TROPICAL FORESTRY PAPERS. No. 7

(Formerly 'Fast Growing Timber Trees of the Lowland Tropics')

PINUS PATULA

Compiled by T.J. WORMALD

DEPARTMENT OF FORESTRY
COMMONWEALTH FORESTRY INSTITUTE
UNIVERSITY OF OXFORD
1975

ERRATA

Pinus patula by T.J. Wormald, CFI

Page

xi Title of table 2.222 should read 'Silvicultural Divisions in South Africa'
Title of figure 2 should read 'Climadiagrams'
Appendix III, table 5.118: for 'overbark' read 'underbark'
Appendix IV, table 5.33: for 'Viphya plateau' read 'Group A forests, Malawi'

5 Para. 1.221, line 8: delete 'annual'

6 Para. 1.3, line 6: for 'facing page' read 'Appendix IV'

8 Para. 2.1: for 'Coztzec' read 'Coetzee'

10 Table 2.221: insert 'Rupere' over 2nd column and 'Metetfa' over 3rd column

21 Table 2.513.31, columns 10 and 11 should be headed *Cupressus lusitanica*'

29 Para. 3.513, line 2: for 'Barrett (1973)' read 'Barrett (1972)'

62 Para. 3.46, lines 5 and 6 should read: "Kenya. The Usutu Pulp Company recommended blanking only in the current season. The use ....."

67 Para. 3.512.1, line 6: for 'figures' read 'tables'

69 Table 3.521.21, columns 3 and 7: should be headed '$\bar{h}_p$ **'

75 Table 3.526.1, column 4: should be headed '$\bar{h}_p$ **'
, bottom line: for 'crown diameter' read 'crown depth'

89 Para. 4.312, last sentence should read: 'although some barkbeetles (Scolytidae) are known to attack *P. patula*, they do not constitute a threat to healthy plantations at present.'
Para. 4.31211, line 15: for '*Gonocephalua*' read '*Gonocephalum*'

90 Para. 4.31212, last sentence should read: 'In Columbia, *Saissetia* spp. (Coccidae) infest the needles of young *P. patula*, but have not caused appreciable damage as yet (Bustillo and Lara, 1971).'

96 Para. 4.31225, line 12: for 'leci' read 'leei'

97 Line 6: for 'sp.' read 'spp.'
Line 8: for 'spp.' read 'sp.'

98 Para. 4.314, line 7: for '*sexeseni*' read '*saxeseni*'

100 Table 4.3151, line 5: for '*Agratis*' read '*Agrotis*'
, line 14: for '*Melampsala*' read '*Melampsalta*'

108 Para. 5.13: formula should read: '$V = 4.835 + 0.3936\ GH_{dom}$'

132 Table 7.221: area of plantations for Tanzania should read '1500 ha'

134 Para. 7.322, line 5: for '6.323' read '7.323'

138 Table 7.472, line 10: for 'sectorial' read 'sectional'

143 Para. 8.1, line 9: for 'dimension' read 'discussion'

144 Fourth para. line 4: delete second bracket, add '3.510.2, Appendix 2).'

157 Insert 'Descamps, M. (1971-72), personal communications' above 'Devillé, F.'

163 For 'Kramwinkel' read 'Kraamwinkel'

165 Eighth reference: for '*levinae*' read '*lewinae*'

167 Seventh reference: for 'H.G.' read 'H.C.'

171 Fifth reference: for 'torsion' read 'tension'

Appendix III. Table 5.117: formula should read:
$V = -0.00041 - 0.0000571DD + 0.0001352DH + 0.00003313DDH$

Appendix III. Table 5.132: formula should read:
$V = 20.764 - 1.269G - 1.3601H + 0.462275GH$

Appendix V. Table 6.211.1: side hardness for Angola should read: '11.49'

Plates. Plate 12f caption, last line: for 'figure 3.512.11' read 'figure 6.214 (Appendix V)'

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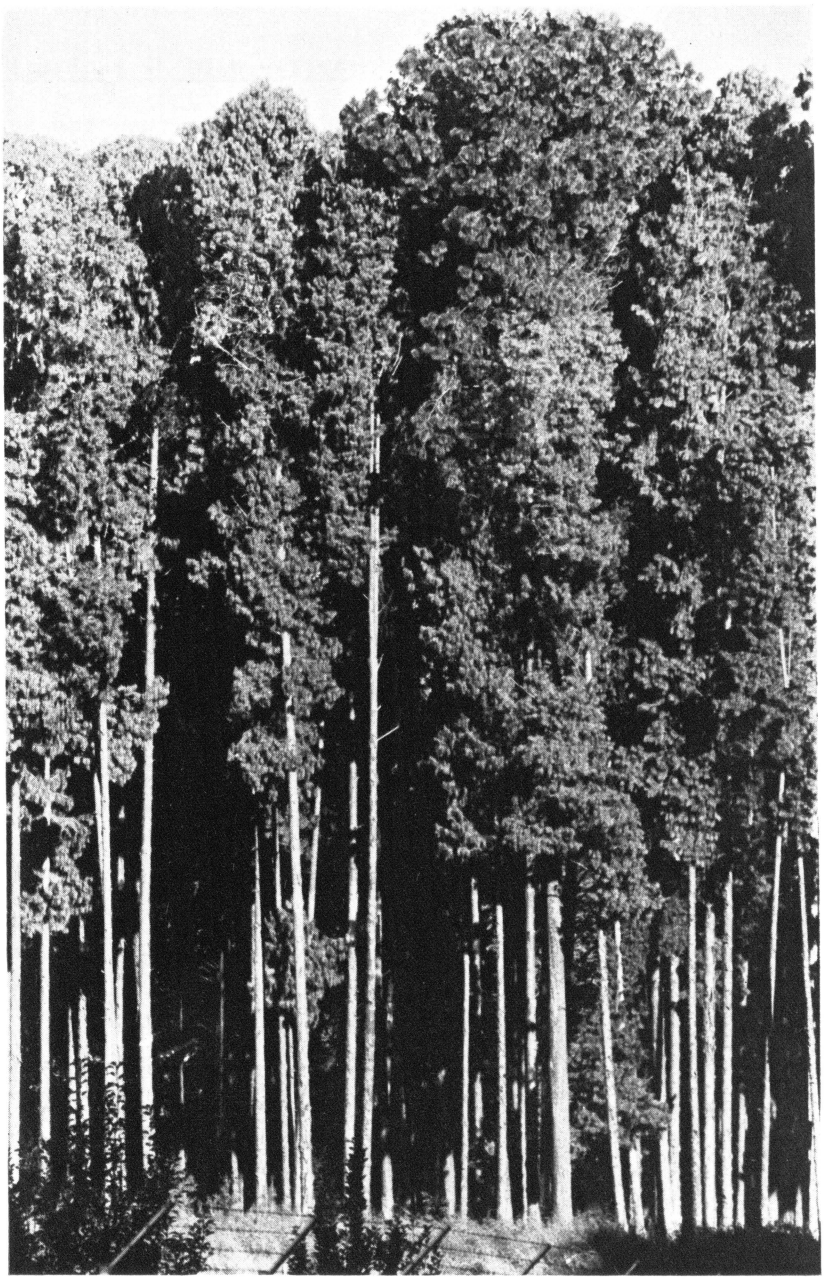

Frontispiece

Fifty-two year old *Pinus patula* on Rhodes Inyanga estate. The seed from which these trees were raised was imported direct from Mexico. Some trees are nearly 50 m high.

