PROVENANCE VARIATION IN STEM VOLUME AND WOOD DENSITY OF *PINUS CARIBAEA, P. OOCARPA* AND *P. PATULA* SSP. *TECUNUMANII* IN ZAMBIA

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SUMMARY

Provenance trials of *Pinus caribaea* Morelet and *P. oocarpa* Schiede/*P. patula* Schiede and Deppe ssp. *tecunumanii* (Eguiluz and Perry) Styles of the international series coordinated by the Commonwealth Forestry Institute[1], University of Oxford, were established in Zambia at 1300m altitude in 1973 and 1974 respectively. The trials were assessed in 1980 for volume under bark (VUB) and wood density (DEN) and these two traits plus the derived indices of within-sample density variation (VAR) and dry matter index (DMI) were analysed. Statistically, there were highly significant differences ($p<0.001$) between provenances of *P. caribaea* for VUB and DMI, and for DEN the provenances were also significantly different ($p<0.05$). Although the trials were not strictly comparable, there was an indication that the wood produced by *P. oocarpa* and *P. patula* ssp. *tecunumanii* would be of a higher density. For both species, some of the lowest VUB producers (Andros and Alamicamba in *P. caribaea* and Huehuetenango in *P. oocarpa*) also had the lowest densities and some of the highest VUB producers (Santa Clara in *P. caribaea* and Camelias in *P. patula* ssp. *tecunumanii*) were among the highest for density. In the Poptun provenance of *P. caribaea*, two separate seed collections from the same natural population produced trees with large differences in DEN. VAR was higher for *P. oocarpa* and the lowest value for this trait was for the island provenance of *P. caribaea*, Guanaja.

RÉSUMÉ

Des tests de provenances de *Pinus caribaea* Morelet et *P. oocarpa* Schiede/*P. patula* Schiede et Deppe ssp. *tecunumanii* (Eguiluz et Perry) Styles faisant partie de la série internationale coordonnée par le Commonwealth Forestry Institute[1], University of Oxford, furent établis en Zambie à une altitude de 1300m en 1973 et 1974 respectivement. Les tests furent évalués en 1980 pour volume sous écorce (VUB) et masse volumique (DEN), et ces deux caractéristiques plus les indices dérivés de variabilité de masse volumique dans les échantillons (VAR) et de l'indice de matière sèche (DMI) furent analysés. Statistiquement il y eut des différences hautement significatives ($p<0.001$) entre provenances de *P. caribaea* pour VUB et DMI, et pour DEN les provenances furent aussi significativement différentes ($P<0.05$). Bien que les tests ne fussent pas tout à fait comparable, il porta à croire que le bois produit par *P. oocarpa* et *P. patula* ssp. *tecunumanii* serait d'une masse volumique plus élevée. Pour les deux espèces quelques-uns des producteurs des VUB les plan bas (Andros et Alamicamba de *P. caribaea* et Huehuetenango de *P. oocarpa*) eurent aussi les masses volumiques les plus basses, et quelques-uns des producteurs des VUB les plus élevés (Santa Clara de *P. caribaea* et Camelias de *P. patula* ssp. *tecunumanii*) eurent les masses volumiques les plus élevées. Dans la provenance Poptun de *P. caribaea* deux récoltes de graines différentes de la même population naturelle produisirent des arbres avec des grandes variations de DEN. VAR fut plus élevé en *P. oocarpa* et la valeur la plus basse pour cette caractéristique fut pour la provenance de l'île de *P. caribaea*, Guanaja.

