy duty	800	700
Flooring - Pedestrian, heavy traffic	700	600
Flooring - Pedestrian, heavy traffic	700	650
Flooring - Pedestrian, normal traffic	650	560
Flooring - Pedestrian, light traffic	450	450

It can be seen that for certain uses the normal density plantation grown material would be unsuitable.

Resin exudation is a severe defect in most joinery and flooring but less so for cladding. Plantation grown material is normally sufficiently low in resin to give few problems but resin pockets and areas around wounded tissue and resinous knots need to be avoided.

The species should, therefore, prove suitable for most joinery and cladding uses if of sufficient density and if resin-free (for joinery). It should also sometimes be suitable for light duty flooring.

8.33 Furniture

Furniture comes in a wide range of qualities. What is required for the President's office or the local Hilton Hotel is not necessarily required for rural use in developing countries. Strength, and appearance are two of the more important properties while gluability is also important for most wooden furniture. Finishing properties are also important for all but the lowest grade furniture and ease of working is important for all but the most costly furniture.

P. caribaea shows an attractive grain with, except in the lowest density material, widely spaced bands of light brown latewood. Provided it is dense and strong enough to do the job in the design chosen there is no reason why it should not make high quality furniture. Modern finishes such as the polyesters and polyurethanes are hard and tough and can impart a strong dent and scratch-resistant surface to a relatively soft wood and for this reason wood hardness and resistance to scratching and indentation are less important than they used to be. Durability is normally not so important for furniture as for joinery - particularly external joinery and therefore normally no treatment is required for pine timber to be used for furniture.

8.34 Packaging and pallets

The requirements for these relatively low grade uses are not exacting. Ease of cutting, nailability and resistance to splitting, adequate strength and resistance to abrasion (for pallets) and absence of taint or smell (for some packaging) are all properties to be considered but the species is suitable for a wide range of packaging uses. For light fruit boxes the low density juvenile corewood may actually be an advantage. The requirements for different packaging uses are so varied that it is impossible to specify for all packaging needs. For pallets a certain degree of strength and nail retention capacity is required.

8.35 Boat building

"Pitch pine" has traditionally been used for planking wooden boats in Britain and North America since the last century. This has probably mainly been P. elliottii but a considerable amount of naturally-grown resinous P. caribaea must have been used and has proved one of the best planking timbers for boats, being easily machined and bent and being at the same time tough, resistant to rapid drying and shrinkage and highly durable. The plantation-grown material has neither the high density and close, uniform ring structure nor the high resin content and water and rot resistance. The denser plantation grown timber treated with a suitable wood preservative may have many of the same characteristics.

8.36 Curios, toys and novelty items

The species turns and machines better than most temperate conifers and is thus suitable for this kind of use. Alston (1981b) stated that the timber is commercially used for these purposes in Fiji.

8.4 Plywood and veneers

There appears to be no record of the species having been peeled or sliced commercially for the production of plywood or veneers. The naturally-grown highly resinous wood would be unsuitable because of the high resin content but plantation-grown material would probably peel to give a veneer of reasonable quality particularly if pruning had produced a log containing clear timber. From experience with other tropical pines such as P. patula it would be expected that the plantation-grown timber would peel relatively easily and would glue satisfactorily provided it was not too resinous. The grain could also be expected to be attractive in peeled veneer with large concentric patterns of latewood. The veneer might also make moderate quality match splints and boxes. Trials of peeling P. patula in Uganda for match boxes and splints suggested that the timber would be fairly suitable for both purposes (author's personal experience).

The Southern pines including P. elliottii are widely used for veneer and plywood in the Southern USA and P. elliottii in New Zealand yields about 55% of veneer. The low density knotty core reduces the veneer grade but drying provided few problems. There is little doubt, therefore, that P. caribaea if not too resinous could be used for plywood manufacture but possibly of fairly low grade if not grown and pruned specially for that purpose.

8.5 Particle board

Three comprehensive trials of particle-board manufacture from plantation grown P. caribaea var. hondurensis wood have been made, two, Chittenden et al. (1972) and Wong (1975) using urea formaldehyde glue to make particle board for internal use and one, Schmidt-Hellerau (1977), using modified melamine-urea resin to produce exterior quality particle board. All three trials produced satisfactory particle board.

Chittenden et al. using material from Fiji tried different quantities of resin and wax and different particle sizes; they also sorted the wood into two density classes and tried various board densities.

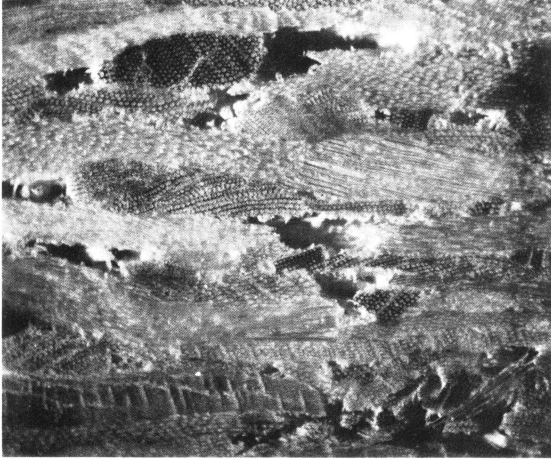
They found that for a given board density and resin content the lower density wood gave better strength and 6% glue was required for wood of 600 kg/m³ density while 5% glue was required for 461 kg/m³ density wood to give properties adequate to conform with british standards for particle board.

Increase of wax content reduced swelling and absorbtion but also slightly reduced impact strength. The best particle size was 30 mm long and 6 mm thick.

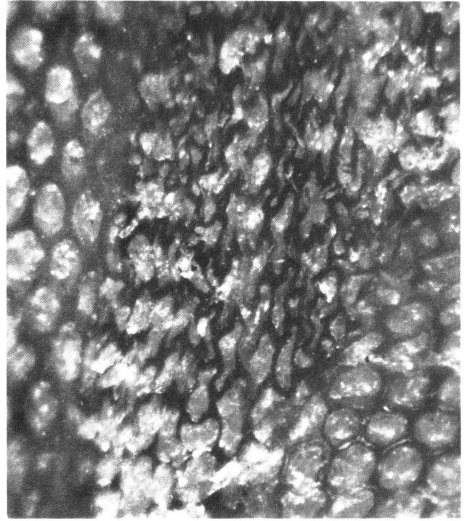
In making three layered board they found that 9% glue was necessary for the surface layers to give adequate smoothness and other properties.

Plate 10 shows photographs of cross sections of particle board made from P. kesiya by the Tropical Products Institute and photographed at C.F.I. Oxford. They show a general view x10 and three x100 views of

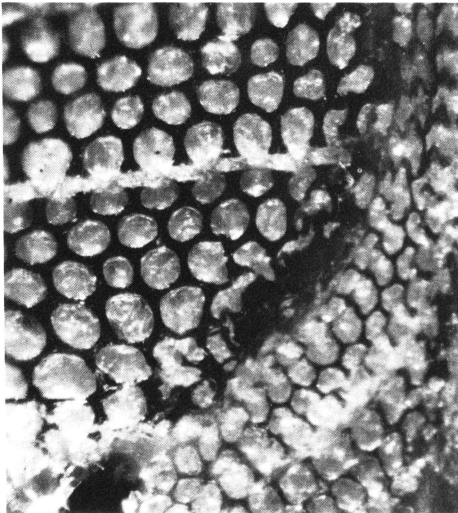
Plate 10. Photomicrographs of particle board in transverse section of P. kesiya showing: (a) gaps in the board near high density particles and conformity of low density wood around the higher density wood (b) low average density wood (c) medium average density wood (d) high average density wood - showing varying degrees of cell collapse and conformity.



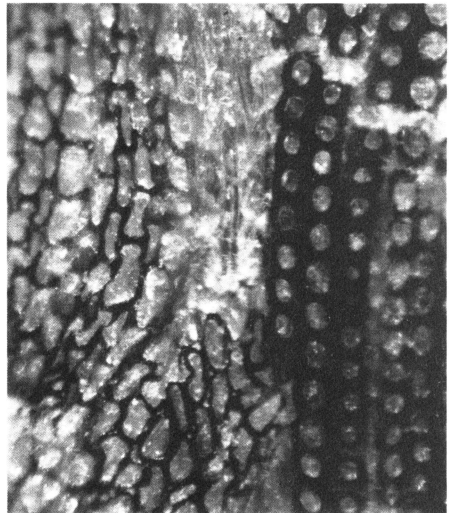
(a) x 10



(b) x 100



(c) x 100



(d) x 100

(Photographs R.A. Plumtre).

board made from three wood densities. The collapse of early wood cells and the degree to which conformity and contact between chips is attained almost certainly has an important effect on board strength and other properties.

The results of the main findings of Chittenden et al. are contained in Tables 1 to 5 in Appendix 5.

Wong (1975) obtained similar results in Malaysia using material of average green density of 495 kg/m^3 from 13 year old trees. He recommended 6% resin and 1% wax to give a 641 kg/m^3 density board conforming to BS2604. Increase of resin to 12% increased strength slightly but had no effect on dimensional stability. Bending strength was increased by increasing flake length and he recommended a 30 mm long flake.

Schmidt-Hellerau (1977) using material from Costa Rica and Nicaragua carried out a laboratory experiment using "Kauramin 542" powder (a modified melamine-urea resin) and obtained particle board with excellent properties for exterior quality particle board.

The species, or at any rate var. hondurensis, therefore, will produce good particle board with low requirement for glue and the species should be a suitable raw material for a commercially viable particle board industry. Unlike most other products made from the wood and partly because greater pressure is needed to get a standard board density low wood density gives higher particle board strength and, therefore, low density thinnings containing a large amount of juvenile core would be a suitable raw material provided they were of adequate size.

8.6 Wood-wool-cement board

A considerable amount of work has been done by the Fiji Forest Department, and the Tropical Products Institute, UK, in the production of wood-wool-cement boards and housing using P. caribaea. Hawkes and Robinson (1978) reported on trials of the species for wood-wool-cement manufacture. Samples from Fiji were made into wood-wool slabs using a ratio of 1:0.4:0.5 of cement to wood (oven dry) to water using a 5.0% calcium chloride solution as a mineralising agent. Tables 25 and 26 below give strengths of whole and quartered boards made in this way. The testing machine was incapable of exerting the force required to break the whole boards and therefore quarter size boards were tested to obtain a value for modulus of rupture.

Strength tests on the slabs showed that they were well above the strength required by BS1105.

Using a 3% solution of calcium chloride strength was no lower and with no calcium chloride little lower for slabs of 500 kg/m^3 density. There was a considerable reduction in strength following reduction of calcium chloride for 450 kg/m^3 and 400 kg/m^3 density slabs. Flame spread tests were also up to Class 1 standard on BS476 part 7. Recommendations were made for the fixing of panels and anchoring of

Table 25. Strength tests on selected samples of full sized wood wool slabs manufactured for demonstration houses

Sample number	Mass kg	Thick- ness mm	Length mm	Width mm	Density kg/m ³	Mass per square metre kg	Compli- ance Type B	Failing load N	Modulus of Rupture N/mm ²
226	71.2	76.24	2,087	905	495	37.70	Yes	>5,000	
224	73.0	76.44	2,091	910	502	38.36	Yes	>5,000	
236	74.4	77.23	2,090	901	512	39.50	Yes	>5,000	
237	72.0	77.22	2,090	902	495	38.24	Yes	>5,000	
238	72.4	77.38	2,091	903	496	38.30	Yes	>5,000	
BS 1105:1972		76±3				41		2.2 KN	0.38 (1.3)

Note: Type A is non load bearing w-w-c board
Type (B) is load bearing w-w-c board

From Hawkes and Robinson (1978).

Table 26. Modulus of Rupture tested on quarter slabs

Sample number	Mass kg	Thick- ness mm	Length mm	Width mm	Density kg/m ³	Mass per square metre kg	Compli- ance Type B	Failing load N	Modulus of Rupture N/mm ²
427A	15.9	74.39	1,038	450	457.6	34.04	Yes	>5,000	>1.81
427B	15.0	74.98	1,034	450	430.0	32.24	Yes	3,775	1.34
427C	16.0	73.79	1,040	450	463.3	34.19	Yes	4,680	1.72
427D	15.5	73.78	1,036	449	451.6	33.32	Yes	4,800	1.77
BS 1105:1972		76±3				41		2.2KN	0.38(1.32)

Note: Type A is non load bearing w-w-c board
Type (B) is load bearing w-w-c board

From Hawkes and Robinson (1978).

roofs to walls. Shear and compression tests, which are not included in British Standards for the material, were done and suggested that the material was satisfactory. Emphasis was laid on the importance of methods of fixing slabs in locations where earthquakes or hurricanes are likely.

The species, therefore, can be assumed to be very suitable for the manufacture of wood-wool-cement slabs but unlike particle board, the inherent density and strength of the wood is likely to be positively correlated with the strength of the board since compression of the board in manufacture is much lower and the natural strength of the uncompressed wood is likely to be more important.

8.7 Resin, turpentine and rosin

The properties of the resin, turpentine and rosin obtainable from the species have been considered in detail in paragraph 6.1. These products can be produced and are of good quality. Whether a viable industry can be established to produce and market them depends very largely on competition from synthetics, including price of raw materials for synthetics and world markets for the natural products. The organisation of the industry and marketing of the product appears to involve coping with considerable fluctuations in demand and price. Efficient and non-destructive methods of tapping need to be used and efficient methods of producing the resin and rosin. It is possible that with plantation-grown trees tapping of the less dominant trees due to be thinned at some stage might achieve a resin yield without reducing the timber production of the stand.

8.8 Pulp and paper

The literature dealing with the suitability of the species for pulp and paper manufacture is extensive. Most of it deals with tests on the species to determine its suitability for normal sulphate pulping but a few references deal with other processes such as mechanical semi-chemical and dissolving pulp. These will be considered first and then the more extensive trials of sulphate pulping.

8.8.1 Mechanical pulps

Schafer and Chichester (1961) found the grinding properties of natural grown material 34 years old to be similar to those of the southern pines while Palmer and Tabb (1973), reviewing pulping properties and quoting unpublished Japanese work, reported that young plantation grown material is less satisfactory and sap staining can cause problems.

8.8.2 Dissolving grade pulps

Wong and Palmer (1973) with 9 year old trees of var. hondurensis from Sabah found it was not possible to produce dissolving grade pulp using simple kraft pulping and bleaching but with a sequence of prehydrolysis, kraft digestion and 5 stage bleaching with chlorine dioxide a pulp yield of 33% was obtained with an alpha-cellulose content of 96%. Compared with commercial dissolving pulps this pulp had low brightness and viscosities that were low but acceptable for some purposes.

8.83 Semi-chemical pulps and bisulphite pulps

Corea and Luz (1976) reported that although pulp from var. hondurensis is very different from that of Northern hemisphere pines the pulps are good enough to justify the establishment of pulpwood plantations.