Photo: R.D. Barnes 1973

FAST GROWING TIMBER TREES OF THE LOWLAND TROPICS

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Foreword

by Professor J.L. Harley, F.R.S.

Since the series "Fast Growing Timber Trees of the Lowland Tropics" started, the scope of our publications on tropical forestry has widened considerably, and the opportunity is now being taken to re-name the series, "Tropical Forestry Papers". The Institute's species monographs will continue to be published in this series, but it is also intended to make available our work on other aspects of tropical forestry, for instance the Manual on Species and Provenance Research which is already in preparation.

Pinus patula has now been planted as a commercial crop on a large scale in Africa for over thirty-five years. Its importance has been recognised by the publication in 1973, of an annotated bibliography by FAO, Rome. The Commonwealth Forestry Institute undertook the preparation of the present monograph to complement this bibliography, and it now becomes No. 7 of "Tropical Forestry Papers".

The Ministry of Overseas Development provided a grant to be spent over twelve months which enabled Mr. T.J. Wormald to be attached to the Commonwealth Forestry Institute while preparing this monograph. During that time he made visits to eastern and southern Africa, and though he was not able to visit Mexico, he received assistance from Dr. B.T. Styles and Dr. W.G. Dyson, both of whom had experience of the species in its natural habitat. Their valuable contributions and those of Dr. I.A.S. Gibson (Diseases), Mr. R.F. Lee (Insect pests), and Mr. R.A. Plumptre (Wood properties), have made the monograph more comprehensive.

It is hoped that through the publication of this work those who have little experience in growing P. patula may be prevented from repeating past mistakes, and those who are experienced in growing it are helped in solving other problems in the culture of this most important species.

J.L. Harley
Professor of Forest Science

Acknowledgements

Advice and criticism from colleagues in the Commonwealth Forestry Institute has been of great value and a particular debt of gratitude is owed to Dr. J. Burley and Dr. R.G. Pawsey and to Messrs. P.G. Adlard, R.H. Kemp, P.J. Wood and H.L. Wright. The typing of the manuscript could not have been completed without the willing and efficient services of Mrs. P.R. Taylor, Miss C.D. Oliver and Miss S.J. Stiff. Mr. H.F. Woodward helped with the arrangement of the plates. Foresters in many countries have been most helpful in answering queries and in making their data available to me; their contributions have been acknowledged in the text.

Particular mention might be made of the New Zealand and Queensland Forest Departments who, despite the fact that the species is of little importance to their countries, were at pains to provide comprehensive reports. On my visits to Africa I received help and information from many foresters, but it would not be invidious to single out for particular thanks Dr. R.D. Barnes, Dr. W.G. Dyson and Mr. J.B. Ball not only for their kindness and hospitality but also for their careful and searching criticism of parts of the text.

T. J. Wormald

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List of plates

1.0 Description of the species, nomenclature, variation and natural distribution

1.1 Taxonomy (by B.T. Styles)

1.11 Botanical nomenclature

Family - Pinaceae

Genus - Pinus (Shaw, 1914; Mirov, 1967; Little and Critchfield, 1969)

1.111 Latin name : Pinus patula Schiede & Deppe in Schlecht. & Cham., Linnaea 6 : 354 (1831)

1.112 Local names

Mexican weeping pine Spreading-leaved pine 'patula' pine	English speaking countries
'pino patula' 'pino chino'	Mexico and Spanish America

1.113 Classification

This species is now placed by Little and Critchfield (1969) in the section Pinus subsection Oocarpae, a classification which has replaced that of Shaw (1914) who included it in his large group Insignes. The subsection Oocarpae includes, besides P. patula, 6 other New World pines. P. radiata Don, P. attenuata Lemm. and P. muricata Don occur in North America (mainly West Coast region and Lower California); P. greggii Engelm. ex Parl. and P. pringlei Shaw are confined to Mexico whilst P. oocarpa Schiede is distributed from Mexico throughout Central America to Northern Nicaragua.

The subsection is characterised by the species having leaves mostly 3 per fascicle, but varying between 2 and 5; the hypodermis consists of cells of 2 different shapes, with resin ducts mostly medial, more rarely internal or septal. Spring shoots are either multinodal, with 2 or more whorls of branches, or uninodal with one whorl only. Cones are mostly oblique, long-persistent on the tree with the scales opening irregularly to release the seeds; the scales have a prickle or protuberance.

1.12 Botanical description

A graceful tree usually 20-30 m, more rarely 30-40 m tall. Bole usually straight and cylindrical, sometimes forked producing two or more stems. Lateral branches whorled, more or less horizontal, sometimes tending to arch upwards; the secondary branchlets pendulous. Bark on the upper bole and branches reddish, becoming scaly, rough and deeply fissured on older trees. Young shoots with several nodes, glabrous; glaucous-green becoming reddish-brown. Bark of branchlets often with a purplish bloom. Buds cylindrical, acute c. 1-2.5 cm long,

with lanceolate, long-pointed, fringed, spreading scales; usually reddish-brown or yellowish, lacking resin.

Leaf-sheaths persistent, reddish-grey; 1.0-1.5 cm long. Leaves persisting for 2-4 years, in fascicles of 3 or 4, rarely 2 or 5; from 15-30 cm long, usually c. 20 cm; yellowish to dark green in colour, slender, pendulous or spreading, often hanging in two distinct rows along the branchlets; margins of leaves serrulate; stomata present on all 3 surfaces; resin ducts 1-5, normally 2-3, position variable; either all medial or sometimes with 1 or 2 internal or external and septal.

Conelets purplish, mainly lateral, pedunculate, borne singly or in small cuusters and up to 8, scales with a small deciduous prickle. Male cones yellow, borne in subterminal aggregated whorls, appearing with the new leaves.

Mature cones long-persistent on the tree, borne in groups of 3-6; very variable in size and shape, from 4-12 cm long x 2.5-4 cm broad; usually conical or narrowly conical, reflexed, asymmetrical and curved, pale glossy grey or brown. Peduncle absent or up to 1.5 cm long. Scales hard c. 2 cm long x 1 cm broad, slightly reflexed; apophysis rhomboidal, flattish, slightly protuberant, umbo blackish, slightly raised or flattended; prickle deciduous.

Seed small, 3-5 mm long, brownish black. Wing c. 1 cm long, brown with blackish lines, thickened at the seed end.

Most closely related to P. greggii with which it readily hybridizes. This species has shorter (7-10 cm long), erect, leaves and the bark of the upper bole and branches is greyish and smooth. The cones of P. pringlei are similar to those of P. patula, but they are more broadly ovoid than conical. Fresh cones are also a light shade of brown and are normally pedunculate. They are less tenaciously persistent on the tree as compared with the latter species. The cones of P. teocote often tend to be ovoid-conical and appear similar to those of P. patula. They are however early deciduous. The leaves, although generally in groups of 3 per fascicle, are very stiff, leathery and more or less erect.

1.13 Variation

Because of its restricted distribution and limited variation the species does not present any real taxonomic problems, although it is sometimes difficult to distinguish it from some forms of related species. Barrett (1972) studied the variation pattern of the important taxonomic characters over almost the entire range and concluded that no infra-specific taxa can be recognised, although some characters do show marked clinal variation.