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RESUMEN

Ensayos de procedencias de *Pinus caribaea* Morelet y *P. oocarpa* Schiede/*P. patula* Schiede & Deppe ssp. *tecunumanii* (Eguiluz & Perry) Styles del red internacional coordinado por el Commonwealth Forestry Institute[1], Universidad de Oxford fueron establecidos en Zambia a los 1300 metros en 1973 y 1974 respectivamente. Las caracteristicas de volumen bajo corteza (VUB) y densidad de la madera (DEN) fueron evaluadas en 1980; estas caracteristicas y tambien los indices derivados de variación de densidad dentro de la muestra (VAR) y del indice de materia seca (DMI) fueron analizadas. Diferencias estadisticas altamente significatívas ($p<0.001$) fueron encontradas entre procedencias de *P. caribaea* para VUB y DMI, y para DEN una diferencia significatíva ($p<0.05$). No obstante que los ensayos no estaban estrictamente comparable, habia una indicación que la madera de *P. oocarpa/P. patula* ssp. *tecunumanii* tiene una densidad mas alta. Para ambas especies, algunos de los productores mas bajos de VUB (Andros y Alamicamba en *P. caribaea* y Huehuetenango en *P. oocarpa*) tambien mostraron las densidades las mas bajas y algunos de los productores mas altos de VUB (Santa Clara en *P. caribaea* y Camelias en *P. patula* ssp. *tecunumanii*) estuvieran entre los que tenian las densidades las mas altas. Dos recolecciónes differentes dentro de la procedencia Poptun de *P. caribaea* produjeron árboles con una gran differencia para DEN. VAR fue mas alta para *P. oocarpa* y la procedencia insular de Guanaja de *P. caribaea* tuvo el valor mas bajo para esa caracteristica.

Introduction

The Commonwealth Forestry Institute[1], Oxford, (CFI) has been responsible since the early 1960s for international provenance trials of *Pinus caribaea* Morelet and *P. oocarpa* Schiede. These trials have now been established in over 400 locations with representation in 50 tropical countries. This paper concerns data from the trials of *P. caribaea* and *P. oocarpa* located at Chati and Ndola East, Zambia, respectively.

Materials and Methods

Details of the Zambian trials are summarised in Table 1. Provenance details for *P. caribaea* are summarised in Greaves (1978) and for *P. oocarpa* in Greaves (1979). Subsequently, four provenances of *P. oocarpa* have been reclassified as *P. patula* Schiede and Deppe ssp. *tecunumanii* (Eguiluz and Perry) Styles (McCarter and Birks, 1985). Details of provenances, country of origin and abbreviations used for the *P. caribaea* trial are given in Table 2 and those for *P. oocarpa/P. patula* ssp. *tecunumanii* are given in Table 3.

Table 1

Details of experimental and environmental conditions of *P. caribaea*, *P. oocarpa* and *P. patula* ssp. *tecunumanii* trials in Zambia.

Locality Name	Lat. (S)	Alt. (m)	Mean Ann. Precip. (mm)	Mean Ann. Temp. (°C)	Trees/ Plot	Measured Trees/ Plot	No. of Blocks	Age at Assess-ment (months)
Chati	13°00′	1300	1273	20.5	10×10	4×4	4	86
Ndola East	13°00′	1300	1174	19.6	10×6	8×2	2	75

1 The Oxford Forestry Institute (OFI) from 1 October 1985.

Table 2
Details of provenances, country of origin and abbreviations for the three varieties of *P. caribaea*.

Variety	Provenance	Country	Abbreviation
var. *hondurensis*	Alamicamba	Nicaragua	ALA
	Brus Lagoon	Honduras	BRU
	Byfield	Australia	BYF
	Guanaja	Honduras	GUA
	Kuakil	Nicaragua	KUA
	Poptun	Guatemala	POP
	Poptun (non CFI)	Guatemala	POP (nCFI)
	Potosi	Honduras	POT
	Santa Clara	Nicaragua	STA
var. *bahamensis*	Andros Island	Bahamas	AND
var. *caribaea*	Buren	Cuba	BUR

Table 3
Details of provenances, country of origin and abbreviations for *P. oocarpa* and *P. patula* ssp. *tecunumanii*.