Hoffman et al. (1978) similarly reported that bisulphite pulps gave lower strengths than expected and 6% lower yield than European pines and spruces but concluded that they are of acceptable quality.

Palmer and Gibbs (1976), however, report a yield for screened sulphite pulp of only 25% which is about 15% lower than for sulphate pulps.

8.84 Sulphate pulps

Not only do different major pulping processes affect the properties of paper but within a process such as the sulphate process the properties are profoundly affected by the length and severity of a number of treatments notably length of cooking time, strength of chemicals used and length of beating time and type of beater used. Bleaching also affects other properties besides colour, it tends to reduce tear strength but gives adequate whiteness. Since the tear strength of the species is normally high some loss of this strength can be accepted. If pulps are to be compared between species and variety or between and within trees it is essential to know the pulping conditions and compare like with like. For the purposes of comparison here properties are compared for a standard cook and at a Canadian standard freeness measuring the degree of beating. Table 27 from Burley and Palmer (1979) shows variance components for trees, cooks and beating times and their interactions for a sample of 20 trees of var. hondurensis from Fiji. The table shows clearly which properties are affected by which variable.

Table 27. Relative importance of variation (variance components expressed as percentages of total variation) for 12 pulp properties

Source of variation	Degrees of freedom	Total yield	Screened yield	Canadian Standard freeness	Drainage time	Air resistance	Sheet density
Trees	19	27.34	48.64	0.94	4.94	2.25	31.56
Cooks	3	67.46	40.43	2.30	6.23	7.96	7.19
Cooks x Trees	57	0.00	2.62	0.00	1.06	1.58	0.13
Duplicates in Cooks and Trees	80	5.19	8.31	0.46	0.75	0.48	1.56
Beating Time	3	0.00	0.00	92.52	54.52	31.91	54.69
Beating Time x Trees	57	0.00	0.00	1.40	7.84	6.30	1.34
Beating Time x Cooks	9	0.00	0.00	0.98	11.19	24.63	0.06
Beating Time x Cooks x Trees	171	0.00	0.00	0.00	2.60	4.80	0.00
Beating Time x (Duplicates in Cooks and Trees)	240	0.00	0.00	0.28	2.40	6.30	0.00
Replicates in all samples	640	0.00	0.00	1.22	8.46	13.78	3.47
	Degrees of freedom	Burst index	Tensile index	Stretch	Tear index	Double folds	Kappa number
Trees	19	11.04	13.42	24.51	46.40	44.58	14.62
Cooks	3	0.89	0.33	3.39	3.03	1.43	78.67
Cooks x Trees	57	0.89	1.10	1.56	0.03	1.02	0.68
Duplicates in Cooks and Trees	80	0.53	0.58	10.90	3.08	3.51	6.04
Beating Time	3	81.39	78.46	5.14	35.60	24.00	0.00
Beating Time x Trees	57	2.06	0.68	7.29	4.03	3.80	0.00
Beating Time x Cooks	9	0.00	0.01	0.38	0.72	0.32	0.00
Beating Time x Cooks x Trees	171	0.00	0.00	0.00	0.00	0.00	0.00
Beating Time x (Duplicates in Cooks and Trees)	240	0.00	0.00	0.00	0.00	0.00	0.00
Replicates in all samples	640	3.20	5.41	46.83	7.11	21.34	0.00

Pulp yield is influenced mainly by the degree of cooking but also quite strongly by the nature of the wood (trees).

Canadian standard freeness is almost entirely a function of beating time. The nature of the wood has little influence.

Drainage time is influenced mainly by beating but also by the interaction of beating and cooks with a small effect of trees and cooks.

Air resistance or porosity is similar to drainage.

Sheet density is mainly influenced by beating but also strongly by the nature of the wood.

Burst index is strongly affected by beating but also by wood properties.

Tensile index is similar to burst index.

Stretch has a large unexplained component but is also affected by the wood properties and their interaction with cooking conditions. It may be sensitive to variations between early and latewood and the quantities of each.

Tear index is strongly related to wood properties and also beating time.

Double folds is similar to tear.

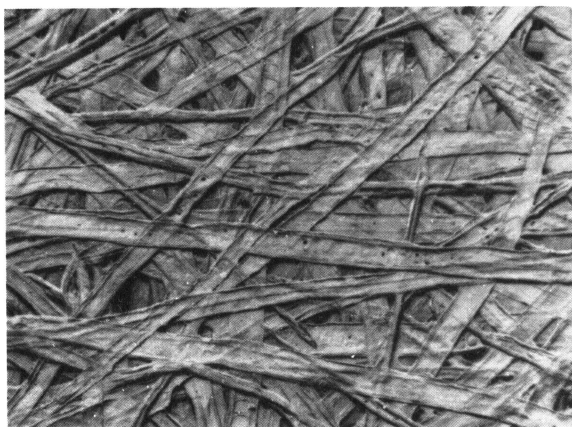
Kappa number is entirely influenced by the properties of the wood and the cooking time since it is a measure of the quantity of lignin present.

It is, therefore, clear that the degree to which a property is influenced by wood properties or pulping processes varies very considerably. The extent of variation, however, is not the only important factor. The major properties burst and breaking length depend largely on the degree of adhesion in the paper while the tear strength depends on the cross-sectional strength of the tracheids. Beating improves adhesion but after a relatively short initial period reduced tear strength. This is shown in Figure 19 below from Palmer and Tabb (1968).

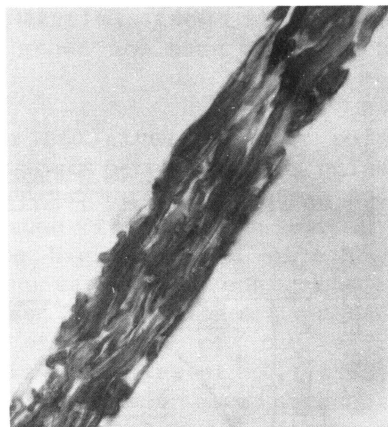
8.841 Differences between species

Plate 11 shows photomicrographs of paper made from Scots Pine and P. caribaea. The plates and figure demonstrate the difference between a temperate pine and P. caribaea. The coarser, thicker walled tracheids of P. caribaea give a higher tearing strength but lower burst and breaking length than the Scots Pine. Unfortunately, the burst and breaking length are more critical than tear for papers such as sack kraft requiring high strength and the low burst and breaking length properties for the P. caribaea make it marginal for the sack kraft range of papers. It is clear that longer beating is beneficial but never brings the P. caribaea up to the value of the P. sylvestris.

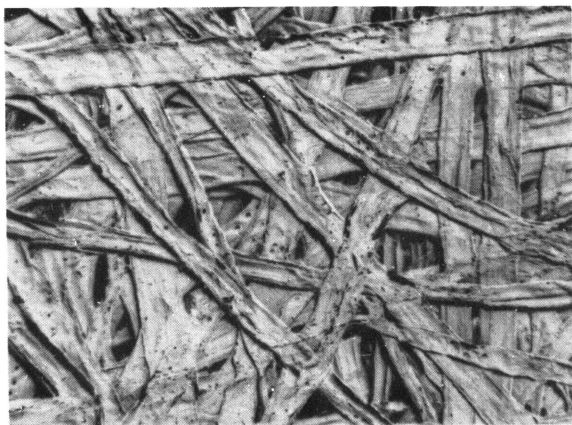
Plate 11. Photomicrographs of paper in plan and cross section (a and a'), *P. sylvestris*, (b and b') *P. caribaea* var. *hondurensis* from plantation in Fiji, (c and c') *P. caribaea* var. *hondurensis* natural grown in Belize (Mountain Pine Ridge). (Photographs by Tropical Development Research Institute).



(a)



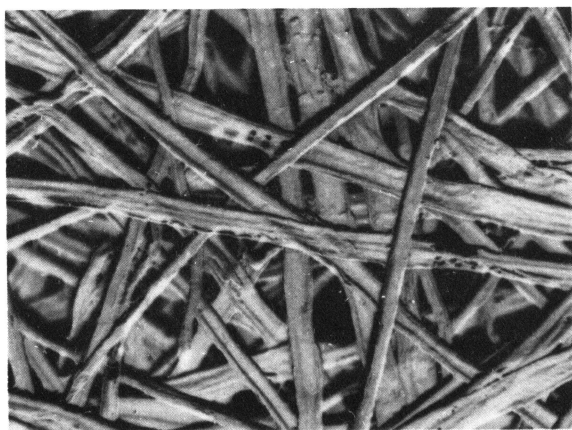
(a')



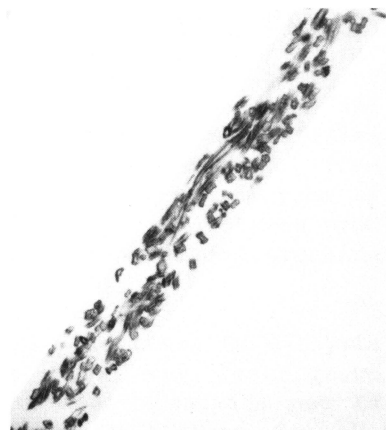
(b)



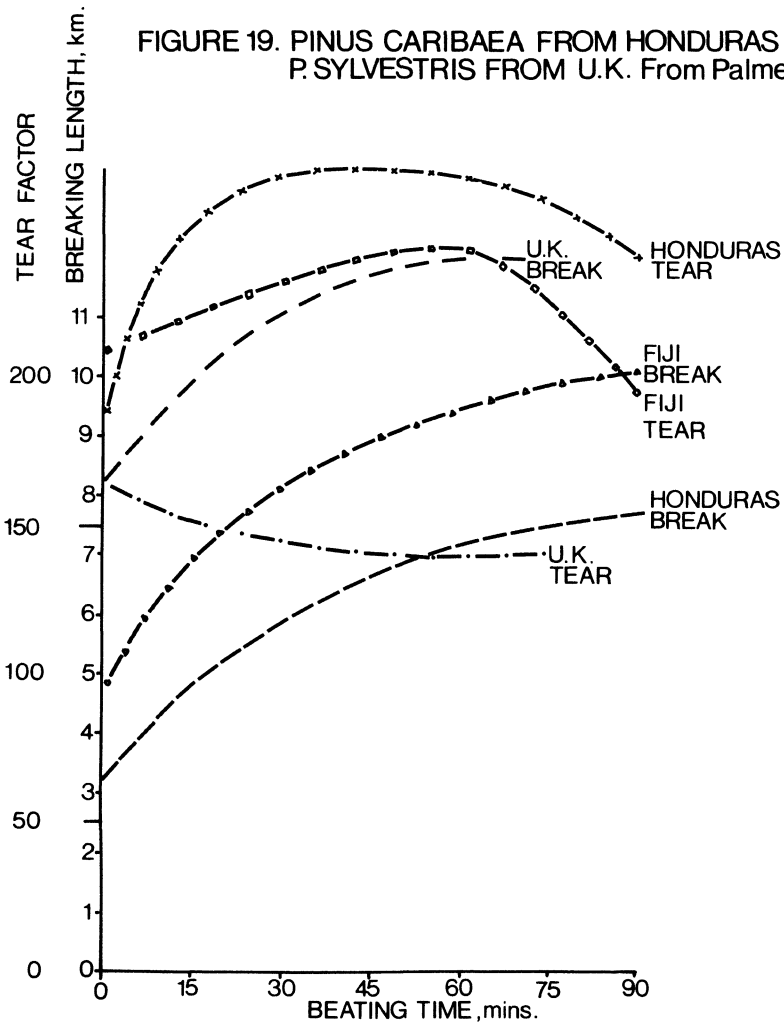
(b')



(c)



(c')



8.842 Differences within the species

Between varieties

Table 28 compiled from information given in papers by Palmer and Gibbs gives roughly comparable figures for the main physical characteristics of unbleached sulphate pulps made from material from all three varieties from different sites, some natural grown and some plantation grown.

On the whole natural grown material is denser and gives inferior pulp to plantation grown material and var. hondurensis gives better pulps (stronger in burst and breaking length) than vars. caribaea and bahamensis. This conclusion is supported by some other workers but Falkenhagen (1979) in South Africa found the highest yield given by var. bahamensis, then var. caribaea and then var. hondurensis while var. bahamensis followed by var. hondurensis and var. caribaea produced the strongest paper. The greater rate of growth of the var. hondurensis gave the highest yields per hectare. Hawkins et al. (1978) in Queensland found that var. caribaea and bahamensis gave stronger pulps than var. hondurensis but were faster grown and had lower wood density. In South Africa wood density of the three varieties were very similar (Falkenhagen (1979)). All were inferior to P. elliottii in paper strength by about 10%.

It is clear that the tendency of varieties bahamensis and caribaea to produce more pronounced bands of dense latewood than var. hondurensis in tropical conditions appears to lead to weaker paper while in less tropical conditions and with faster growth the quality of the paper appears to improve.

8.843 Variation between natural and plantation grown material

Table 25 indicates that natural grown material tends to give higher tearing strength but lower burst and breaking length associated with higher wood density.

8.844 Variation between sites, between ages of tree and between rates of growth

Figure 20 from Palmer and Tabb (1968) shows variation of tear and breaking length strengths with beating time for natural grown material from Honduras (Belize), 9-10 year old plantation grown material from Fiji and 5 year old material from Sabah. Again the pattern emerges of a close correlation between age, site and wood density and between wood density and tearing strength and to a lesser extent burst and breaking length.

Figure 21 shows differences between 6 and 12 year old trees in Malaysia while Figure 22 shows differences between slow and fast grown plantation material in Trinidad. The breaking length appears not to vary with rate of growth but the tear strength is greater for the slower grown material.

Table 28. Pinus caribaea and comparable species unbleached sulphate pulps from different locations

Physical characteristics interpolated at 500 and 300 C.S.F.