Loock in Martínez (1948) described a new variety (longipedunculata) to account for certain populations occurring in Oaxaca State which have pedunculate rather than sessile cones and which are smaller than the type. This variety has since been shown to be of little taxonomic

worth (Barrett, 1972, Styles, pers.comm.) Trees in the type locality have now been discovered with both sessile and pedunculate cones with a continuum of intermediate types; both types can even occur on a single individual tree. Furthermore Barrett has shown that trees with pedunculate cones occur sporadically throughout the whole range of the species. The other characters allegedly correlated with the presence or absence of a peduncle also show similar continuous variation.

Disjunct populations of a pine occurring in the State of Chiapas which have been named P. oocarpa var. ochoterenai by Martínez (1940) may in fact belong to P. patula. Critchfield and Little (1966) support this view, and Styles (ined.), who has recently studied these trees in situ, states that they strongly resemble this species in habit and general morphology. The slender pendulous leaves, rough red bark of the upper bole and conical pedunculate cones are all characters diagnostic of P. patula. Further studies on leaf anatomy and analyses of the chromosome karyotype are in progress to elucidate relationships.

A variegated form of the species which appeared in a nursery in the Province of Buenos Aires, Argentina has been named P. patula var. zebrina, Milano (1948). It may prove of some horticultural interest through vegetative reproduction and has been registered under the cultivar name 'Zebrina' (Harrison, 1966).

Two other varieties, P. patula var. macrocarpa Masters and P. patula var. stricta Benth. are now referred to P. greggii Engelm.

1.14 Synonymy

The full nomenclatural details are as follows:-

Pinus patula Schiede and Deppe in Schlecht. & Cham., Linnaea 6:354 (1831).

Synonyms

Pinus subpatula Roezl ex Gord. Pinetum, Suppl. 84 (1862).

? P. oocarpa var. ochoterenai Martinez, in Anal. Inst. Biol. Mex. 9(1): 65 (1940).

Pinus patula var. longipedunculata (longepedunculata) Loock ex Martínez, Los Pinos Mexicanos: 333 (1948).

Pinus patula var. zebrina Milano in Lilloa 17: 146 (1949). This is now known as P. patula cv. 'Zebrina'.

1.2 Appearance and growth periodicity

1.21 Appearance

1.211 Height

P. patula grows to a height of 30 m or more in Mexico and obtains diameters up to 1.2 m (Loock, 1950). For three trees, from

Vivorillas in Vera Cruz, on which he made ring counts he gave the following data:-

Age	Height	Diameter overbark
60	21 m	48 cm
75	27 m	56 cm
81	23 m	66 cm

At the age of thirty years diameter ranged from about 25 cm to 45 cm. At Inyanga in Rhodesia a small stand planted in 1921 was nearly 50 m high at fifty one years of age in 1972 (Barnes, 1974) (See frontispiece). Poynton (1974) claimed that the tallest tree in South Africa was 45 m high and grows at Woodbush; it would be rather older than the Rhodesian stand. In Kenya trees on permanent sample plots on the north-eastern Aberdares had attained a dominant height of nearly 35 m in less than twenty years.

1.212 Stem form

The form of the tree is moderate to good. The best trees have straight cylindrical stems and retain apical dominance to an age of thirty years or more. Defects include excessive forking, which is sometimes caused by mechanical damage (see 4.15 and 4.323), but which is also under genetic control, crooked stems, sweep, bow and sinuosity, and nodal swelling (see plate 5).

1.213 Branching

Loock (1950) stated that in Mexico branches were irregularly placed in the stem, but in exotic plantations they are borne in very regular whorls. Usually there are four branches to the whorl, but whorls with as many as eight branches may occur. The distance between whorls is variable, some trees tend towards the production of a single internode each year (uninodal growth); Paterson (1967) noted internodes of up to 3 m in length. Foxtailing occasionally occurs. But the majority of stems are multinodal with short distances between whorls; Paterson found a mean internode length of 0.4 m on his samples of 18 twenty year old trees.

Branches on young trees in exotic plantations are commonly borne at an angle above the horizontal. Loock (1950) stated that in Mexico branches were pendent, but this is not the case in Africa. Paterson (1967) measured a mean branch angle of 21.5°, but noted that the angle tended to increase to about 30° towards the top. He instanced one exceptional tree with a mean branch angle of 55° to the horizontal.

1.214 Crown

Open grown trees tend to be spreading, but when grown at close spacing the lower branches are quickly suppressed and crowns are relatively narrow (see plate 10). However there is much variation both in open and close grown stands. Trees with a high branching angle tend to lose apical dominance and to become round-headed. This

phenomenon also occurs when the tree is grown out of its climatic range particularly at low altitudes and therefore in hotter climates.

1.215 Bark

Young bark is characteristically a reddish orange colour and is scaly. The mature bark is grey brown and vertically ridged. The age at which mature bark is produced is variable and appears to be unrelated to dominance and only loosely correlated with age and size of the tree. Small sub-dominants with a long section of mature bark can be found adjacent to large dominants with very little mature bark. Some trees develop an almost completely smooth bark (see plate 5); this type of bark appears to be more common at low altitudes and on drier sites. The origin of the rough-barked form is discussed in Section 2.

1.216 General

The crown may be rounded or spirelike but the light green vertically hanging needles borne on pendent secondary branches and the reddish young bark distinguish P. patula everywhere as a graceful, attractive tree.

1.22 Growth periodicity

1.221 Terminal growth

Norskov-Lauritsen (1963) noted that in the Transvaal on a two to three year old tree terminal extension of the leader and of the main branches occurred in up to eight flushes throughout the year. Growth never entirely ceased even in July and August, which are the coldest months. However on a twenty-five year old tree only one annual flush of growth occurred and for eight or more months in the year terminal extension was negligible. The young tree produced up to six annual internodes in a year. Two or more internodes could elongate simultaneously, this was particularly apparent in older trees in which the nodes were often defined by female strobili. If these flower bearing multinodal shoots are considered to be effectively one internode, growth in the older tree was uninodal. Simultaneous elongation of two internodes also took place in the young trees. Drew (1969) in a phenological study of P. patula on the Viphya plateau in Malawi found that terminal growth ceased in December but that diameter growth continued until February. The rains there last from November to April.

1.222 Flowering

In the northern part of its range in Mexico, flowering, as judged by the period when pollen is ripe, lasts from January to April; in Oaxaca the season is more limited - January to February. The flowering season on any one site will be much shorter than the four months quoted for the whole of the northern part of the range, but the variation in flowering time between individuals is large in natural stands and the season is likely to be longer in Mexico than in plantations in Africa.

Drew (1969) noted that the flush of flowers, both male and female, occurred in September. He associated this with a rise in air temperature starting in August. The writer noted the occurrence of female flowers on P. patula on the Viphya plateau as early as May, but saw little sign of male flowers. Barnes and Mullin (1974) found that male flower production in Rhodesia was almost entirely confined to the spring flush in September and early October but that, though this was the season for the main flush of female flowers, a subsiduary flush of female flowers occurred earlier in the year. Dyson and Paterson (1966) noted that in Kenya two flushes of flowers occurred coinciding with the rain (April/May main flush; October/November, secondary flush), while the female flowers were produced throughout the year. Barnes and Mullin (1974) considered that the synchronisation of male and female flowering was good at altitudes of 1500 m and above, but that at lower altitudes male flowering become progressively later and synchronisation was poor. They also considered that good spring rains followed by a hot dry late summer were conducive to a good crop of flowers. In Queensland the flower flush also occurs in September and it is thought that the primordia are laid down in the previous autumn (April). (Queensland, 1974).