Species	Provenance	Country	Abbreviation
P. oocarpa	Angeles	Honduras	ANG
	Bonete	Nicaragua	BON
	Bucaral	Guatemala	BUC
	Canas	Guatemala	CAN
	Chuacus	Guatemala	CHU
	Conacaste	Guatemala	CON
	Dola Hill	Zambia	DOL
	Huehuetenango	Guatemala	HUE
	Junquillo	Nicaragua	JUN
	Lagunilla	Guatemala	LAG
	Maraquito	Honduras	MQT
	San Marcos	Honduras	MAR
	Siguatepeque	Honduras	SIG
	Zamorano	Honduras	ZAM
	Zapotillo	Honduras	ZAP
P. patula	Camelias	Nicaragua	CAM
ssp. *tecunumanii*	Mountain Pine Ridge	Belize	MPO
	Rafael	Nicaragua	RAF
	Yucul	Nicaragua	YUC

The trials were measured in 1980 and results for a range of traits in *P. caribaea* were reported in Gibson (1982). Survival in the *P. caribaea* trial was 86% and in the *P. oocarpa/P. patula* ssp. *tecunumanii* trial was 81%. At the time of measurement, increment cores of 8 mm diameter were taken bark-to-bark at breast height from the three largest diameter trees in each measured plot in each block. This sub-sample is likely to contain the final crop trees and those most likely to be included in any future

breeding population. Following shipment to CFI, the cores were oven-dried to 12% moisture content, weighed and the gravimetric density determined using dry weight and wet volume calculated from nominal 8 mm increment core diameter and fresh core length (Barnes, Gibson and Bardey, 1983). The cores were then machined to 5 mm thickness in both axial and radial planes and, following resin extraction, the mean density (DEN) was determined using the Joyce–Loebl micro-densitometer. Hughes and Sardinha (1975) and Kanowski (1985) described the procedures used at CFI with respect to densitometry. In addition to mean density, data from the densitometer can also be used to calculate within-sample variation. This term is derived identically to the standard deviation but does not have its statistical connotations and is referred to here as variation of density (VAR). The lower the variation of density the more uniform the wood is in terms of density. Volume (VUB) was determined for each tree sampled for density using under bark diameter at breast height, total height and a form quotient based on the outside bark diameter at breast height and at 6 m (Gibson, Barnes and Berrington, 1983). The dry matter index (DMI) is the product of DEN and VUB.

Due to the different ages and to differences in sites between the two trials, no statistical comparison was made between species. The analysis of variance was applied to data for DEN, VAR, VUB and DMI. Differences between provenances within trials were tested at the 5% level using the Q statistic as described by Chew (1976).