Country of origin	Age years	Kappa number	Yield of oven-dry unbleached pulp, per cent oven-dry wood		Canadian Standard freeness	Bulk cm ³ /g	Burst factor	Breaking length km	Tear factor
			Total	Screened					
var. <u>hondurensis</u>									
Sabah, plantation	5	58	56.0	49.2	500	1.40	65	8.6	136
					300	1.35	70	9.3	127
		45	48.9	46.5	500	1.43	61	8.1	145
					300	1.35	68	8.9	136
		35	46.8	46.6	500	1.36	57	8.3	136
					300	1.30	63	9.1	130
Fiji, plantation, Site D	10	43	50.9	50.7	500	1.49	72	9.7	205
					300	1.46	75	10.3	200
		28	45.1	45.0	500	1.50	67	9.0	230
					300	1.45	72	9.7	224
		22.5	43.9	43.9	500	1.49	42	6.4	86
					300	1.44	44	7.0	80
Fiji, plantation, Site V	9	32	49.2	49.1	500	1.54	63	7.8	200
					300	1.48	66	8.5	185
		23	45.6	45.6	500	1.53	61	8.3	185
					300	1.50	65	8.8	165
Trinidad, plantation, slow grown	12	39	45.6	44.1	500	1.65	68	8.8	225
					300	1.58	73	9.2	205
Trinidad, plantation, fast grown	12	35	46.2	45.8	500	1.60	64	8.4	205
					300	1.54	67	9.1	195
Belize, Coastal Plain	11-40	40.8	46.0	44.7	500	1.71	48	6.6	176
					300	1.65	52	7.0	164
		26.3	43.4	43.1	500	1.64	42	6.3	138
					300	1.59	47	6.7	133
Belize, Mountain Pine Ridge	10-20	37.3	45.8	44.5	500	1.73	45	6.5	169
					300	1.67	54	7.2	158
		24.5	43.5	43.3	500	1.69	40	6.0	138
					300	1.63	44	6.7	133
var. <u>bahamensis</u>									
Great Abaco Island	Natural growth, exact age unknown, probably 30-50	43	42.9	41.5	500	1.66	40	6.3	140
		32.5	40.5	40.2	300	1.60	44	6.9	130
					500	1.57	42	6.6	165
					300	1.53	45	7.1	155
		25	40.5	40.4	500	1.57	39	6.5	135
					300	1.50	42	6.9	125
var. <u>caribaea</u>									
Cajalbana, Natural grown	about 20	43.2	46.5	45.1	500	1.77	41	5.9	180
					300	1.71	46	6.5	171
Cuba, Topes de Collantes, Plantation grown	12	39.2	44.5	44.1	500	1.53	48	6.8	135
					300	1.48	51	7.2	121
<u>Pinus sylvestris</u> UK grown	-	72.4	52.7	46.7	500	1.57	64	9.2	175
					300	1.50	69	9.8	155
		54.6	48.1	45.8	500	1.50	75	10.4	165
					300	1.48	79	10.9	155
		36.0	45.5	45.2	500	1.47	70	10.0	165
					300	1.40	74	10.5	155
Mixed Southern Pines USA grown	-	52.3	49.0	48.5	500	1.60	61	8.6	175
					300	1.53	67	9.5	165
		40.8	45.5	45.1	500	1.53	60	8.5	185
					300	1.50	64	9.0	175
		22.6	43.7	43.2	500	1.59	41	7.0	100
					300	1.53	44	7.4	90
<u>Picea sitchensis</u> UK grown	-	54.0	50.7	48.6	500	1.32	79	11.2	110
					300	1.27	82	11.6	105
		33.0	44.3	43.9	500	1.40	59	9.1	95
					300	1.35	64	10.0	85
		22.3	42.6	42.4	500	1.39	50	8.1	80
					300	1.34	54	8.9	75
Spruce USA grown	-	87.2	56.4	54.8	500	1.36	94	12.8	115
					300	1.32	100	13.0	100
		55.6	50.7	50.3	500	1.44	83	11.4	140
					300	1.38	92	12.4	130
		23.2	43.5	43.5	500	1.35	56	9.1	90
					300	1.30	60	9.6	85

From Palmer and Gibbs (1972, 1975 and 1976).

Notes: Kappa No. is a measurement of the amount of lignin in a pulp. Kappa No. x 0.5 gives an approximate estimate of the percentage of lignin in the pulp.

Yield, Total = oven dry cooked pulp as a percentage of oven dry wood.

Screened = oven dry pulp that passes a 0.15 mm screen as a percentage of oven dry wood.

Canadian Standard Freeness (CSF) is a measure of the rate at which water is separated from pulp.

Basis weight is oven dry weight of one square metre of the paper.

Bulk is $\frac{\text{thickness}}{\text{basis weight}}$

Burst factor is air pressure in lbs required to burst a circle of paper 1.2 inches in diameter divided by the basis weight.

Breaking length is $\frac{\text{Tensile strength (of a 15 mm wide strip)} \times 66700}{\text{basis weight}}$

Tear factor is $\frac{\text{tearing strength}}{\text{basis weight}}$

Conversion factors In order to convert old "Factors" into new standard "Indices". The following conversions are necessary.

Tear index (mNm²/g) = Tear factor x 0.098

Burst index (KPa-m/g) = Burst factor x 0.098

Tensile index (Nm/g) = Breaking length in metres x 0.0098

Humidities All new indices are tested at 50% RH whereas "factors" were tested by some authorities (Tropical Products Institute, UK among others) at 65% RH. This reduces the value of some comparisons particularly double fold strength.

FIGURE 20. PINUS CARIBAEA. From Palmer and Tabb (1968)

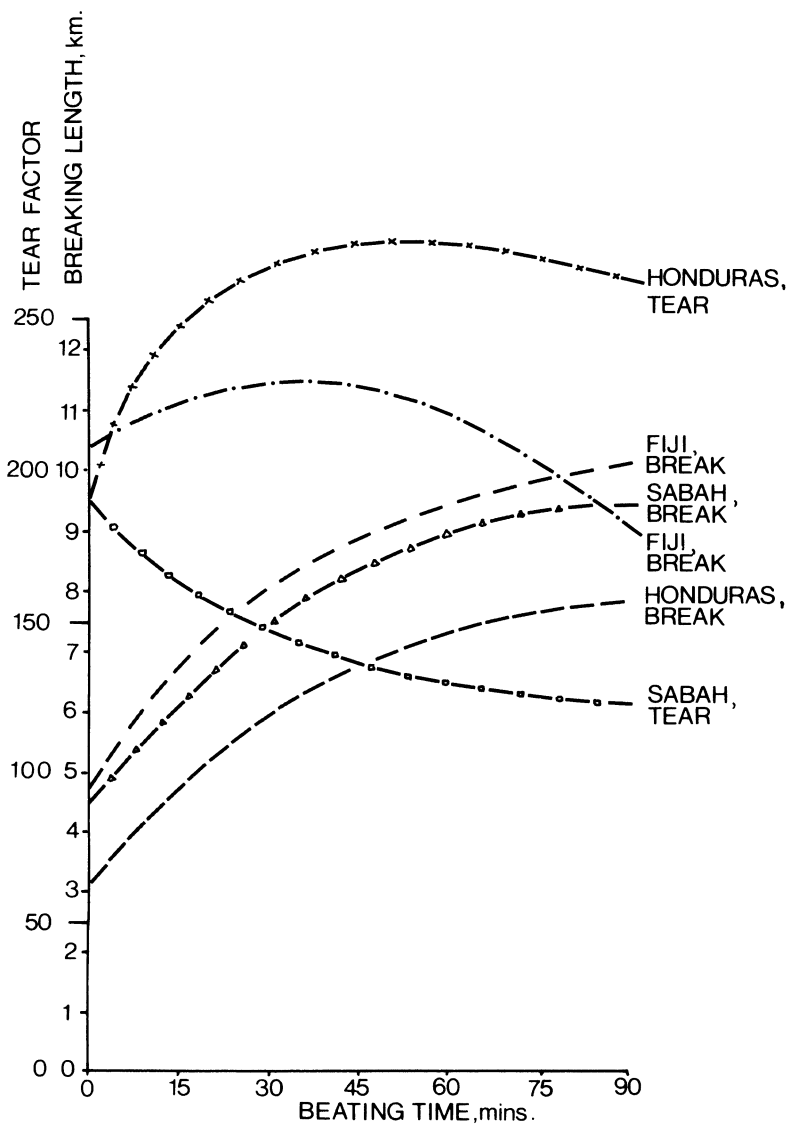
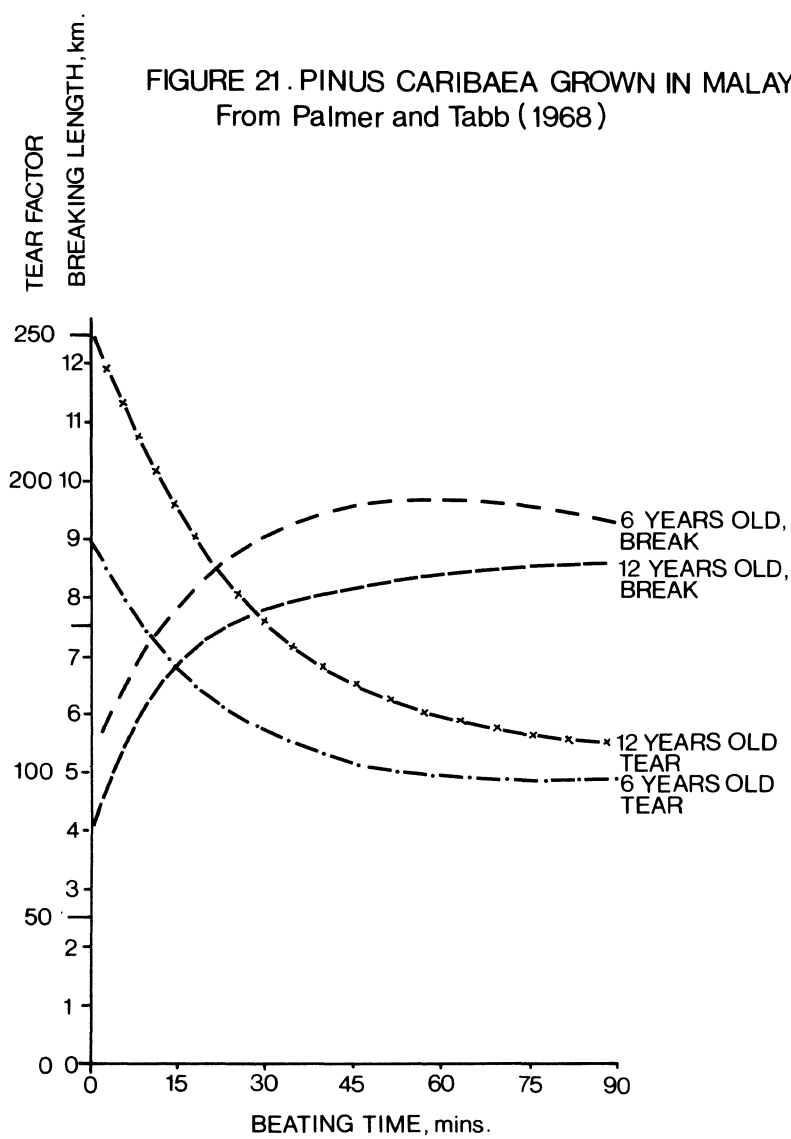


FIGURE 21. PINUS CARIBAEA GROWN IN MALAYA
From Palmer and Tabb (1968)



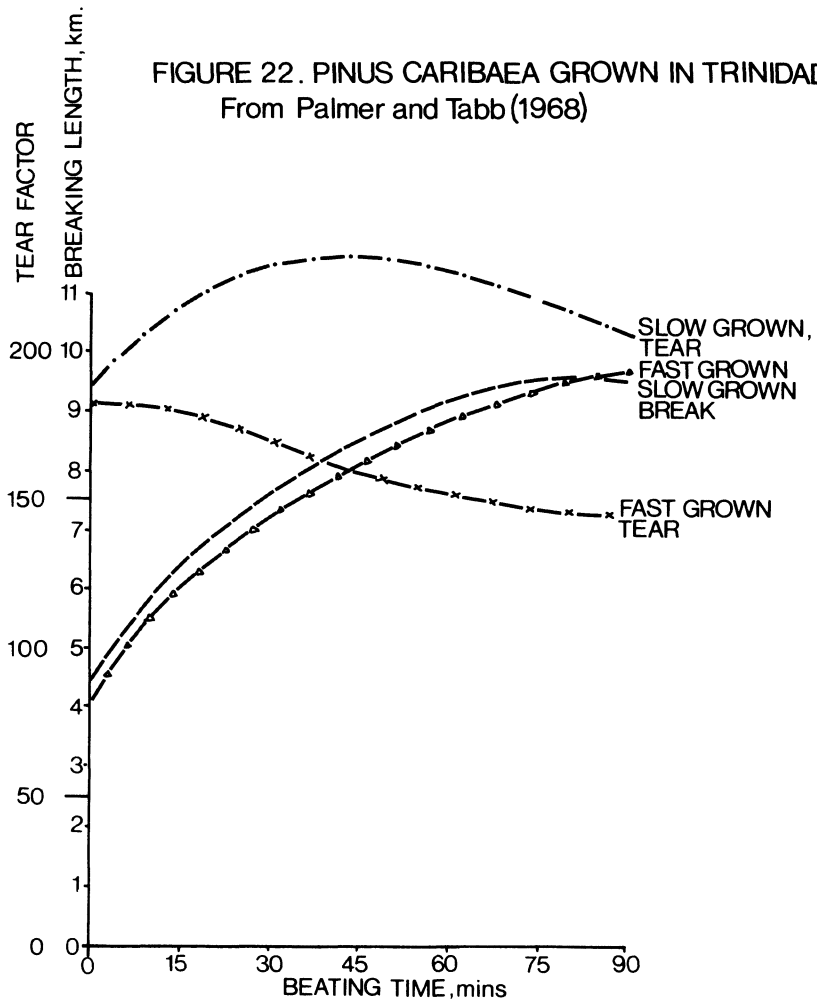


Table 29.. Tree means for 12 pulp properties for 20 trees from Fiji

Property				1 Total yield	2 Screen yield	3 CSF	4 Drainage	5 Air resistance	6 Paper density	7 Burst	8 Tensile	9 Stretch %	10 Tear	11 Double folds	12 Kappa No.
Tree identity	Ring width rank	Density rank	Tree density												
D1/6	7	14	0.522	46.9	46.2	578.0	4.6	18.4	0.63	5.74	85.98	3.8	13.58	1088.2	37.19
D1/57	10	4	0.626	47.7	46.1	566.4	4.5	14.3	0.59	5.69	85.22	4.2	19.96	1073.0	37.45
D1/71	16	6	0.568	46.0	44.1	551.0	4.5	35.8	0.63	5.97	87.31	4.1	16.49	1266.8	38.03
D2/11	17	3	0.634	47.4	44.6	565.4	4.6	9.8	0.59	5.08	76.72	4.4	17.61	1096.9	49.61
NH1/24	2	18	0.442	44.2	43.2	573.6	4.6	33.5	0.67	5.63	83.13	4.2	14.67	1306.5	40.83
NH1/40	1	19	0.441	42.4	42.2	572.2	4.6	35.4	0.67	5.48	80.63	4.3	13.45	1254.7	34.78
NH1/44	4	10	0.554	46.8	45.0	567.3	4.7	17.9	0.59	5.41	81.06	4.2	16.75	1088.8	41.78
NH1/51	6	15	0.507	43.7	42.0	594.8	4.4	16.0	0.63	5.63	79.35	4.4	17.36	1306.1	40.72
S1/8	12	9	0.558	46.0	44.8	563.8	4.7	11.6	0.56	5.48	81.94	4.4	18.59	1039.2	38.48
S1/31	14	8	0.564	45.5	44.6	549.9	4.7	31.5	0.59	4.84	72.86	4.6	18.03	1147.2	37.88
S1/36	15	7	0.565	46.6	45.9	540.3	4.7	19.9	0.63	5.77	84.33	4.1	17.72	1235.3	36.73
S1/45	20	1	0.721	47.1	45.2	536.2	4.7	18.1	0.56	4.95	73.62	4.7	20.75	906.7	35.06
S1/55	19	17	0.480	46.4	46.0	561.7	4.7	39.3	0.63	6.45	93.49	4.1	14.58	1479.5	31.53
S1/64	9	16	0.492	45.6	44.7	594.4	4.5	10.1	0.63	5.63	63.45	4.8	19.85	1724.2	38.14
S2/1	5	20	0.438	46.1	45.8	564.2	4.6	37.3	0.63	5.79	83.13	4.6	18.30	1646.3	31.31
S2/6	11	12	0.554	46.5	45.7	564.3	4.6	25.2	0.63	4.81	72.74	4.2	16.68	1152.6	34.19
S2/37	8	13	0.535	44.8	44.3	562.1	4.6	19.3	0.63	5.76	85.61	4.0	14.55	1219.4	32.01
S2/51	13	11	0.554	47.0	45.1	593.8	4.5	6.2	0.63	5.75	82.26	4.4	18.73	1421.7	37.54
S2/79	18	2	0.641	47.1	46.4	527.0	4.8	39.7	0.59	4.86	72.62	4.5	18.82	1020.1	34.03
S2/84	3	5	0.576	45.8	45.0	577.3	4.5	18.2	0.63	5.39	77.93	4.5	18.73	1398.5	34.45
Standard error of a tree mean				0.21	0.18	5.18	0.02	4.54	0.01	0.042	0.58	0.07	0.22	26.69	0.931
Overall mean				46.0	44.9	565.2	4.6	22.9	0.62	5.51	80.88	4.3	17.25	1243.6	37.09
Bulk sample				45.2	44.3	562.6	4.6	19.2	0.63	5.22	84.21	4.2	17.63	1227.5	33.76