1.3 Occurrence in Mexico

Barrett (1972) recorded P. patula (including the alleged variety longipedunculata) as growing from about 18°N in Oaxaca northwards as far as 24°N in Tamaulipas (see map facing page). The sites favoured by the species are the eastern slopes of the Sierra Madre Oriental with some outliers at the northern end of the range occurring on peaks further to the west. To the south the species spreads into the Sierra Madre del Sur. The main occurrence is in three blocks between Teotitlan in Oaxaca at 18°N to Molango in Hidalgo at 20° 50'N. Loock (1950) considered the main belt of P. patula to be even more restricted - from Honey at 20°N to Molango at 20° 50'N. the occurrence in Chiapas noted by Critchfield and Little (1966) was thought by Barrett more likely to be P. oocarpa, but the relationship of these species has not yet been fully clarified (see 1.13).

Barrett (1972) made a detailed study of the morphology of P. patula in its natural range. He found that all cones in the southern part of the range (Oaxaca) had peduncles, but that in the north only some 25 percent had them. Fuller (1961) had previously noted the presence of pedunculate and sessile cones on one tree. Barrett also found that peduncles in the south were larger (about 12 mm) that in the north (3-8 mm). However he came to the conclusion that, though there were differences, the continuity of the variation from the pedunculate to the typical strain suggested that they were not discrete genetic entities.

In the centre of its range the species is found mainly in a zone described by Loock (1950) as warm temperate with more occasional occurrences in a cool temperate zone on some volcanic peaks. Loock gave the altitude range as 1850 m to 2750 m, but Barrett (1972) quoted an altitude of 1650 m at Sierra de Guatemala, the northern most outlier, and altitudes up to 3000 m at Concepcion in the south.

The eastern slopes of the Sierra Madre Oriental receive rain from the Gulf of Mexico, rainfall drops off markedly to the west. It is a summer rainfall zone with a relatively short winter dry season much ameliorated by mists. The annual rainfall varies from about 1000 m to 1500 m. Occasional frosts occur (Loock, 1950).

Loock described the soils as a loose, porous sandy loam of good depth and stated that P. patula reached its best development in ravines and on flats with deep, moist, well drained loamy soils which are somewhat sandy. On shallow and moisture deficient soils P. teocote replaced P. patula. Barrett described most of the soils on his sixteen collections sites as being deep sandy-clays.

P. patula is often found in pure dense stands, but the occurrence is discontinuous and now over much of its range it only grows in areas inaccessible to agriculture (Barrett, 1972). Throughout its range P. patula can be found associated with P. teocote; at El Madrono it is also associated with P. greggii, which is here near the southern end of its range. It is reported to have hybridised with these two species at El Madrono.

At Pinal de Amoles it is associated with P. rudis and at Sierra de Guatemala with P. montizumae. In the centre of its range associated pine species include P. leiophylla, on the moister sites, and P. pseudostrobus and P. michoacana. To the south besides P. pseudostrobus it is also found growing with P. lawsonii, P. ayacahuite and P. strobus var chiapensis. Of the other softwood species it associates with Taxus mexicana, Podocarpus reichei, Abies religiosa and Cupressus spp. The hardwood species found growing with P. patula vary from temperate species such as Fagus, Tilia, Cercis, Acer and Liquidambar in the north to subtropical species in the south. Quercus spp. are frequent associates and also Alnus spp.

The ranges of P. oocarpa and P. pringlei overlap that of P. patula both in the centre of its range and in Oaxaca (Critchfield and Little, 1966), but Barrett did not mention them as being associated with P. patula. These two species are usually found at lower altitudes than P. patula, however Loock (1950) stated that odd trees of P. pringlei have been found in P. patula stands in South Africa that had been raised from Mexican seed; this would indicate that the two species must mix on some sites in Mexico.

2 Pinus patula as an exotic

2.0 Introduction

P. patula was first introduced to South Africa from Mexico in 1907 (Poynton, 1961). Though there are records of earlier introductions to other countries - Adams (1915) mentioned a specimen planted near Canterbury in New Zealand raised from seed though to have been obtained from Australia in 1877 - the South African introduction marks the start of the wide scale use of P. patula as a plantation species. Even so it was not until the mid 1940s, in the period of expansion after the 1939-45 war, that the species was planted on a big scale. Then its fast growth, good silvicultural features and, above all, the easy availability of seed from South African sources made it an obvious choice for many countries in East, Central and Southern Africa. By 1970 the area under P. patula in Africa was 424 thousand hectares, of which 300 thousand had been planted in the previous fifteen years (see Table 2.501). In those countries in Africa that plant this species on a commercial scale the plantations of P. patula represented 50 percent of the total area planted to softwoods. Some 14 thousand hectares have also been established in New Zealand, Queensland, New South Wales, India, Sri Lanka, Argentina, Brazil, Ecuador and Colombia. But though there are indications of an increase in the area to be planted to P. patula in South America, it is the highland countries of Africa that have to date invested most in this species.

2.1 Provenance trials

Little has been done to identify the provenances of P. patula in Mexico. Loock (1950) made the first comprehensive collection of seed from a larger part of its range in 1947. Since then collections have been made in 1960 as a result of an F.A.O. seminar; in 1969 by Olesen (for Malawi) and Mortenson (for East Africa); also in 1969 by Coztzec and Fisk for South Africa; Barrett made a comprehensive collection for Argentina in 1971; the Instituto Nacional de Investigaciones Forestales of Mexico (I.N.I.F.), supported by F.A.O., has started to make a systematic collection of P. patula provenances which, it is to be hoped, will be tested by all countries interested in growing the species. Previous provenance collections either have been very incomplete, as in the case of the seed distributed to the participants of the 1960 F.A.O. Seminar, or else they have only been tested in one or two countries.

The majority of the plantations in Africa originate from plantations raised from seed of unknown provenance brought into South Africa between 1907 and about 1928. It has been suggested that many of the original exports of seed from Mexico may have been from the area of Las Vigas which is the most accessible P. patula site on the main road to the east coast of Mexico. But Poynton (1961) suggested that at least one importation, which produced the rough bark variety thought to approach P. greggii in form may have come from the state of Hidalgo which is well to the north and west of Las Vigas. Olesen (1972) considered that the seed sent to South Africa originated from Los Reyes, Hidalgo. However, more recently, as a result of a

morphological analysis of the trees of one of the stands producing the rough barked P. patula, it is thought that the seed may have originated from northern Oaxaca. Several of the trees of this stand bear a close resemblance to P. pringlei.

Nevertheless much of the P. patula growing in Africa is very uniform in appearance and it is reasonable to deduce that it may have originated from a restricted seed source. Because of this lack of variation it has been urged (Hodgson, 1963) that there is a pressing need for provenance trials. However, the general experience in Africa appears to be that "local" provenances are as good as or better than provenances introduced from Mexico or even from other African countries. Trials are young and these conclusions have been reached on the basis of measurements of juvenile characteristics. But it is possible that the P. patula provenance trials currently being run will tend to confirm the superiority of the local provenances.

Barnes (1974) has suggested that, though its natural distribution is discontinuous, its range is limited, and it is possible that a small seed collection can include wide genetic variation (see 7.11). There is also the possibility that in a new environment a species such as P. patula can express characteristics which have been suppressed in its narrow indigenous range and therefore there may be advantages in introducing a tree from a neighbouring country where it is also an exotic.