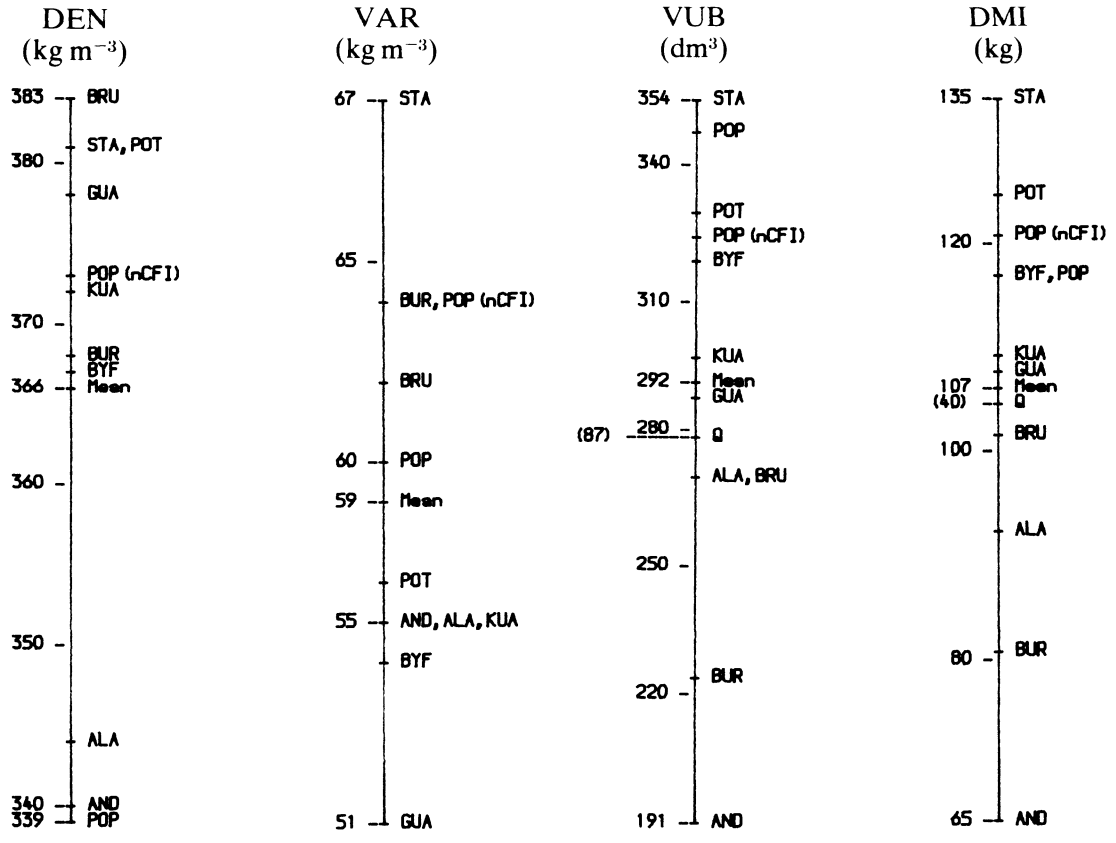
Results

The results of the analysis of variance are summarised in Figure 1 for *P. caribaea* and in Figure 2 for *P. oocarpa/P. patula* ssp. *tecunumanii*. Provenances were significantly different in the traits VUB and DMI for *P. caribaea* ($p<.001$) and also in DEN but for provenances of *P. oocarpa/P. patula* ssp. *tecunumanii* there were no statistically significant differences in any of the traits. The Q statistic exceeded the range for all four traits in *P. oocarpa/P. patula* ssp. *tecunumanii* and for DEN and VAR in *P. caribaea* and has not been presented for these traits.