1. Total yield, oven dry unbleached pulp % oven dry wood
2. Screened yield, oven dry unbleached screened pulp % oven dry wood
3. Canadian Standard freeness
4. Drainage time, seconds
5. Air resistance_G, Gurley, 100 cm³/6.45 cm², seconds
6. Density, g/cm³

7. Burst index, kPa m²/g
8. Tensile index, Nm/g
9. Stretch, %
10. Tear index, mNm²/g
11. Double folds, Kohler-Molin, 7.85 N load
12. Kappa number

In a subsequent study on material from Fiji, Palmer and Gibbs (1979) found very little difference in wood density or paper properties between fast and slow grown trees of var. hondurensis. They concluded that, since the volume of wood per hectare for the fast grown trees was almost double that of the slow grown, the trees should be grown as fast as possible.

8.845 Variation between trees within a site

Table 29 from Ong (1978) and Burley and Palmer (1979) shows ring width (growth rate), wood density and paper properties for 20 individual trees from Fiji chosen to give a wide range of densities. The variation between trees in terms of rate of growth, mean wood density and paper properties is very considerable and a small number of trees such as tree D1/71 and S1/55 appear to be superior to the average in most critical properties. There would, therefore, appear to be possibilities for selection and breeding for trees to give better paper-making properties.

Petroff and Tissot (1980) also found between-tree variation in 200 samples from Vanuatu (New Hebrides).

A further examination of between-tree variation of paper properties was carried out by Burley and Palmer (1979) and Goodwin-Bailey (1982). (See Table 1 in Appendix 6, on 20 trees of var. hondurensis from Uganda.) Again a very wide variation between trees was found. This site produced low density wood at an altitude of about 1200 m a.s.l.. Table 2 in Appendix 6 shows the Fiji trees and four cooking conditions of which cook D is directly comparable with cook 2 of Table 1.

The tearing strength in Uganda is markedly lower than in Fiji but burst is similar. Summaries of these properties showing the between site differences are given in Table 30.

Table 30. Comparison of the mean tree values of the principle pulp properties for P. caribaea var. hondurensis from Fiji and Uganda.

	Overall mean		Standard Error of a tree mean	
	Uganda	Fiji	Uganda	Fiji
Kappa number	35.79	37.76	2.12	0.931
Total Yield	44.16	46.00	0.22	0.21
Screened Yield	43.90	44.90		0.18
Freeness	528.89	565.20	5.75	6.18
Drainage	5.05	4.60	0.11	0.02
Basis Weight	60.02		0.21	
Thickness	89.02		2.90	
Porosity	84.12	22.90	14.09	4.54
Bulk	1.47			
Sheet Density	0.69	0.62	0.003	0.01
Burst Index	5.43	5.51	0.03	0.04
Tensile Index	86.36	80.88	2.67	0.58
Stretch	2.79	4.30	0.09	0.07
Absorbed Energy	1.95		0.105	0.22
Tear Index	9.07	17.25	0.47	
Double Folds	888.43	1243.60	55.42	26.69

8.846 Within-tree variation

Because of the problems of pulping small samples of wood few trials of paper making have been made with samples representing less than one whole tree. Watson and Dadswell (1962) however, separated early and latewood, pulped each separately and found that they got better burst and fold strengths from earlywood and better tear strength from latewood. Barrichelo et al. (1979) also reported that the denser outer portion of the trees gives higher tearing strength and bulk and lower tensile and bursting strength than the inner core.

8.847 Correlations between physical and chemical wood properties and paper properties

Table 31 from Goodwin-Bailey (1982) for Uganda-grown material shows coefficients of determination for linear and curvilinear models relating major wood properties to paper properties, while Table 32 shows the same for the Fiji grown material.

Very few of the correlations between wood properties and paper properties are high enough to make it possible to predict paper properties from wood properties, since an r^2 of between 70-80% is required, but the relationships between the wood and paper properties are in many cases close enough to allow screening of trees to select those likely to give better quality paper than others. Alpha-cellulose is one of the best predictors of paper properties, while breast height wood density is one of the better correlated wood properties.

Table 3 of Appendix 6 from Burley and Palmer (1979) shows a correlation matrix of paper properties where figures are of r and not r^2 . This gives the relationships between these properties for the 20 trees in Fiji.

Table 31. Comparison of linear and non-linear regression coefficients for a selection of pulp properties for trees from Uganda.
Values presented as coefficients of determination (r^2)% rather than correlation coefficients (r).

	TOTAL YIELD		BURST INDEX		TENSILE INDEX		TEAR INDEX	
	linear	non-linear	linear	non-linear	linear	non-linear	linear	non-linear
Density								
B. Height	21	21	36	37	40	43	41	41
Fibre Length	20	28	14	33	12	31	6	7
Early wood (0.05 - 0.5)	12	12	36	36	41	42	52	53
Late wood (0.5 - 1.10)	9	9	36	37	41	43	50	50
Holo-cellulose	30	30	19	19	18	18	5	8
Alpha-cellulose	32	65	1	1	0	0	32	39
Lignin	48	53	0	17	0	19	22	25

From Goodwin Bailey (1982).

Table 32. Comparison of linear and best non-linear coefficients of determination for a selection of variables for material from Fiji

Independent variable	Total yield		Burst index		Tensile index		Tear index	
	Linear %	Non-linear %	Linear %	Non-linear %	Linear %	Non-linear %	Linear %	Non-linear %
Density, extracted	42	46	19	25	17	18	41	42
Fibre length	12	12	6	23	0	24	31	46
Latewood percentage	41	50	25	32	21	21	49	53
Density class 0.96-1.10	36	64	19	26	18	18	49	53
Holocellulose	45	50	0.0	6	1	1	14	16
α -cellulose	66	77	9	35	13	25	56	58
Lignin	31	32	2	3	6	6	32	34

From Burley and Palmer (1979).

8.85 Mixed pulps

Foelkel and Barrichelo (1975) in Brazil mixed P. oocarpa and Eucalyptus saligna and found the mixed pulp gave paper stronger in tear but weaker in burst and tensile strength to the best of the individual species. Palmer and Gibbs (1971) suggested mixing hardwood pulps with P. caribaea pulps for writing and printing papers.

Uprichard (1977) mixed P. caribaea pulp with pulp made from coconut stemwood and found that the mixed pulp had strength properties intermediate between the strengths of the pure pulps.

Foxtailing and paper properties

Hoffman et al. (1978) found no significant differences between paper made from foxtailed and non-foxtailed trees and as with wood density it appears that foxtailing is not a serious defect in paper making.

Wood and pulp from foxtailed and non-foxtailed trees were compared by Colodette (1981) who found larger lumens, thinner walls and higher flexibility for cells from foxtailed trees and the foxtailed wood was more easily delignified and produced pulps with higher strength properties. If anything, therefore, foxtailing seems to improve paper properties.

Conclusions on pulp and paper properties

There appears to be little difference in the quality of the species for paper making if it is fast or slow-grown. On the whole a method of growing it which produces rapid growth with fibres that are not too coarse is desirable. Differences between trees are so large that breeding to improve the wood for paper making appears to be a good possibility and, if the tree is to be grown to produce sawnwood and

pulp, pruning of the first log followed later by heavy thinning could produce a good quality bottom log with lower density upper logs suitable for pulp or lower grade saw timber.

8.9 Fibre board

Kellogg (1951) reported that the natural grown timber from the Bahamas was too resinous for fibre board manufacture but Packman (1959) later reported that good hardboard had been made from both sapwood and mixed sapwood and heartwood by the defibrator process. The inclusion of highly resinous heartwood in proportions of up to 25% of the total mixture had no significant detrimental effect on the strength of the boards and resin apparently improved water resistance; board made from unrefined and partly refined pulp was acceptable as standard hardboard (BS No. 1142) after hot air treatment alone. Oil tempering with 2% linseed oil brought it well into the super hardboard class. Packman's results are shown in Table 33 and 34 below.

Table 33. Fibre boards from P. caribaea chips containing 25 per cent. heartwood

	Pulp								Boards			
	Yield, per cent.	Fibre Classification, per cent.						Williams Freeness (5.0 g.) sec.	Treatment	Specific gravity	Modulus of Rupture (lb./sq. in.)	Water Absorption per cent.
		Above 10 mesh	10/14	14/25	25/52	52/100	Below 100					
Unrefined pulp	86	16	19	27	12	7	19	7	Nil Heat only 2 per cent. oil 3.5 per cent. oil 5 per cent. alum alum + heat	1.06 1.05 1.07 1.11 1.05 1.06	4,975 6,300 8,600 9,760 3,675 4,720	36 26 14 10 63 14
Partially refined blended mixture		9	17	26	14	9	24	16	Nil Heat only 2 per cent. oil 3.5 per cent. oil 5 per cent. alum alum + heat	1.10 1.09 1.09 1.11 1.09 1.08	5,980 7,060 10,110 10,325 4,600 5,750	30 25 14 10 56 13

From Packman (1959).

Table 34. Fibre boards from sapwood of *P. caribaea*

	Pulp								Boards			
	Yield per cent.	Fibre Classification, per cent. (Rotating disc screen)						Williams Freeness (5.0 g.) sec.	Treatment	Specific gravity	Modulus of Rupture (lb./sq. in.)	Water Absorption per cent.
		Above 10 mesh	10/14	14/25	25/52	52/100	Below 100					
Unrefined pulp	87	17	20	25	12	8	18	7.5	Nil Heat only 2 per cent. oil 3.5 per cent. oil	1.06 1.10 1.15 1.14	5,280 7,115 9,645 10,095	63 34 19 15
Refined pulp		6	15	28	14	10	27	95	Nil Heat only 2 per cent. oil 3.5 per cent. oil	1.11 1.16 1.12 1.14	7,225 8,790 9,330 9,450	51 28 16 11
Partially refined blended mixture		10	19	30	16	10	15	20	Nil Heat only 2 per cent. oil 3.5 per cent. oil	1.09 1.07 1.14 1.15	6,855 7,240 8,545 9,610	52 29 18 14

From Packman (1959).

Chawla and Negi (1980) made a fibre board from *P. caribaea* needles with sodium hydroxide in a Sprout-Waldron refiner. Pulp yield was low. The board pressed at 165-170°C in the laboratory produced a 0.8-1.1 g/cm² density board of low strength which was considered suitable for low grade uses. Blending with wood pulp gave higher strength.

The wood, therefore, makes good fibre board and the resin appears to be an asset rather than a hindrance.

9.0 General conclusions on the species

The species is one of great versatility and variability particularly variety hondurensis. It not only grows in a very wide range of conditions and sites but produces a large variety of different types of wood being genetically very varied and responsive to site, climatic and silvicultural stimulæ. The prospects of obtaining any particular quality of wood are, therefore, quite good given the right sites and provenances, and the right silvicultural and breeding techniques. The gains in quality as well as quantity are potentially very large. Failure to take wood quality into account when growing P. caribaea could result in a product which is only a fraction of the value of the product which could have been obtained particularly if the product is going to have to compete on the world market. In particular, simple selection of the right variety and provenance for a site and the use of good silviculture including correct thinning and pruning are vital in obtaining good wood quality.

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APPENDIX I Preservation Properties

Table 1. Summary of effectiveness of different preservatives in stake tests in Mississippi.