Whatever the genetic mechanism may have been, the introduction of P. patula through South Africa has, without any attempt at searching out the most suitable provenance, resulted in the successful adaptation of this species to a wide geographic area.

2.2 Sites favoured for P. patula

Zobel (1972) has pointed out that the success of P. patula as an exotic, like that of P. radiata, could hardly be predicted from a study of conditions in its very limited range. Nevertheless it is now growing on suitable sites from the equator to 31° south in Africa and as far as 42° from the equator in New Zealand.

2.21 Rainfall

Loock (1950) reported that in the southern part of the P. patula range in Oaxaca rainfall may be as low as 500 mm a year, but over most of its natural range the rainfall is from 1000 to 2000 mm. In its natural range it is in a summer rainfall zone - 90 percent of the rain falling between May and October. In South Africa it thrives in the summer rainfall area of the Transvaal, Orange Tree State, Natal and down to the Transkei. However in East Africa it thrives in the monsoonal two peak rainfall climate in which the majority of the rain falls in the relatively cooler season (see climadiagrams - figure 2). Indeed in East Africa as in New Zealand it grows alongside P. radiata, a winter rainfall species.

It appears to do well on most summer rainfall sites with a rainfall over about 750 mm a year. But the rainfall distribution, that is the length and severity of the dry season, is important. At Turbo in Kenya, even though the rainfall is about 1250 mm a year, P. patula fails on shallow soils because of water stress in a long dry season.

2.22 Temperature

P. patula can be grown successfully at latitudes as high as 40° (in New Zealand), but it is probable that it is the low mean temperatures that retard its growth outside the tropics and sub-tropics. It can withstand temperatures as low as -10°C provided it is in a dormant state (Golfari, 1970) and light frosts even when it is growing actively do not harm it. A young plant has survived the mild 1973/74 winter in the writer's garden in Eastern England and is healthy. Within the area of its main occurrence, below 30° of latitude from the equator, other than on the higher slopes of the Andes and of the Drakensbergs, there are few sites where low temperature is the main limiting factor.

Little in the way of detailed information has been published on the temperatures of sites favoured by *P. patula*. Most often the limits of *P. patula* sites are defined by altitude and temperatures must be inferred from the altitude. Marsh (1972) has given information on the climatic conditions considered suitable for *P. patula* in South Africa (see Table 2.222). At Sabie the mean maximum temperature of the hottest month is 26.5°C; this is one of the main *P. patula* growing areas of the Eastern Transvaal, but there is some tendency for the crowns to become rounded. Barnes (1974) has pointed out that whereas the species thrives at Rupere in Rhodesia, it grows very poorly at Mutetfa. A comparison of site statistics indicates that rainfall at Mutetfa should be adequate and and that the major difference is the temperature of the sites.

2.221 Table. Climatic conditions at two Rhodesian Forest Stations

Altitude		1825 m	914 m
Rainfall		1750 mm	1270 mm
Number of rainy days		132 days	110 days
Temperatures			
Mean monthly maximum	highest	22.8°C (Nov)	28.9°C (Jan)
	lowest	15.6°C (June)	20.8°C (June)
Mean monthly minimum	highest	13.9°C (Dec	18.3°C (Dec)
	lowest	7.8°C (June)	11.7°C (June)

It is possible that a mean monthly maximum of 29°C may be unacceptably high. Barnes considered that in Rhodesia (approximately 20° S latitude) 1650 m was about the optimum altitude of *P. patula*.

Evans (1974) found that the optimum altitude in the Usutu plantations in Swaziland was 1250 m with a sharp decline in growth below 1000 m.

Ochieng (1969a) considered that height growth increased with increasing temperature in Kenya. He produced data which indicated that maximum height increment occurred at about 2000 m altitude. At that altitude the mean maximum temperature of the hottest month (February) is about 26°C. He also stated that *P. patula* grows very well at Kakamega at an altitude of 1675 m and with a February mean maximum temperature of about 28°C (Ochieng, pers. comm.). However, there are indications that though the early growth on low altitude warm sites is faster, height increment culminates much earlier than on the higher cooler sites (Marshall and Foot, 1969). This observation in Malawi has been confirmed in Swaziland.

2.24 Soils

P. patula grows on a wide range of soils. In the highlands of East Africa it does well on young fertile volcanic soils; on other sites in East and South Africa it has thrived on mature leached infertile soils derived from the basement complex. The fertility of the soil appears not to be of great importance, though Barnes (1974) recorded better growth on doleritic soils than on soils derived from schist, but whether this was attributable to greater fertility is not clear. Van Goor (1966) noted that P. patula together with P. kesiya was more efficient at taking up Nitrogen, Phosphorus and Boron than were P. elliottii and P. caribaea. The effects of Boron deficiency noted in Tanzania are discussed in section 4. At Sao Hill in southern Tanzania the soils are derived from the basement complex and growth is less good than on neighbouring sites, such as Kiwira, where the soil is derived from volcanic rocks. However the Sao Hill plantations were established on old farmland and the growth difference may be more related to grass competition.

The common feature of the soils on site favoured by P. patula are that they are acid, and that they have a good moisture supply. Deep soils which remain moist throughout the dry season favour P. patula. Pereira (1952 and 1955) found that on deep loam soils in Kenya P. patula could draw on all the moisture from the first 4.3 m of soil.

But it is rooting depth, rather than soil depth, that is important. At Bugamba in south-west Uganda P. patula grows on 15 cm of soil but it can send roots down through fissures in the rock; at Turbo, in Kenya, it can grow quite satisfactorily in shallow soils over a laterite pan, providing, as happens with some soft laterite, it can penetrate the pan.

2.25 Summary

The limits of the P. patula range are defined by three factors

1. Soil moisture availability
2. Soil acidity
3. A third factor though to be related to the maximum temperature

The critical level of soil moisture appears to be fairly high for successful growth. The measurement of soil moisture availability and stress is not easy on a large scale. Climatic classifications which quantify the periods of water deficit are helpful in arriving at an understanding of the stresses under which a crop is growing. The Penman method is considered to give a good approximation of evapotranspiration, but the measurements needed to apply this method are not read at many forest weather stations (Theron, 1973). Poynton (1971) in constructing his silvicultural map of South Africa used the Thornthwaite system which is easier to apply but which gives a rather less satisfactory interpretation in tropical countries. In appendix I some climadiagrams, devised by Walther and Lieth (1967), have been reproduced for areas in which P. patula is grown.

2.3 Alternative species

It is worthwhile to give some consideration to other species that can be grown on sites which are being planted to P. patula. On

some of these sites it is now being recognised that P. patula is not the most suitable species.

On hot dry sites at the lower altitudinal limit of the P. patula range P. oocarpa and P. kesiya are better able to withstand moisture stress. It has also been suggested that P. pseudostrobus and P. michoacana may do well on these sites. All these species require careful provenance selection and tree breeding work to obtain stands of acceptable form.

On the hotter but wet sites P. caribaea and P. elliottii will out perform P. patula. It is sometimes claimed that P. elliottii is also a more suitable species for planting on dry sites, but there is no evidence that it is more drought hardy than P. patula and some evidence that it is not (Poynton, 1966).