Discussion

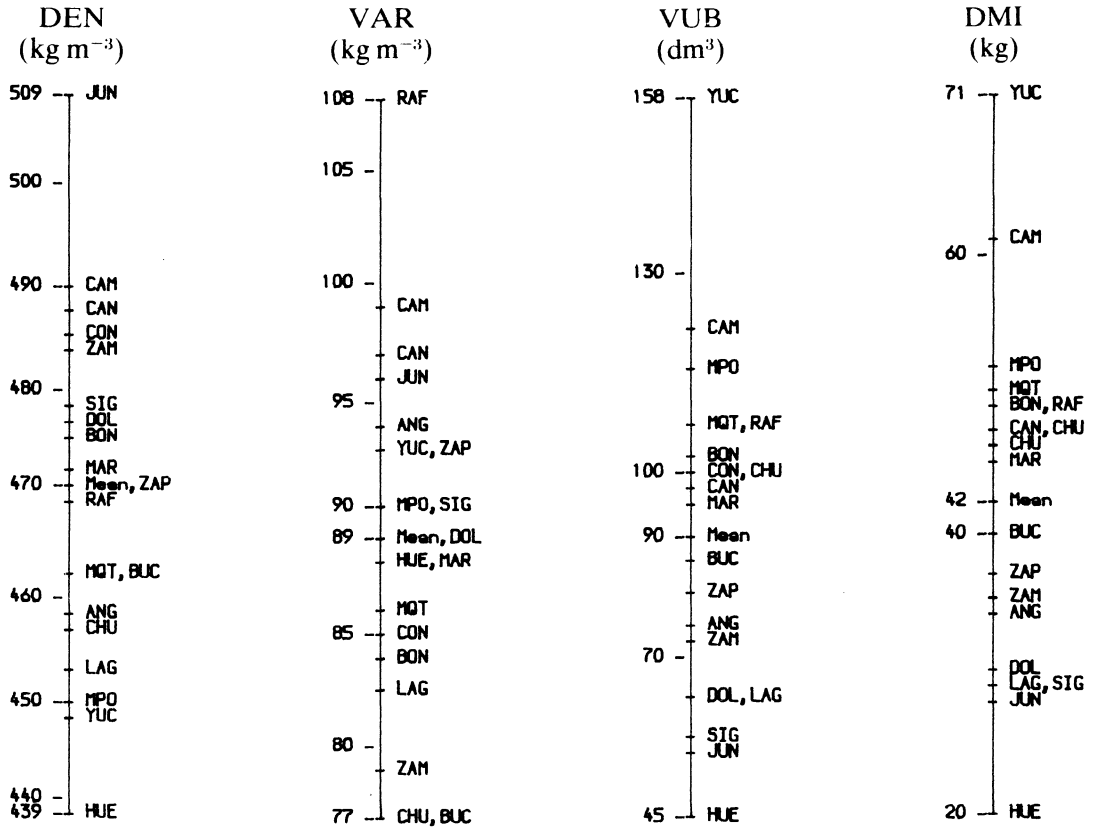
In *P. caribaea*, the provenances ALA, AND and POP had a much lower DEN than all others (Figure 1). It is interesting that ALA and AND also had lower VUB which makes it possible to say with confidence that the slowest growing provenances do not necessarily have the highest density. The same can be said for *P. oocarpa* (Figure 2) where the provenance HUE had both the lowest DEN and the lowest VUB. In *P. patula* ssp. *tecunumanii*, CAM ranked high in both DEN and VUB which enabled it almost to reach the DMI of YUC despite the latter's great superiority of VUB. In *P. caribaea*, STA ranked highest for VUB and was among the highest for DEN. Another interesting feature is the large difference in DEN between the two collections of the POP provenance. This indicates the importance of clear definitions of provenance in terms of specific area as well as numbers and identities of trees sampled. Although the statistical significance of the differences between provenances for VAR were low it is interesting that *P. caribaea* provenances STA and GUA had the highest and lowest values respectively, while their values for DEN were almost identical.

Decisions on specific provenances to be used in afforestation must be made after careful field evaluation. Use of the trait DMI must be evaluated in conjunction with mean density because density is itself an important economic trait and is included in many tree improvement programmes (Wilcox, 1978; Jett and Talbert, 1982). The



Source:	df	F ratio and p value			
Blocks	3	3.41($p<.05$)	1.33($p>.25$)	4.23($p<.001$)	1.00($p>.25$)
Provenances	10	2.52($p<.05$)	0.83($p>.25$)	8.29($p<.001$)	6.43($p<.001$)
s.e. Provenance		11.00	5.00	17.78	8.04

Figure 1. Analysis of variance and ranked means for densitometric density (DEN), within-sample variation (VAR), volume under bark (VUB) and dry matter index (DMI) of *P. caribaea* provenances at Chati.



Source:	df	F ratio and p value			
Blocks	1	.94(p>.25)	.51(p>.25)	.00(p>.25)	.01(p>.25)
Provenances	18	1.34(p>.25)	.93(p>.25)	1.37(p>.25)	1.30(p>.25)
s.e. Provenance		15.00	8.00	23.18	11.04

Figure 2. Analysis of variance and ranked means for densitometric density (DEN), within-sample variation (VAR), volume under bark (VUB) and dry matter index (DMI) of *P. oocarpa* and *P. patula* ssp. *tecunumanii* provenances at Ndola East.

density of the slowest growing provenance of *P. caribaea* was approximately 24% less than that of the fastest growing provenance of *P. patula* ssp. *tecunumanii*. Therefore, if density is an overriding factor, provenances of *P. patula* ssp. *tecunumanii* might be selected even though DMI values for that species are much lower than those for *P. caribaea*. Stem form and branching characteristics must also be taken into account before selecting provenances for further tree improvement work (Mikkola, 1979).