APPENDIX I

Table 1. Summary of 2- by 4-inch stake test results obtained in Mississippi with wood preservative in general use

Preservative	Average retention	Average life	Remarks
	<u>Pcf</u>	<u>Yr</u>	
Acid copper chromate (Fed. Spec. TT-W-546)	0.26 ¹ (.13)	11.6	
	.30 (.14)	-	90 pct failed after 10 yr
	.51 (.25)	-	40 pct failed after 9 yr
	.52 (.26)	-	20 pct failed after 31 yr
	.60 (.29)	4.6	
	.75 (.37)	-	30 pct failed after 31 yr
	1.01 (.50)	-	20 pct failed after 9 yr
	1.54 (.76)	-	20 pct failed after 9 yr
Ammoniscal copper arsenate (Fed. Spec. TT-W-549)	.25 (.24)	-	30 pct failed after 32 yr
	.53 (.51), 1.00 (0.97), 1.29 (1.25)	-	No failures after 32 yr
Chromated copper arsenate	.26 (.15)	-	70 pct failed after 31 yr
Type I (Fed. Spec. TT-W-550)	.50 (.29), .78 (.44)	-	No failures after 31 yr
Type II (Fed. Spec. TT-W-550)	(.26), (.37), (.52)	-	No failures after 27 yr
	(.79), (1.04)		
Chromated zinc arsenate (former Fed. Spec. TT-W-538)	.28 (.11)	-	80 pct failed after 25 yr
	.42 (.22)	-	80 pct failed after 36-1/2 yr
	.44 (.29)	-	56 pct failed after 36-1/2 yr
	.48 (.20), .97 (.40), 1.27 (.53)	-	No failures after 25 yr
	.55 (.29)	-	56 pct failed in 36-1/2 yr
	.73 (.38)	-	10 pct failed in 36-1/2 yr
	.98 (.52) to 1.34 (.70)	-	No failures after 36-1/2 yr
Chromatated zinc chloride (Fed. Spec. TT-W-551)	.49 (.30)	14.2	
	.76 (.47)	20.2	
	.76 (.46)	-	30 pct failed after 9 yr
	1.02 (.63)	20.1	
	1.02 (.62)	-	30 pct failed after 9 yr
	1.50 (.92)	-	60 pct failed after 25 yr
	1.57 (.96)	-	10 pct failed after 9 yr
	2.91 (1.78)	-	20 pct failed after 25 yr
	6.0 (3.67)	-	No failures after 25 yr
Copper naphthanate			
0.11 pct copper in No. 2 fuel oil	10.3	15.9	
.29 pct copper in No. 2 fuel oil	10.2	21.8	
.57 pct copper in No. 2 fuel oil	10.6	-	80 pct failed after 35 yr
.86 pct copper in No. 2 fuel oil	9.6	-	60 pct failed after 35 yr
Creosote, coal-tar	4.1	14.2	
	4.2	17.8	
	4.6	21.3	
	8.0	-	40 pct failed after 36-1/2 yr
	8.3	-	20 pct failed after 27 yr
	10.0	-	60 pct failed after 36 yr
	11.8	-	20 pct failed after 36-1/2 yr
	14.5	-	No failures after 36 yr
	16.5	-	No failures after 36-1/2 yr
Low residue, straight run	8.0	17.8	
Medium residue, straight run	8.0	18.8	
High residue, straight run	7.8	20.3	
Medium residue			
Low in tar acids	8.1	19.4	
Low in naphthalene	8.2	21.3	
Low in tar acids and naphthalene	8.0	18.9	
Low residue, low in tar acids and naphthalene	8.0	19.2	
High residue, low in tar acids and naphthalene	8.2	20.0	

Table 1 - continued.

Preservative	Average retention	Average life	Remarks
	<u>Pcf</u>	<u>Yr</u>	
Creosote, coal-tar-continued			
English vertical retort	5.3	-	60 pct failed after 28 yr
	8.0	18.9	
	10.1	-	30 pct failed after 28 yr
	15.0	-	No failures after 28 yr
English coke oven	4.7	16.3	
	7.9	13.6	
	10.1	-	70 pct failed after 28 yr
	14.8	-	70 pct failed after 28 yr
Fluor chrome arsenate phenol type A (Fed. Spec. TT-W-535)	.2 (0.12)	10.2	
	.3 (.19)	18.0	
	.35 (.22)	-	38 pct failed after 17 yr
	.50 (.31)	-	50 pct failed after 17 yr
	.61 (.38)	24.1	
	.75 (.47)	-	No failures after 17 yr
Pentachlorophenol (various solvents)			
Liquefied petroleum gas	.14	-	20 pct failed after 15-1/2 yr
	.19	-	60 pct failed after 15-1/2 yr
	.34	-	No failures after 15-1/2 yr
	.34	-	20 pct failed after 13 yr
	.49	-	No failures after 13 yr
	.58	-	No failures after 15-1/2 yr
	.65	-	No failures after 13 yr
Standard solvent (mineral spirits)	.14	-	90 pct failed after 15-1/2 yr
	.18	-	50 pct failed after 15-1/2 yr
	.2	9.5	
	.2	13.7	
	.38	-	No failures after 15-1/2 yr
	.4	15.5	
	.67	-	No failures after 15-1/2 yr
Heavy gas oil (Mid-United States)	.2	-	33 pct failed after 28-1/2 yr
	.4	-	10 pct failed after 28-1/2 yr
	.6	-	10 pct failed after 28-1/2 yr
No. 4 aromatic oil (West Coast)	.2	-	80 pct failed after 27 yr
	.4	-	20 pct failed after 27 yr
SWPA-P9 (heavy petroleum)	.11	-	No failures after 15-1/2 yr
	.19	-	No failures after 15-1/2 yr
	.29	-	No failures after 15-1/2 yr
	.53	-	No failures after 13 yr
	.67	-	No failures after 15-1/2 yr
Untreated stakes	-	1.8-3.6	

¹ Retention values in parentheses are based on preservative oxides.

From Davidson (1977).

APPENDIX II Resin Properties

Table 1. Resin contents of different groups of rings in different ages of tree taken from b.h. increment cores from variety hondurensis in Fiji.

APPENDIX II

Table 1. Resin contents of breast height increment cores

Site	Resin content (%) for rings:			
	1-5	6-10	11-15	16-20
<u>Crops 23-25 years</u>				
Ra (Nadarivatu, 1955)	50.6	25.8	5.9	3.3
Lololo (Tavakuba, 1957)	22.6	2.2	1.8	1.6
Nadi (Nausori Hglds, 1956)	27.8	3.5	2.6	2.8
Means	33.7	10.5	3.4	2.6
<u>Crops 15-18 years</u>				
Ra (Lewa Valley, 1962)	24.3	6.3	1.7	
" (Nadarivatu, 1963)	8.1	3.1	2.7	
Lololo (Drasa, 1962)	15.7	2.1	1.6	
" (Drasa Seed Stand)	24.4	7.5	2.3	
" (Drasa, 1964)	17.8	2.7	2.0	
Nabou (1965)	22.1	3.8	1.9	
Nadi (1962)	25.2	4.4	2.3	
" (1964)	11.6	2.6	2.7	
Means	18.6	4.1	2.1	
<u>Crops 11-14 years</u>				
Ra (Koro No. 2, 1967)	5.3	3.2		
Lololo (Drasa, 1966)	4.7	1.7		
" (" , 1967)	2.7	1.9		
" (1967)	6.9	1.9		
" (Spacing trial, 1969)	6.6	1.7		
Nabou (Nawaicoba, 1967)	6.7	2.1		
Nadi (1967)	11.8	1.5		
" (1969)	5.8	3.2		
Seaqqa (1967)	8.2	1.5		
" (")	7.8	5.4		
" (1969)	2.4	1.7		
Means	6.3	2.3		

Table 1 - continued.

Site	Resin content (%) for rings:			
	1-5	6-10	11-15	16-20
<u>Crops 10 years</u>				
Lololo (1971)	4.5			
" (")	4.0			
" (1972)	4.6			
" (")	3.7			
" (1974)	3.3			
" (")	2.6			
Nabou (1974)	3.2			
" (")	3.5			
Seaqqa (1971)	7.6			
" (1972)	4.5			
Korotari (1971)	4.2			
" (1972)	5.8			
Bua (Lekutu Village, 1971)	4.0			
" (1975)	2.4			
" (1976)	3.4			
	Mean	4.1		

From Cown et al. (1981)

APPENDIX III Shrinkage Properties

Table 1. Tables of radial, tangential, longitudinal and volumetric shrinkage in groups of rings from the pith at different heights in the tree. (From 15 trees in Fiji of variety hondurensis).

Table 2. Tree mean air dry shrinkage and oven dry shrinkages for 15 trees in Fiji in three sites of variety hondurensis.

APPENDIX III

Table 1. Shrinkage summary of stem position (15 trees) from Fiji

Stem Level	Shrinkage (%), green to air-dry at rings:-					Shrinkage (%), green to oven-dry at rings:-				
	1-5	6-10	11-15	16-20	Mean	1-5	6-10	11-15	16-20	Mean
(a) <u>Longitudinal shrinkage*</u>										
Butt	.13	+.04	+.03	.02	.02	.43	.20	.20	.25	.27
B.H.	+.06	+.03	+.04		+.04	.11	.10	.33		.18
5m	+.07	+.19	+.11		+.12	.06	.06	.10		.07
10m	+.14	+.14	+.04		+.11	.01	.07	.05		.04
15m	+.05	+.07			+.06	.11	.10			.10
Mean	+.04	+.09	+.05	.02	+.06	.14	.11	.17	.25	.13
(b) <u>Radial shrinkage</u>										
Butt	2.0	3.2	3.2	3.5	2.8	3.5	5.5	5.7	6.2	5.0
B.H.	1.9	3.3	3.5		2.8	3.5	5.8	5.8		5.1
5m	1.6	2.8	3.1		2.4	2.9	5.1	5.7		4.4
10m	1.6	2.4	3.0		2.2	3.1	4.5	5.6		4.2
15m	2.0	2.7			2.2	3.6	4.9			4.2
Mean	1.8	2.9	3.2	3.5	2.5	3.3	5.2	5.7	6.2	4.6
(c) <u>Tangential shrinkage</u>										
Butt	3.5	4.6	4.8	4.7	4.4	5.6	7.4	7.8	7.8	7.0
B.H.	3.6	4.7	4.7		4.3	5.7	7.6	7.7		7.0
5m	3.1	4.5	4.6		4.0	5.2	7.1	7.5		6.5
10m	3.2	3.9	4.2		3.7	5.5	6.4	7.0		6.0
15m	3.0	3.6			3.3	5.2	6.1			5.5
Mean	3.3	4.3	4.6	4.7	3.9	5.4	6.9	7.5	7.8	6.4
(d) <u>Volumetric shrinkage</u>										
Butt	6.4	8.5	8.5	8.5	8.0	10.4	13.7	13.7	13.8	12.9
B.H.	6.3	8.7	9.2		8.1	9.8	13.8	13.3		12.3
5m	5.7	8.3	8.3		7.4	8.4	12.8	13.8		11.7
10m	5.8	7.6	8.3		7.2	9.1	11.6	13.4		11.4
15m	6.1	7.2			6.6	9.4	11.1			10.2
Mean	6.1	8.1	8.6	8.5	7.5	9.4	12.6	13.3	13.8	11.7

* Positive values indicate expansion. (From Cown et al. 1972).

APPENDIX III

Table 2. Shrinkage summaries for individual trees from Fiji

Site	Tree No.	Green to air-dry				Green to oven-dry			
		Longitudinal	Radial	Tangential	Volumetric	Longitudinal	Radial	Tangential	Volumetric
Ra (Lewa Valley 1962)	16	+0.06	1.3	3.9	6.4	.09	2.7	6.1	9.3
	17	+0.25	2.3	3.7	7.7	.00	4.1	5.8	11.1
	18	+0.13	2.2	4.6	8.1	+0.01	3.9	7.2	11.9
	19	.09	2.1	3.5	5.7	.23	3.8	6.0	10.3
	20	.09	1.8	3.2	5.6	.38	3.2	5.3	9.2
	Mean	+0.05	1.9	3.8	6.7	.14	3.5	6.1	10.4
Lololo (Tavakubu 1956)	41	+0.10	2.5	4.0	6.9	.08	4.5	6.5	11.3
	42	.03	1.8	3.3	6.0	.14	3.6	5.6	9.4
	43	+0.06	4.2	4.5	9.2	.03	7.1	7.6	15.1
	44	+0.14	2.0	3.8	6.9	+0.02	3.8	6.3	10.8
	45	+0.15	2.8	3.8	7.2	+0.02	5.0	6.2	11.4
	Mean	+0.08	2.7	3.9	7.2	.04	4.8	6.4	11.6
Lololo (Drasa 1962)	92	+0.15	3.0	4.3	8.1	.02	5.4	6.6	12.4
	95	+0.01	3.0	4.1	8.1	.22	5.4	6.9	12.8
	96	+0.14	3.3	4.6	8.8	.06	6.1	8.0	15.2
	97	+0.11	2.8	3.6	7.4	.21	5.2	6.4	12.9
	98	+0.02	2.5	3.4	7.5	.30	4.6	5.6	11.0
	Mean	+0.09	2.9	4.0	8.0	.16	5.3	6.7	12.9
Overall means		+0.07	2.5	3.9	7.3	.09	4.5	6.4	11.6

From Cown et al. (1972).

APPENDIX IV Wood Density

Table 1. Summary of weighted breast height wood density of variety hondurensis and location, altitude, climate, silviculture and rates of growth for 18 sites in East Africa.

Table 2. Analysis of variance table for mean density breast height of 118 trees in 13 sites in East Africa for the eight inner rings common to all sites and for all rings (calculating densities of the outer rings of the younger sites using a curvilinear regression formula calculated for each site).

Figures 1-5. Contours of wood density within selected trees of variety hondurensis from Fiji showing mean wood density and its variation within the stem. Contours are computer plotted around a matrix of points of ring average wood density located at the distance of the centre of the ring from the pith at 5%, 15%, 25%, 35%, 45%, 55%, 65% and 75% heights of the tree. Intervals between single line contours are 0.05 g/cm^3 of wood density and between double contours are 0.25 g/cm^3 .

Figure 6. Percentages of wood in different density classes of twenty trees of variety hondurensis from Fiji.

APPENDIX IV

Table 1. *Pinus caribaea* increment cores, East Africa, 1973. Site information

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
		Approximate location				Climate, nearest station			Planting			Details of sample				
		Latitude	Longitude	Altitude m	Rainfall mm	Mean temp. °C	Max temp. warmest month, °C	Min. temp. coolest month, °C	Date	Spacing m	No. of cores	Spacing m	Mean Tree height (m)	Mean dbh cm	No. of rings	Mean density weighted g/cc
Kenya	1. Kwale, plot 1A	4°13'S	39°27'E	200	1040	26.0	32.0	20.0	1956	2.3	10	3.8	15.0	18.4	17	0.64
	2. Kwale, plot 3A	4°13'S	39°27'E	200	1040	26.0	32.0	20.0	1956	2.3	10	3.7	15.8	20.7	17	0.68
	3. Kwale, plot 5A	4°13'S	39°27'E	200	1040	26.0	32.0	20.0	1956	2.3	10	4.7	13.5	20.9	17	0.62
Tanzania	4. Longuza arboretum, plot 307	5°07'S	38°42'E	220	1539	25.4	33.4	17.5	1960	2.3	10	2.3	17.1	17.6	12	0.59
	5. Kwamalukanga, plot 671	5°14'S	38°35'E	330	1389	26.2	34.9	18.8	1965	2.4	10	2.5	9.8	14.3	8	0.47
	6. Maumbugwe, plot 589	5°13'S	38°57'E	120	1265	24.1	29.9	18.8	1963	2.4	10	3.4	11.7	17.0	10	0.49
	7. Bana, plot 553	6°45'S	38°45'E	50	971	25.8	32.2	18.1	1963	2.3	10	2.4	14.0	18.5	10	0.48
	8. Bana, compartment 1	6°45'S	38°45'E	50	971	25.8	32.2	18.1	1965	2.3	10	2.5	13.3	17.7	8	0.41
	9. Vikundu, plot 552	6°52'S	39°17'E	80	1115	25.8	31.2	18.9	1963	2.3	10	2.4	13.1	16.2	10	0.57
	10. Kazimzumbwe, plot 551	6°52'S	39°08'E	170	1093	25.8	32.2	18.1	1963	2.3	10	2.4	12.2	15.2	10	0.51
	11. Lushoto arboretum, plot 42	4°47'S	38°17'E	1500	1061	17.1	26.4	9.3	1954	2.3	10	4.0	28.0	40.0	19	0.46
	12. Katuge, plot 612A, no. 2	1°15'N	32°20'E	1092	1000	-	-	-	1964	2.3	10	2.7	13.8	18.5	9	0.46
	13. Singo Hills, plot 474	0°50'N	31°45'E	1023	1100	-	-	-	1963	2.3	10	2.7	16.1	20.5	10	0.53
Uganda	14. Abera, plot 425	2°45'N	32°20'E	1108	1400	-	-	-	1959	-	10	-	-	-	14	0.53
	15. Kachung, plot 427	1°39'N	32°57'E	1100	1250	-	-	-	1962	-	10	-	-	-	11	0.49
	16. Kafu, plot 507	1°35'N	32°05'E	1250	990	-	-	-	1960	-	7	-	-	-	13	0.55
	17. Kei, plot 494	3°45'N	31°10'E	1349	1500	-	-	-	1960	-	7	-	-	-	13	0.55
	18. Opit, plot 426	2°40'N	32°25'E	1108	1400	-	-	-	1962	-	9	-	-	-	11	0.52

From Andrew and Plumptre (1973).