Within the region in which P. patula will normally grow satisfactorily there are large zones where it is severely affected by hail and subsequent attack by Diplodea pinea (see Chapter 4). P. elliottii and P. taeda are both virtually unaffected by D. pinea and are to a large extent replacing P. patula in the hail belt of Southern Africa. P. elliottii is possibly less demanding than P. patula and grows adequately on poorer soils, but P. taeda is more demanding. It is generally considered that early growth of these two species is slower than for P. patula, but that by the age of thirty the yield may be as good or, in the case of P. taeda, better.

Other softwood species that compete with P. patula for consideration are P. radiata and Cupressus lusitanica. P. radiata has not been planted for many years in the summer rainfall region of southern Africa because of its susceptibility to D. pinea, but until recently, when it became infected with Dothistroma pini, it was planted extensively in Kenya and Tanzania. It is more drought resistant and on comparable sites could yield up to 30 percent more than P. patula. (See figure 2.31. Appendix I for a comparison of P. patula, P. radiata and C. lusitanica height growth). Because of of D. pini it has only been planted on a very reduced scale in East Africa since 1965, but in New Zealand it is so valued for its rate of growth and quality of timber that an extensive programme to control D. pini is undertaken in preference to planting P. patula, the next best species. It is possible that P. radiata may once again be planted on a larger scale in East Africa. Barnes (1970) has suggested the possibility of planting P. radiata again in Rhodesia. C. lusitanica is widely planted in East Africa, but hardly at all in southern Africa, except in Angola. It is very sensitive to grass competition when young but otherwise will grow on the same sites as P. patula. The yield of the genetically improved strains now being produced in East Africa is probably as good as P. patula and the timber is considered to be superior for structural purposes, but not for pulp.

Of the hardwoods the most likely species to be planted as an alternative to P. patula are Eucalyptus spp. and E. grandis in particular. As an example of the relative popularity of the two; in 1971 in the East Transvaal the area of E. grandis in private ownership was 60,300 hectares as against 53,500 hectares of P. patula. The attraction of E. grandis is that yields are high and returns over a ten year rotation, are quick. Initial establishment of E. grandis is not as easy as for P. patula because

of its sensitivity to grass competition, but it can regenerate by coppice. If there is a market for poles or pulp E. grandis may well appear a more rewarding tree crop to grow. In Kenya however, when the railway authority changed from wood to oil burning engines, large areas of Eucalyptus plantations which had been established to provide fuel for the railway became redundant, were felled and planted to conifers including P. patula.

2.4 Fertility problems in the second rotation

Some concern has been expressed that repeated cropping with exotic conifers, and in particular P. patula in Swaziland, will lower the fertility of the site. Available evidence suggests that this is not happening in Swaziland. In fact it appears that initial growth of the second rotation is better than for the first, and that this lead is maintained up to the age of ten years. (Evans 1971 and 1973). Robinson et al. (1966) and Robinson (1967) could find no evidence of physical change under a crop of C. lusitanica but some evidence that fertility does deteriorate as a result of cropping maize, potatoes, and beans under the shamba system. The subsequent tree crop whether a hardwood (Eucalyptus spp. or Vitex keniensis) or a conifer quite possibly improved the site fertility.

A chemical analysis of nineteen year old trees from the Usutu plantations has recently been made and is given in table 2.41: Appendix I.

2.5 Performance of P. patula in various countries

For a statement of areas planted to P. patula refer to table 2.501.

2.51 Africa

2.511 Southern Africa

2.511.1 South Africa

P. patula was first introduced to South Africa from Mexico in 1907 (Poynton, 1961). This was followed by further introduction also from Mexico up till 1928, when all seed was supplied from local sources which had started to become productive in the early 1920s. By 1972 the area of P. patula plantations was 235 thousand hectares which represented 47 percent of the total area planted to all softwoods; 62 percent of the P. patula area was in private ownership (as a contrast only 29 percent of the other pine and softwood species were in private ownership). These statistics give some indication of the relative ease of establishment and profitability of P. patula in South Africa.

These plantations are chiefly in the East Transvaal (37% of all P. patula plantations) South Transvaal (17%), Transkei (13%) and the Natal Midlands (11%). The sites are usually grasslands of the middle veld (see 3.413), where establishment is easier, though some of the publicly-owned plantations have been established in scrub at

2.501 Table. Areas (in 100 ha) under P. patula by age classes

(Figures in brackets give the area of P. patula as a percentage of all softwood planting)

Country	Pre 1935	1936/40	1941/45	1946/50	1951/55	1956/60	1961/65	1966/70	Total to 1970	
South Africa	32	39	57	246	411	486	410	555	2236	South African Department of Forestry - Report on commercial timber plantations 1971/72)
	(12)	(24)	(36)	(55)	(55)	(59)	(43)	(48)	(47)	
Swaziland				58	200	61	92	96	507	
				(82)	(89)	(63)	(82)	(81)	(81)	
Rhodesia			2	12	56	123	123	45	361	(Barnes, pers. comm.)
			(86)	(81)	(77)	(74)	(79)	(63)	(74)	
Angola						4	22	83	100	(I.I.A.A., 1973)
									(60)	
Madagascar		2	1		34	93	62	98	290	(Deville, 1973)
									(60)	
Malawi				4	21	38	40	156	259	(Foot, 1967)
				(73)	(85)	(77)	(52)	(94)	(79)	(May, pers. comm.)
Kenya				2	24	53	64	174	317	(Choate, 1969)
				(2)	(24)	(38)	(27)	(64)	(33)	(Odera, pers. comm.)
Tanzania					6	11	46	50	113	
									(41)	
Uganda					1	7	12	15	35	(Karani, 1973)
									(37)	
TOTAL	32	41	60	322	753	876	871	1272	4227	
									(52)	
Other African countries - Zaire, Cameroon, Ethiopia, etc.									say 20	
New Zealand	2		3		3		1		9	(Weston, 1973)
Queensland	2		4		7		3		16	(Queensland, 1974)
Papua and New Guinea									3	(Nikles, 1974)
India and Sri Lanka									say 15	
Argentina									say 10	
Brazil									say 25	
Other South American Countries									say 40	
									4365	

Notes: (These figures mostly refer to areas of P. patula standing in 1970. It must be remembered that some sawlog plantations planted as late as 1945 and nearly all pulpwood plantations planted before 1955 had been felled by 1970; therefore areas planted to P. patula before these dates must have been larger than shown here. The figures for Malawi (Foot, 1967) do refer to areas planted, but very little clear felling of P. patula has taken place in that country).

lower altitudes, which is more costly (Parry, 1952).

A South African Department of Forestry Report on commercial Timber Plantations for 1971/72 does not differentiate between the pine species in giving statistics on the sale of produce, but judging from the returns for all softwoods for those zones in which P. patula comprises more than half of the crop, about 23 percent of the P. patula plantations are grown for pulpwood and 77 percent are being grown for sawlogs. Approximately half the sawlog plantations are privately owned and half publicly owned, but about 70 percent of the pulpwood plantations are privately owned and are situated chiefly in South Natal, the Natal midlands and East Transvaal; a large proportion of the publicly owned pulp plantations are in the Transkei.

The pulp is grown on a fifteen to nineteen year rotation; the sawlogs in the publicly owned plantations are grown on a thirty five year rotation, but in privately owned plantations the mean rotation is twenty six years (range 23-29 years).

The main silvicultural problems in growing P. patula in South Africa are the form of the trees, fungal diseases, particularly in connection with hail damage, and fertility problems which may be associated with the needle mat that builds up in pine plantations.