The lower densities in provenances of *P. caribaea* agree with the findings of Barnes *et al.* (1977). In that study, provenances of *P. caribaea* planted at lower altitudes in Zimbabwe (less than 1000 m) had significantly higher densities ($p<.05$) than the same provenances planted at higher altitudes (greater than 1000 m). The authors suggested that this increase in density at lower altitudes was due to increased moisture stress. The Zambian trials are both located at an altitude of 1300 m. If these trials had been located at a lower altitude or in areas of greater moisture stress it is possible the differences in densities between *P. caribaea* and *P. oocarpa* would not have been as great.

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REFERENCES

BARNES, R. D., GIBSON, G. L. and BARDEY, M. A. (1983). Variation and genotype-environment interaction in international provenance trials of *Pinus caribaea* var. *hondurensis* and implications for population improvement strategy. *Silvicultura* **8**: 35–43.

BARNES, R. D., WOODEND, J. J., SCHWEPPENHAUSER, M. A. and MULLIN, L. J. (1977). Variation in diameter growth and wood density in six-year-old provenance trials of *Pinus caribaea* Morelet on five sites in Rhodesia. *Silvae Genetica* **26**: 163–167.

CHEW, V. (1976). Comparing treatment means: A compendium. *Horticultural Science* **11**: 348–357.

GIBSON, G. L. (1982). Genotype-environment interaction in *Pinus caribaea*. Unit of Tropical Silviculture, Interim Report, Commonwealth Forestry Institute, Oxford, 112 p.

GIBSON, G. L., BARNES, R. D. and BERRINGTON, J. S. (1983). Provenance productivity in *Pinus caribaea* and its interaction with environment. *Commonwealth Forestry Review* **62**: 93–106.

GREAVES, A. (1978). Descriptions of seed sources and collections for provenances of *Pinus caribaea*. *Tropical Forestry Papers* No. 12, Commonwealth Forestry Institute, Oxford, 89 p.

GREAVES, A. (1979). Descriptions of seed sources and collections for provenances of *Pinus oocarpa*. *Tropical Forestry Papers* No. 13, Commonwealth Forestry Institute, Oxford, 144 p.

HUGHES, J. F. and SARDINHA, R. M. (1975). The application of optical densitometry in the study of wood structure and properties. *Journal of Microscopy* **104**: 91–103.

JETT, J. B. and TALBERT, J. T. (1982). Place of wood specific gravity in the development of advanced-generation seed orchards and breeding programs. *Southern Journal of Applied Forestry* **6**: 177–180.

KANOWSKI, P. J. (1985). Densitometric analysis of a large number of wood samples. *Journal of the Institute of Wood Science* **10**: 145–151

McCARTER, P. S. and BIRKS, J. S. (1985). *Pinus patula* subspecies *tecunumanii*: The application of numerical techniques to some problems of its taxonomy. *Commonwealth Forestry Review* **64**: 117–132.

MIKKOLA, L. (1979). The analysis of a *Pinus caribaea* Morelet provenance trial at the age of nine years in Zambia. Research Note, Division of Forest Research, Kitwe, Zambia, No. **20**, 15 p.

WILCOX, M. D. (1978). Some problems in selecting to improve wood properties. In: 'Progress and problems of genetic improvement of tropical forest trees'. Brisbane, Australia, 4–7 April 1977, Eds. D. G. Nikles, J. Burley, and R. D. Barnes. 213–225.