APPENDIX IV

Table 2. Mean density, g/cc - analysis of variance

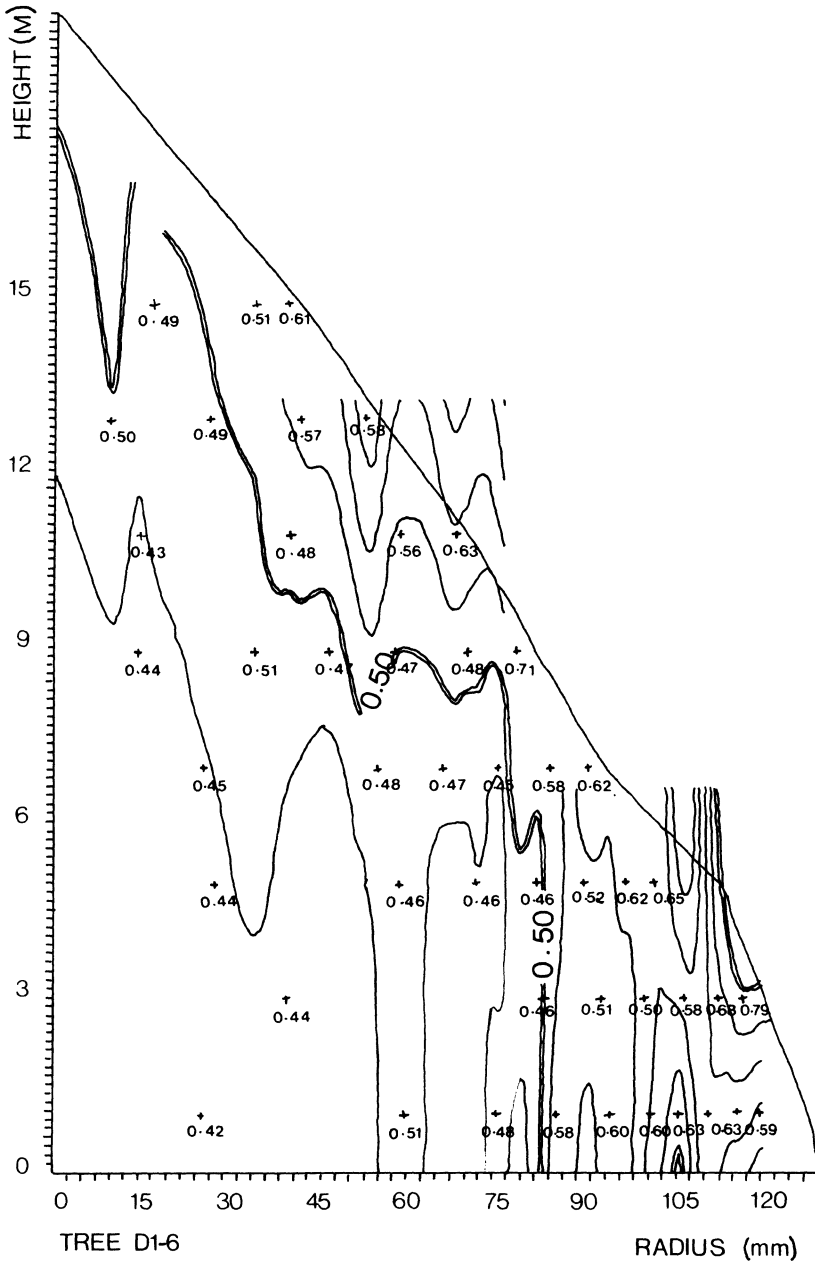
	(i) Orthogonalised sampled - 8 inner rings				(ii) Full sample - site and ring affects adjusted			
<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>VC %</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>VC %</u>
Sites	12	0.3758	12.0 ***	23.7	12	0.6752	12.3 ***	24.7
Trees in sites	117	0.0314	5.6 ***	17.7	117	0.0549	8.4 ***	19.2
Rings	7	0.3407	10.5 ***	13.1	18	0.2433	7.6 ***	12.3
Site x ring int'n	84	0.0323	5.8 ***	14.7	126	0.0319	4.9 ***	12.1
Residual	818	0.0056		30.8	1295	0.0066		31.6

Note: *** indicates statistical significance, P 0.001

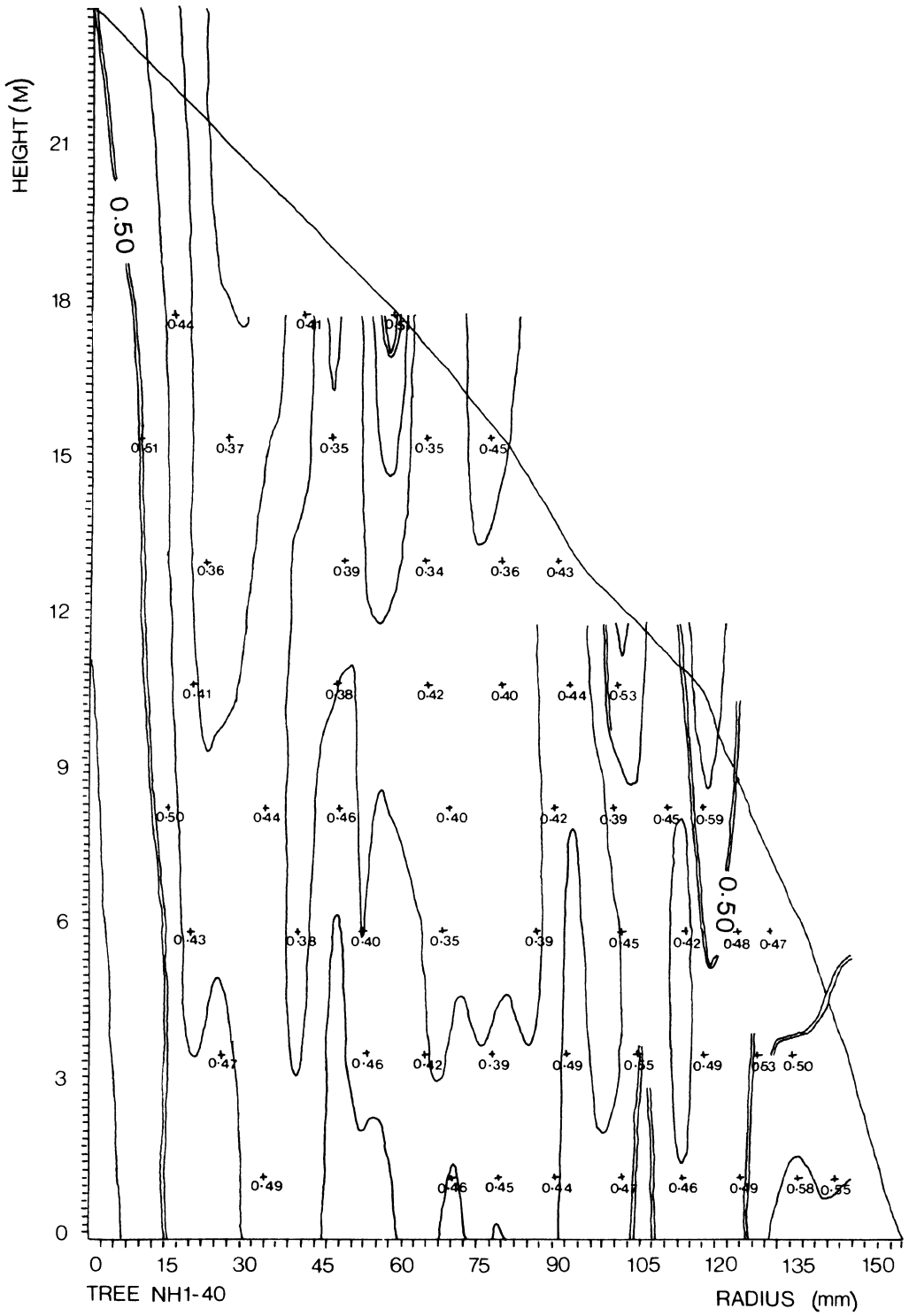
From Andrew and Plumptre (1973)

APPENDIX 4 FIGURE 1. DENSITY (EXTRACTED)

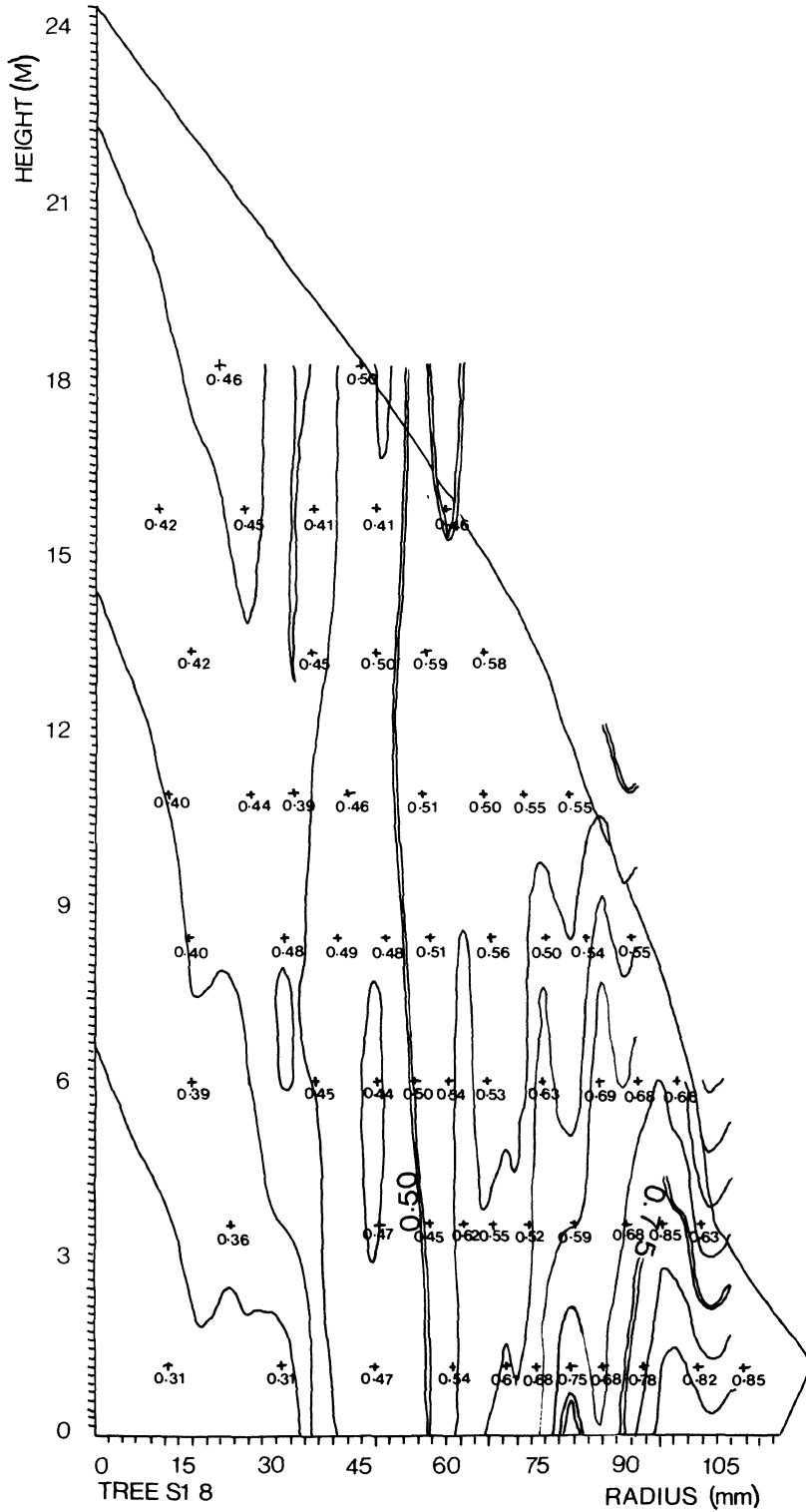
TREE 1 MEAN DENSITY = $0.522/g\text{ cm}^3$ FROM ONG 1978