Butt sweep and nodal swelling are two stem defects that are particularly prevalent in South Africa and, to lesser extent in Rhodesia and Malawi. It has been suggested that at least one importation of seed to South Africa from Mexico must have come from a stand - or a tree - having nodal swelling and that this defect can be seen in a P. patula plantation at La Venta outside Mexico City which was planted at the time that South Africa was obtaining seed from Mexico (Denison, 1973b).

The two fungi that cause most concern in South Africa are Rhizina undulata and Diplodia pinea (see also 4.22). The former can cause widespread deaths in young plantations established immediately after a burn; however it is claimed that a delay of six months between burning and planting considerably reduces the risk from Rhizina and that the build up of slash can be a worse risk than of mild risk of Rhizina attack (Denison, 1973b).

It appears that the policy of burning of the lop and top after clear felling is being continued. D. pinea can cause very serious losses after hail storms (see 4.15) particularly in the warm humid zones and this is one reason for diversifying into P. elliottii and P. taeda which are very much less susceptible. As an example of this diversification, in the East Transvaal the area planted to P. patula between 1951 and 1955 was 76 percent of the total area planted to softwoods, whereas between the years 1966 and 1971 the proportion had fallen to only 40 percent.

Some concern has been expressed recently at the build up of a needle mat which may be 20 cm or more thick under older plantations. It is feared that this spongy humus layer may help to induce water

stress in these plantations. The writer observed some experiments in burning this needle mat together with slash in a 15 to 20 year old plantation at Sabie. The operation was so slow that it did not appear to be feasible for removing the needle mat over large areas, though it may have some application for clearing fire lines near public highways. However the effect on the plantations should be studed carefully, particularly in relation to infection by R. undulata.

Natural regeneration of P. patula which can be profuse after a fire, a windblow or clearfelling can be a problem. Some attempts have been made to utilise natural regeneration, but the expenses of thinning in the first few years are high and in general volunteer crops are considered to be a nuisance.

A rough barked variety of P. patula is recognised in South Africa and is considered to be more vigorous and to give higher yields than the typical variety. The bark is more ridged and there is a complete absence of the orange-red bark on young stems and branches which is so characteristic of P. patula; in other respects the tree is very similar to P. patula. (See also 2.1).

2.511.2 Swaziland

The first plantation scheme of any size started in 1947 at Piggs Peak with the formation of Peak Timber Company which specialises in growing timber to sawlog size on a twenty to thirty year rotation. This was followed in 1948 with the formation of the Usutu Pulp Company which produces pulp on a fifteen year rotation. Both companies plant a high proportion of P. patula. The distribution between sawlogs (24 year rotation) and pulp (15 year rotation) plantation was 43 percent to 57 percent all being owned privately; however the Government will be establishing some plantations from 1974 onwards.

The softwood planting areas are in the high veld grasslands to the west of the country, but extend down to altitudes of less than 1000 m. It is noticeable that in the lower plantations height growth has culminated early and that the crowns are rounded. In these conditions P. elliottii puts on better height growth for longer.

Because of the excessive losses from R. undulata (see 4.223) after burning - up to 80 percent in some plantations - there has been a move away from burning as a means of clearing top and lop after clear felling. In the steeper areas it is also considered to be a bad policy to burn the top soil because this causes erosion. The fact that in pulp plantations trees are utilised down to 2.14 cm diameter, including some branches, greatly simplifies the disposal of debris.

Hail damage, followed by D. pinea attack, is serious in some areas. Even where D. pinea does not kill the tree the hail damaged stem frequently produces multiple leaders. This forking is not of great importance in pulp plantations, but is a serious problem in the Pigg's Peak area where trees are grown for sawlogs.

P. patula comprises about 80 percent of the areas planted to

softwoods. Despite the problems experienced with P. patula, which have been mentioned above, there does not appear to be much inclination to reduce this proportion.

2.511.3 Angola

P. patula is thought to have been first planted in 1942, but no further establishment was undertaken until 1957 when some 100 hectares were planted on a private estate. Since then the area planted annually has increased to about 200 hectares. The total area under P. patula in 1970 was about 11000 hectares mostly established in the highlands north and south of, and around, Nova Lisboa. P. patula represents about 60 percent of the area under softwoods, the other main species being planted is Cupressus lusitanica, though P. kesiya is also being used. At S. da Bandeira Poynton (1974) noted that a mature stand lacked vigour and that the stems were sinuous. Despite a dry season of 3 to 4 months P. patula at 5 or 6 years of age appears to be growing well at Cuima even on shallow soils over laterite. But whether increment will be maintained remains to be seen.

2.511.4 Mozambique

P. patula has only been planted on a modest scale; both P. elliottii and P. taeda are planted more extensively (Poynton, 1974). Most of the country would appear to be too low for P. patula.

2.511.5 Rhodesia

The first introduction was made in 1920 from an unknown source in Mexico; the trees were established in what is now Stapleford Forest Reserve in the Eastern Highlands and some specimens were still standing in 1968 (Barrett and Mullin, 1966). Thereafter until recently the bulk of the seed was imported from South Africa, even though seed from local sources became available from 1930 onwards. Up till 1934 P. radiata was the main softwood species planted in Rhodesia, but from then onwards, following severe fungal attackes (Diplodia and Dothistroma) P. patula became the preferred species.

P. patula at 36 thousand hectares in 1970 accounted for 74 percent of the area under softwoods in Rhodesia, but since 1965 the proportion of P. patula planted annually has dropped to about 65 percent of the softwood programme with an increase in the area of P. elliottii and P. taeda. A larger proportion of the P. patula plantations are privately owned.

P. patula plantations are confined almost entirely to the highlands in the east of the country, where there is a rainfall of 900 mm or higher. It is grown as an ornamental in Salisbury and appeared to be surviving the 1973 drought remarkably well in that city.

An interesting aspect of some provenance trials planted in 1970, which incorporate local Rhodesian provenances as well as eight Mexican provenances, is that the local provenances have proved to be very much less susceptible to Pineus attack (see 4.312.22) than the

Mexican provenances; (local 1 to 3 percent infection, Mexican 3 to 26 percent). There appears to be no reason why the local provenance should have developed this resistance; there are no records of Pineus in southern Africa before the 1960's.

2.512 Madagascar

The tree is thought to have been introduced to Madagascar in about 1923, but the source is unknown. Planting of P. patula on a large scale in the central highlands at Antsirabé and more especially in the Haute Matsiatra started in the mid 1950s. Between 1965 and 1970 the average annual planting rate of P. patula was 2000 hectares and the total area in 1970 amounted to 30 thousand hectares representing 60 percent of the area under softwoods. However, the proportion under P. patula will steadily decrease to an anticipated 30 percent in 1985 when planting in the Haute Mangoro, which is being afforested with P. kesiya, is completed. (Devillé 1973b)

The system of raising plants in boulettes (earth balls with a high clay content) is still practised in Madagascar but these are being replaced by polythene tubes, which appear to produce a better plant. (Wood, 1971).

2.513 East Africa

2.513.1 Malawi

P. patula was introduced into Malawi from South Africa in 1923 and plots were established on Zomba plateau. These started well, but all eventually failed. In 1933 mycorrhiza was brought in from Rhodesia and as a result plots were successfully established at Zomba, Dedza and Kanjedza. Planting on a commercial scale started in 1946 (Marshall and Foot, 1969). Between 1965 and 1969 some 17 thousand hectares of P. patula were planting on the Viphya plateau and this block of plantations represented in 1970 a large proportion of the total area of 26 thousand hectares planted to this species. P. patula comprises 79 percent of the area under softwoods. There are plans for a considerable extension of the softwood area on and near the Viphya plateau but it is probable that for the lower altitudes a species other than P. patula will have to be used.