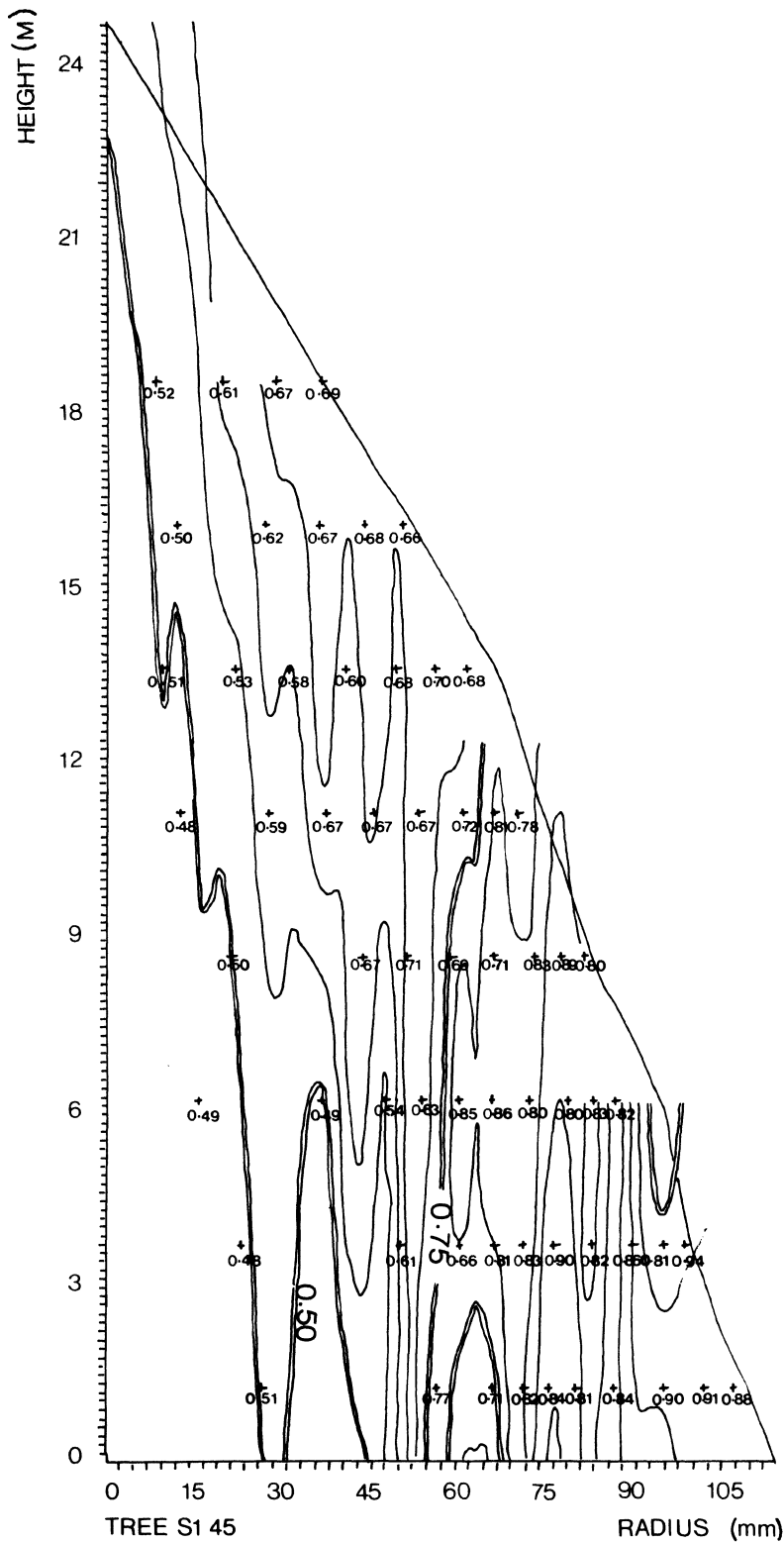
APPENDIX 4 FIGURE 2. DENSITY (EXTRACTED)
TREE 6 MEAN DENSITY: 0.441 g/cm³ FROM ONG 1978



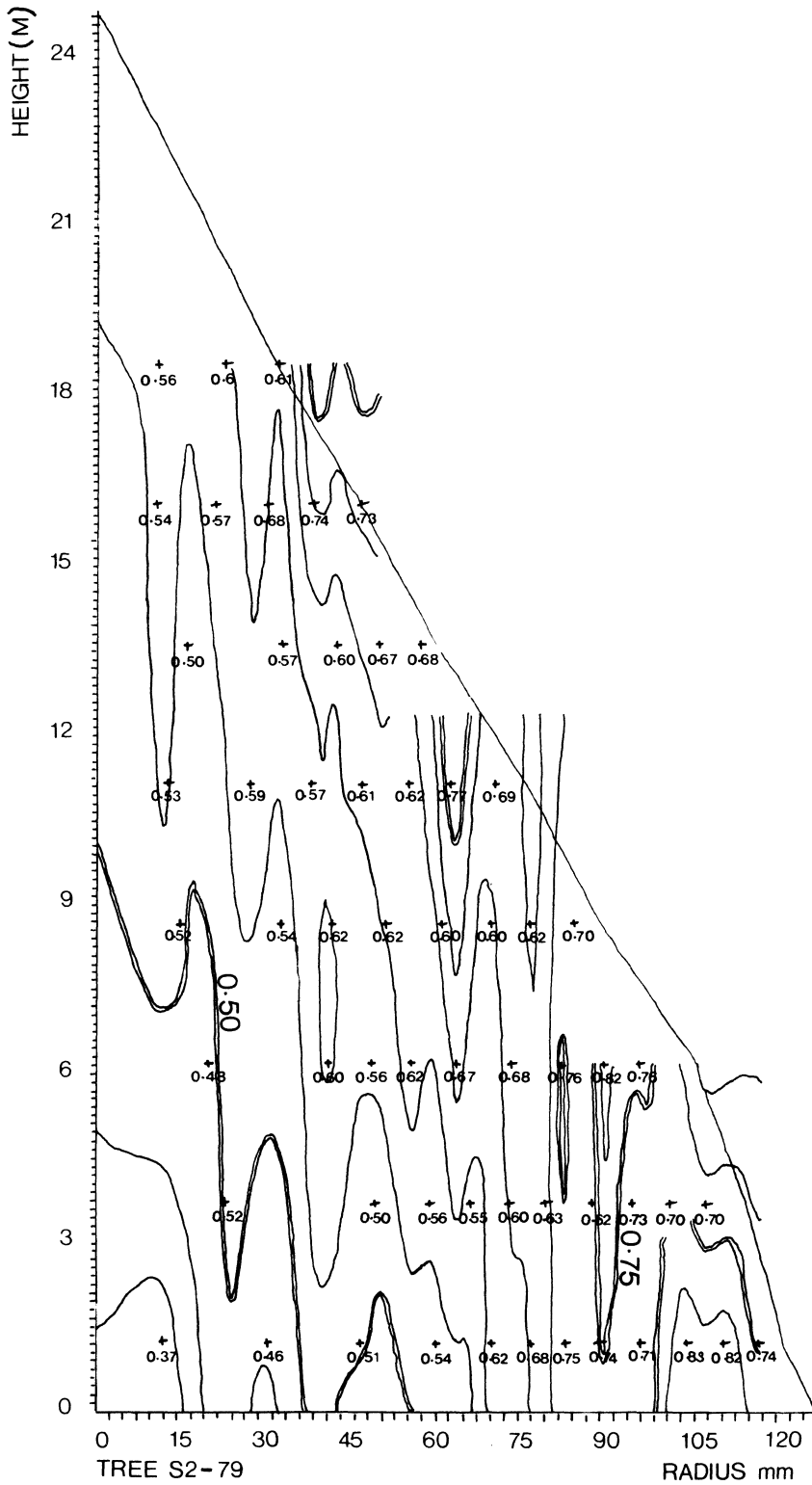
APPENDIX 4 FIGURE 3. DENSITY (EXTRACTED)
TREE 9 MEAN DENSITY 0.558g/cm³ FROM ONG 1978



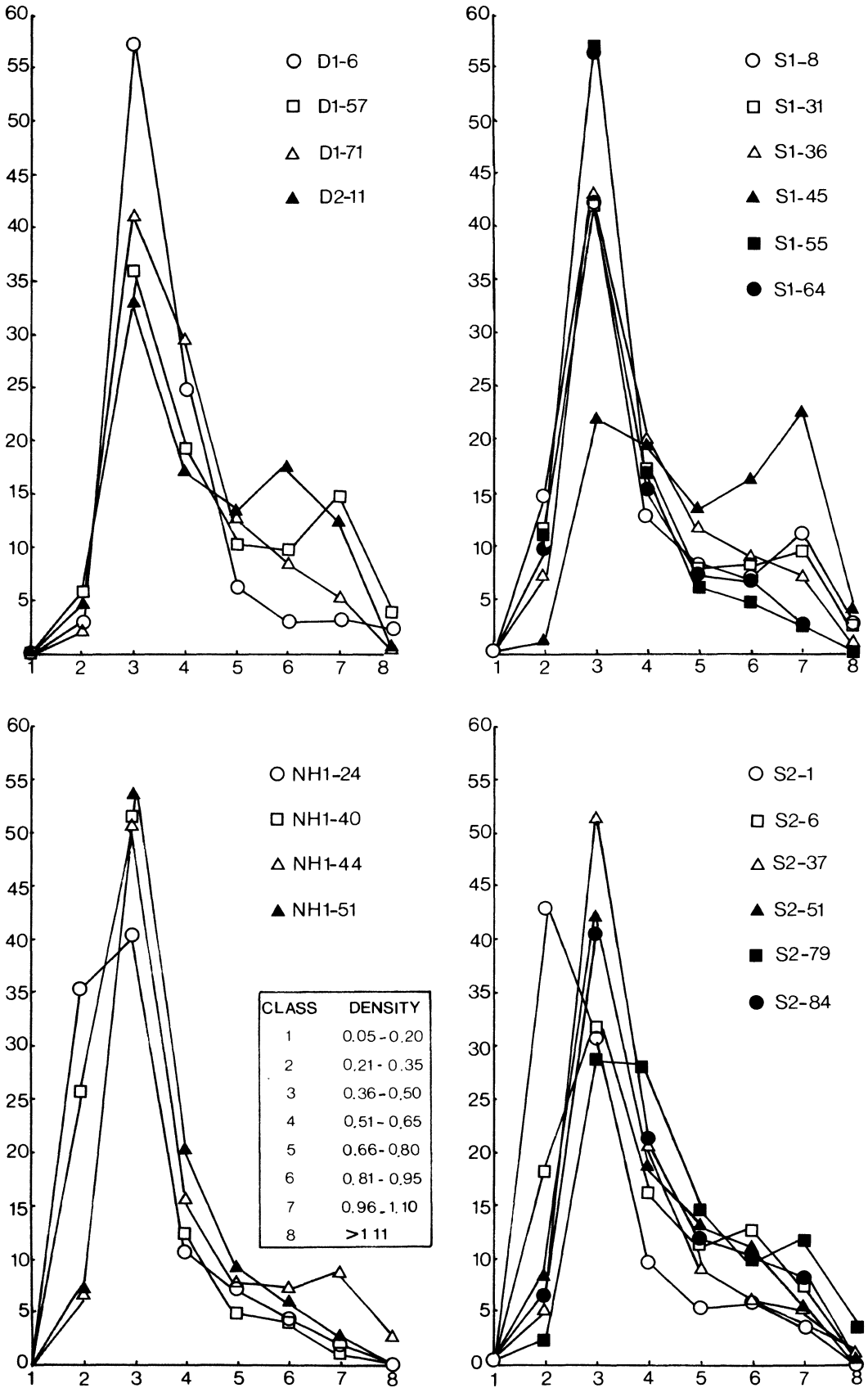
APPENDIX 4 FIGURE 4. DENSITY (EXTRACTED)
TREE 12 MEAN DENSITY 0.712 g/cm³ FROM ONG 1978



APPENDIX 4 FIGURE 5. DENSITY (EXTRACTED)
 TREE 19 MEAN DENSITY: 0.641 g/cm^3 FROM ONG 1978



APPENDIX 4 FIGURE 6. PERCENTAGE OF WOOD IN DENSITY CLASSES (20 TREES) from Ong (1978)



APPENDIX V Particle Board Properties

Table 1. Effects of varying resin content with high density timber.

Table 2. Effects of varying resin content with low density timber.

Table 3. Effects of varying wax content.

Table 4. Effects of varying board density.

Table 5. Effects of varying particle thickness and length.

All Tables from Chittenden et al. (1972).

APPENDIX V

Table 1. Variation of Resin Content

Basic density of timber 600 g/m³

Wax content 1.0 per cent

Particle dimensions: length 30 mm, thickness 0.6 mm

Resin content per cent	Board density kg/cm ³	Modulus of Rupture kg/cm ²	Tensile Stress Perpendicular to Plane kg/cm ²	Screw Holding kg	Surface Soundness kg	Impact Strength mm	Water Absorption per cent	Thickness Swelling per cent	Dimensional change per cent from 65% RH at 25°C			
									40% RH at 25°C		90% RH at 25°C	
									length	thickness	length	thickness
8.0	638	180	7.7	83	123	533	17	9.2	-0.11	-0.9	0.09	3.4
7.0	648	167	6.1	72	137	610	15	9.9	-0.05	-0.5	0.09	3.4
6.0	641	162	5.9	66	170	457	12	3.6	-0.12	-0.9	0.11	7.7
5.0	663	176	5.9	66	133	610	28	17.6	-0.09	-0.8	0.07	3.8
4.0	643	144	4.4	60	67	406	20	12.7	-0.16	-1.2	0.03	4.8
3.0	664	159	6.0	63	94	534	12	8.4	-0.11	-0.8	0.15	2.6
2.0	629	87	1.2	26	30	279	35	30.2	-0.13	-1.4	0.12	4.1
BS 2604:1963	480 min	140	3.5	36	110	-	-	12.0 max	No limits given		0.35 max	7.0 max

(1) Impact strength - No limit set in British Standard 2604:1963 but a limit of not less than 380 mm set in British Standard 2604:1955

(2) Water absorption - No limit set in British Standard 2604:1963 but a limit of not greater than 75% set in British Standard 2604:1955

APPENDIX V

Table 2. Variation of Resin Content

Basic density of timber 461 kg/m³

Wax content 1.0 per cent

Particle dimensions: length 30 mm, thickness 0.6 mm

Resin content per cent	Board density kg/cm ³	Modulus of Rupture kg/cm ²	Tensile Stress Perpendicular to Plane kg/cm ²	Screw Holding kg	Surface Soundness kg	Impact Test mm	Water Absorption per cent	Thickness Swelling per cent	Dimensional change per cent from 65% RH at 25°C			
									40% RH at 25°C		90% RH at 25°C	
									length	thickness	length	thickness
8.0	639	235	10.3	82	235	635	8	4.3	-0.12	-0.80	0.19	3.0
7.0	651	239	8.3	77	81	686	13	8.8	-0.05	-0.09	0.14	3.3
6.0	648	208	8.4	77	181	711	7	3.9	-0.13	-1.00	0.16	3.4
5.0	658	228	6.8	70	154	483	16	8.6	-0.05	-0.50	0.10	4.1
4.0	641	194	5.3	63	107	660	9	6.2	-0.10	-0.08	0.17	3.6
3.0	659	193	4.8	65	100	584	8	5.4	-0.20	-0.80	0.13	2.8
2.0	639	135	2.9	43	54	292	22	16.9	-0.05	-1.10	0.11	5.2
BS 2604:1963	480 min	140	3.5	36	110	- ⁽¹⁾	- ⁽²⁾	12.0 max	No limits given		0.35 max	7.0 max

(1) Impact strength - No limit set in British Standard 2604:1963 but a limit of not less than 380 mm set in British Standard 2604:1955

(2) Water absorption - No limit set in British Standard 2604:1963 but a limit of not greater than 75% set in British Standard 2604:1955

APPENDIX V

Table 3. Variation of Wax Content

Basic density of timber 600 kg/m³

Resin content 8 per cent

Particle dimensions: length 30 mm, thickness 0.6 mm

Wax content per cent	Board density kg/m ³	Modulus of Rupture kg/cm ²	Tensile Stress Perpendicular to Plane kg/cm ²	Screw Holding kg	Surface Soundness kg	Impact Test mm	Water Absorption per cent	Thickness Swelling per cent	Dimensional change per cent from 65% RH at 25°C			
									40% RH at 25°C		90% RH at 25°C	
									length	thickness	length	thickness
Nil	661	206	7.8	82	93	889	66	18.7	no results			
0.25	665	193	7.1	87	74	635	44	18.6	-0.19	-1.20	0.11	4.1
0.50	640	182	8.4	85	54	659	28	13.1	-0.19	-0.60	0.05	3.2
1.00	638	180	7.7	83	123	533	17	9.2	-0.11	-0.90	0.09	3.4
BS 2604:1963	480 min	140	3.5	36	110	- (1)	- (2)	12.0 max	No limits given		0.35 max 7.0 max	

(1) Impact strength - No limit set in British Standard 2604:1963 but a limit of not less than 380 mm set in British Standard 2604:1955

(2) Water absorption - No limit set in British Standard 2604:1963 but a limit of not greater than 75% set in British Standard 2604:1955

APPENDIX V

Table 4. Variation of Board Density

Basic density of timber 538 kg/m³

Resin content 8 per cent

Wax content 1.0 per cent

Particle dimensions: length 30 mm, thickness 0.6 mm

Board density kg/m ³	Modulus of Rupture kg/cm ²	Tensile Stress Perpendicular to Plane kg/cm ²	Screw Holding kg	Surface Soundness kg	Impact Test mm	Water Absorption per cent	Thickness Swelling per cent	Dimensional change per cent from 65% RH at 25°C			
								40% RH at 25°C		90% RH at 25°C	
								length	thickness	length	thickness
412	49	1.7	35	20	178	52	15.4	-0.02	-0.6	-0.03	5.3
489	89	4.7	45	50	229	31	13.2	-0.05	-1.0	0.05	3.4
559	133	5.2	58	47	406	23	10.9	-0.09	-0.7	0.05	6.5
643	187	8.9	94	121	508	14	7.7	-0.16	-0.8	0.06	5.2
727	291	13.9	122	322	762 ⁽¹⁾	8 ⁽²⁾	5.9	-0.09	-1.1	0.03	3.0
BS 2064:1963 480 min	140	3.5	36	110	-	-	12.0 max	No limits given		0.35 max	7.0 max

(1) Impact strength - No limit set in British Standard 2604:1963 but a limit of not less than 380 mm set in British Standard 2604:1955

(2) Water absorption - No limit set in British Standard 2604:1963 but a limit of not greater than 75% set in British Standard 2604:1955

APPENDIX V

Table 5. Variation of Particle Thickness and Length

Basic density of timber 538 kg/m³Resin content 8 per centWax content 1.0 per cent

Particle Dimensions		Board density kg/m ³	Modulus of Rupture kg/cm ²	Tensile Stress Perpendicular to Plane kg/cm ²	Screw Holding kg	Surface Soundness kg	Impact Test mm	Water Absorption per cent	Thickness Swelling per cent	Dimensional change per cent from 65% RH at 25°C			
length mm	thickness mm									40% RH at 25°C		90% RH at 25°C	
										length	thickness	length	thickness
15	0.2	652	205	8.7	96	190	406	10	6.4	-0.06	-0.9	0.06	3.1
-	0.4	655	187	8.4	80	158	483	20	11.5	-0.05	-0.9	0.06	3.2
-	0.6	632	164	4.9	60	140	406	33	12.9	-0.07	-1.1	0.03	3.1
-	0.8	650	163	10.3	84	213	457	22	14.1	-0.17	-0.8	0.11	7.0
20	0.2	646	222	10.6	95	207	508	12	7.8	-0.03	-0.9	0.08	3.1
-	0.4	646	202	10.8	93	154	508	13	6.9	-0.05	-1.0	0.08	2.9
-	0.6	670	216	10.5	86	189	488	29	15.2	-0.11	-0.7	0.07	3.1
-	0.8	661	186	10.4	96	273	610	26	13.8	-0.10	-0.8	0.08	6.1
30	0.2	653	216	8.9	100	132	533	13	11.2	-0.09	-1.0	0.12	5.5
-	0.4	650	202	8.3	95	227	457	18	11.5	-0.03	-0.9	0.17	3.5
-	0.6	648	204	9.4	96	208	525	17.5	10.8	-0.03	-1.1	0.12	3.2
-	0.8	646	184	11.0	92	173	559	18	11.6	-0.10	-1.1	0.07	6.5
40	0.2	642	226	10.2	106	184	559	7	4.3	-0.12	-0.8	0.16	5.2
-	0.4	653	203	8.1	91	207	508	28	13.4	-0.09	-1.1	0.08	5.0
-	0.6	647	215	10.9	91	153	508	20	11.4	-0.11	-1.1	0.09	5.3
-	0.8	662	206	9.3	93	185	559	26	14.6	-0.05	-0.9	0.10	6.6
BS 2604:1963		480 min	140	3.5	36	110	- (1)	- (2)	12.0 max	No limits given		0.35 max	7.0 max

(1) Impact strength - No limit set in British Standard 2604:1963 but a limit of not less than 380 mm set in British Standard 2604:1955

(2) Water absorption - No limit set in British Standard 2604:1963 but a limit of not greater than 75% set in British Standard 2604:1955

APPENDIX VI Paper Properties

- Table 1. Paper properties of twenty trees of variety hondurensis from Uganda pulped individually using two different cooks.
- Table 2. Paper properties of twenty trees of variety hondurensis from Fiji pulped individually using four different cooks. (The trees were selected to give a wide range of tree mean density).
- Table 3. Correlation matrix of pulp properties for twenty trees pulped individually from Fiji. (The same trees as in Table 2 above).

Table 1. Twenty trees from Uganda of variety hondurensis: Principle paper properties evaluated at 500 Canadian Standard Freeness for pulp digested with 15% (cook 1) and 20% (cook 2) active alkali for four hours. Values represent the mean of duplicate cooks.

Tree number	COOK 1						COOK 2					
	Beating time, mins.	Density g/cm ³	Burst Index kPa m ² /g	Tensile Index Nm/g	Stretch %	Tear Index mNm ² /g	Beating time, mins.	Density g/cm ³	Burst Index kPa m ² /g	Tensile Index Nm/g	Stretch %	Tear Index mNm ² /g
1	5.69	0.77	6.91	109.11	3.32	7.43	3.42	0.79	5.57	107.94	2.93	6.17
2	5.98	0.74	7.38	120.80	2.96	8.16	4.34	0.76	6.13	119.70	2.74	8.03
3	5.95	0.69	5.75	90.77	3.10	10.13	4.12	0.73	4.89	83.66	2.77	9.83
4	6.14	0.75	7.02	111.12	2.84	7.33	4.52	0.75	6.73	105.76	3.34	8.20
5	5.06	0.78	5.85	97.15	2.84	6.79	3.69	0.77	5.37	93.27	2.88	7.81
6	5.37	0.75	6.36	101.49	3.20	7.42	3.53	0.77	4.95	7.35	2.79	6.87
7	6.20	0.71	6.39	98.62	3.20	9.81	4.22	0.75	5.31	87.66	3.04	9.43
8	5.44	0.74	6.37	98.17	3.73	8.98	4.05	0.77	5.20	85.99	3.11	8.81
9	6.22	0.73	6.29	104.77	2.79	7.17	4.19	0.75	5.35	94.47	2.64	6.70
10	6.50	0.73	6.99	106.49	3.21	9.82	4.72	0.75	5.73	92.30	2.76	8.81
11	5.71	0.75	6.77	105.59	3.14	7.90	4.50	0.76	5.55	93.58	2.97	7.85
12	6.69	0.73	6.79	103.29	3.32	8.34	4.80	0.77	5.55	92.01	3.04	7.51
13	5.65	0.71	6.96	109.64	3.04	9.17	4.29	0.7	6.01	99.95	2.85	8.38
14	6.12	0.69	7.38	109.33	3.11	10.50	4.58	0.71	6.34	100.99	2.80	9.96
15	6.14	0.71	6.57	107.89	3.11	8.77	4.27	0.75	5.42	91.00	3.04	8.30
16	6.59	0.74	6.39	101.10	3.13	7.88	4.21	0.76	4.98	87.38	2.73	7.40
17	5.69	0.73	7.34	113.51	2.82	8.02	4.48	0.74	5.99	100.96	2.78	8.25
18	7.14	0.70	6.61	98.18	3.48	9.92	4.77	0.74	5.32	89.05	2.91	8.72
19	6.99	0.69	6.73	102.73	2.92	10.13	5.07	0.70	5.98	97.71	2.63	9.91
20	6.20	0.74	6.82	104.13	3.25	7.98	4.53	0.77	5.71	96.10	2.94	7.73

APPENDIX VI

Table 2. Twenty trees from Fiji of variety hondurensis: Pulp evaluation at 500 Canadian Standard Freeness (Tree mean values for four duplicate digestions A-D)

Tree number	A				B				C				D			
	Beating time, mins.	Density, g/cm ³	Burst index kPa m ² /g	Tear index mNm ² /g	Beating time, mins.	Density g/cm ³	Burst index kPa m ² /g	Tear index mNm ² /g	Beating time, mins.	Density g/cm ³	Burst index kPa m ² /g	Tear index mNm ² /g	Beating time, mins.	Density g/cm ³	Burst index kPa m ² /g	Tear index mNm ² /g
D1/6	6.0	0.64	6.8	13.5	5.7	0.65	6.4	12.9	5.6	0.66	6.5	12.6	5.0	0.67	5.7	12.0
D1/57	5.7	0.61	6.6	18.1	5.3	0.61	6.6	18.1	5.4	0.62	6.4	18.3	4.6	0.63	6.4	17.8
D1/71	5.5	0.64	6.6	15.9	5.2	0.65	6.6	15.7	4.8	0.66	6.6	15.4	4.4	0.68	6.0	14.4
D2/11	5.7	0.61	5.5	16.5	5.4	0.62	5.8	16.9	5.3	0.63	5.7	16.5	4.6	0.64	5.7	15.6
NH1/24	5.9	0.67	6.2	14.5	5.6	0.66	6.1	14.5	5.2	0.69	6.5	13.9	4.8	0.70	6.1	12.6
NH1/40	5.8	0.69	6.4	12.4	5.4	0.68	6.2	12.9	5.3	0.70	5.9	12.9	4.6	0.71	5.2	11.5
NH1/44	5.4	0.61	6.1	15.6	5.2	0.61	6.0	15.7	5.2	0.62	6.2	15.7	4.7	0.62	5.9	15.5
NH1/51	6.7	0.64	6.4	16.8	6.1	0.66	6.6	15.7	5.6	0.66	6.5	15.3	5.1	0.68	5.9	14.4
S1/8	5.6	0.59	6.3	17.5	5.4	0.59	6.3	18.0	5.2	0.59	6.4	17.9	4.8	0.61	6.0	17.8
S1/31	5.2	0.60	5.3	18.3	5.2	0.61	5.5	17.6	4.7	0.61	5.5	18.0	4.4	0.62	5.2	17.2
S1/36	5.4	0.62	6.3	18.0	4.7	0.63	6.6	17.1	4.9	0.63	6.4	16.3	4.4	0.64	6.1	16.3
S1/45	5.0	0.58	5.2	20.8	5.0	0.57	5.7	20.4	4.4	0.58	5.6	20.7	4.0	0.60	5.3	20.7
S1/55	5.6	0.66	7.5	13.5	5.4	0.67	7.4	13.0	5.2	0.67	7.2	13.1	4.4	0.67	6.6	13.3
S1/64	6.4	0.64	6.6	17.9	6.2	0.66	6.8	18.6	5.7	0.66	6.2	18.6	5.2	0.66	5.9	17.6
S2/1	5.7	0.64	6.8	17.4	5.2	0.64	6.7	17.8	5.2	0.66	6.3	16.0	4.8	0.66	6.2	16.5
S2/6	5.8	0.64	5.6	15.9	5.5	0.64	5.5	16.0	5.0	0.65	5.1	15.9	4.4	0.66	5.2	15.6
S2/37	5.5	0.64	6.7	14.2	5.1	0.65	6.5	14.1	4.8	0.66	6.3	13.6	4.8	0.66	5.9	13.7
S2/51	6.4	0.63	6.6	18.5	5.5	0.64	6.8	16.6	5.9	0.64	6.9	16.6	5.3	0.65	6.3	16.6
S2/79	5.2	0.59	5.2	18.9	4.7	0.60	5.5	19.0	4.6	0.61	5.8	18.8	4.2	0.61	5.2	17.4
S2/84	6.0	0.64	6.2	18.4	5.8	0.64	6.3	18.5	5.0	0.64	6.0	18.4	4.8	0.66	5.6	16.7

From Burley and Palmer (1979)

APPENDIX VI

Table 3. Matrix of simple correlations between pulp variables

	Total yield	Screened yield	Freeness	Drain. time	Air resistance	Burst index (est.)	Tensile index (est.)	Stretch	Tear index (est.)	Double folds	Burst index (500 CSf, 35K)	Tensile index (500 CSf, 35K)	Tear index (500 CSf, 35K)
Total Yield	1.00	0.86	-0.34	0.23	-0.26	-0.13	-0.05	-0.01	0.49	-0.27	-0.03	-0.05	0.49
Screened Yield		1.00	-0.42	0.43	-0.01	-0.03	0.04	-0.08	0.33	-0.12	0.07	-0.01	0.38
Freeness			1.00	-0.85	-0.48	-0.35	0.21	0.01	-0.15	0.55	0.17	0.17	-0.32
Drain. time				1.00	0.50	-0.38	-0.27	0.15	0.08	-0.37	-0.15	-0.26	0.28
Air resistance					1.00	0.08	0.13	-0.11	-0.40	0.11	0.16	0.12	-0.27
Burst index (est.)						1.00	0.96	-0.45	-0.37	0.34	0.85	0.92	-0.47
Tensile index (est.)							1.00	-0.63	-0.49	0.34	0.83	0.97	-0.57
Stretch								1.00	0.73	0.24	-0.29	-0.62	0.74
Tear index (est.)									1.00	-0.03	-0.22	-0.48	0.97
Double folds										1.00	0.43	0.29	-0.11
Burst index (500 CSf, 35K)											1.00	0.80	-0.30
Tensile index (500 CSf, 35K)												1.00	-0.57
Tear index (500 CSf, 35K)													1.00

From Burley and Palmer (1979)

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