The establishment of the Viphya plantations has been achieved in a very short period with only a minimum of preliminary site testing. The P. patula has grown remarkably well, but there are areas of complete failure where the soil has been too shallow (see also experience at Turbo in Kenya 2.513.2) and other areas where establishment has been poor possibly as a consequence of uncontrolled weed growth on rather more productive sites.

Up till 1957 seed was obtained from South Africa, and the incidence of nodal swelling is high in some plantations. Seed is now obtained from local seed stands, and a tree breeding programme has been undertaken.

2.513.2 Kenya

Early introduction of P. patula dates from 1926 but planting on a commercial scale did not start until the 1940's (Paterson, 1967). Large scale afforestation with P. patula dates from the early 1950's. In 1970 the area under P. patula amounted to 32 thousand hectares which represented 33 percent of the area under softwoods. The current planting programme is about three thousand hectares a year of P. patula, which is 45 percent of the total softwood programme.

Until about 1957 seed was obtained entirely from South Africa but since that date several plantations considered to be of superior form and vigour have been set aside to be specially treated as seed stands and these now supply the bulk of the country's seed requirements, supplemented by general collections.

The form of the trees in Kenya appears to be better than in Southern Africa. Butt sweep and nodal swelling are not nearly so prevalent. Undoubtedly some selection against these defects must have taken place in the south African plantations from which seed for Kenya was collected. Stem form is considered to be subject to genetic control. However trees in Southern Africa and Malawi, raised presumably from seed collected in similar plantations show these defects to a far greater degree. Therefore, unless it just happened that Kenya was exceptionally lucky in the seed selection, it would appear that these defects are also influenced by environmental factors.

In contrast to the countries of Southern and Central Africa, where P. patula plantations have been established into grasslands, in Kenya this species has mostly been planted into high altitude bamboo (Arundinaria alpina) forests using the shamba system. P. patula, because it covers the ground quickly and shades out weeds, is very suitable for establishing by this system. However, with a rise in the standard of living the shamba system will become less and less attractive to the cultivators and can be expected to be phased out. By the time that occurs most of the bamboo forest that it is intended to put under exotic conifers will have been converted and shamba cultivators are not essential for establishing the second rotation crops.

In the mid 1960's a scheme was started at Turbo to raise trees for a pulp mill. The location of the plantations was largely dictated by the only feasible site for the mill. The plantations are being established on farmland - primarily wattle (Acacia mearnsii) and maize. Over much of the area it is possible to use a mechanised form of the shamba system, planting the trees into maize fields. The major species used has been P. patula but problems have arisen because of the presence of laterite pans. Because of a relatively long dry season the site is in fact marginal for P. patula and it will be advisable to diversify into other species.

2.513.3 Tanzania

The history of the introduction of P. patula into Tanzania is much the same as in Kenya except that the Germans had tried the species

at Amani (1000 m altitude) in the early years of their administration. Planting on a large scale started in 1960. By 1970 eleven thousand hectares had been planted which accounted for 41 percent of the total softwood area. The main P. patula planting sites are the Northern Highlands (north and west Kilimanjaro and Mt. Meru), the Usumbara mountains in the north east, the Ukaguru Hills, Sao Hill and the Southern Highlands. Table 2.513.31 gives some growth statistics.

In the Southern Highlands and at Sao Hill, though P. radiata is usually taller than P. patula, it is always described as being less healthy and vigorous. It is also interesting to note that though on these sites the dry season lasts for six months, P. patula does well; this can partly be accounted for by the fact that mists and overcast days are frequent and also by the fact that the soils are of a good depth. The soils at Sao Hill are derived from the basement complex rocks and are very much less fertile than those on other sites such as Kiwira in the Southern Highlands which are volcanic in origin; this fact appears to have affected the growth of P. elliottii very much more than the growth of P. patula. In the older plots on Mount Kilimanjaro it is very noticable that the total production from P. patula is low in comparison with the other species.

Fertility problems have been encountered in the Southern Highlands, and Sao Hill, notably Boron deficiency (Procter, 1967), but this can quite easily be corrected by the application of borax.

2.513.4 Uganda

Plantation forestry is not the major forestry activity in Uganda and though P. patula was the exotic species most widely planted, P. caribaea which is being established on the shore of Lake Victoria and at Katugo is now planted more extensively. P. patula is only planted in a few highland sites in the west of the country; there were some 3500 hectares of the species in 1970, representing 37 percent of the area under softwoods, but it is unlikely that this area will be much enlarged.

2.513.5 Ethiopia

Much of the Ethiopian highlands are high enough and receive sufficient rain to be able to grow P. patula. It is a summer rainfall area and there is no reason why the species should not thrive; indeed it may do so. However in 1965 it was estimated that there were only one thousand hectares of conifer plantations in the whole country, as compared to fifteen thousand hectares of broad-leaved, presumably Eucalyptus, plantations.

2.513.6 Rwanda and Burundi

These countries on the south-western boundary of Uganda have a suitable climate for growing P. patula, but it is thought that Eucalyptus species are most frequently planted. It is a densely populated area and there is little suitable land available for forest plantations.

2.513.31 Table. Mean annual increment height (Total volume underbark in brackets) for P. patula and some other species at various sites in Tanzania

	Altitude	Rainfall	Age	Parameter Ht in m (Total Vol in m^3/ha)	P. patula	P. radiata	P. elliottii	P. taeda	P. lusitanica	
Ukuguru	1075	1145	4	Ht	0.47	0.57	0.62	-	1.07	-
Sao-Hill (Southern Highlands)	1920	965	2-4	Ht	1.57	1.64	0.52	-	-	-
Njombe (Southern Highlands)	1555	1780	8-9	Ht	1.75	2.10	1.32	1.58	1.43	-
Kiwira (Southern Highlands)	2285	1650	9-10	Ht	1.68	2.36	1.16	-	-	-
Mbeya Mountain (Southern Highlands)	2440	1525	4	Ht	1.58	1.44	-	-	-	-
Kitulo(Elton)Plateau (Southern Highlands)	2680	1525	10	Ht	1.30	1.46	0.67	-	-	-
Old Moshi (S. Kilimanjaro)	1675	2005	14-16	Ht (Total Vol)	1.31 (19.7)	-	1.33 (26.9)	1.37 (23.9)	-	-
Uru (S. Kilimanjaro)	1830	1780-2030	14	Ht (Total Vol)	1.65 (17.7)	1.79 (28.5)	-	-	-	1.63 (20.6)
Rongai (N. Kilimanjaro)	2010	815	16	Ht (Total Vol)	1.35 (20.4)	-	-	-	-	1.31 (24.3)
Kareshi (N. Kilimanjaro)	1525	510-760	2	Ht	0.70	0.88	0.64	-	-	1.10
Kamanga (N. Kilimanjaro)	1675	760	6	Ht	1.10	1.74	0.79	-	-	-
Usseri glades	2290	890	3	Ht	0.73	0.64	0.64	-	-	0.85
Bismarck Hut	2740	1020	4	Ht	0.76	0.76	-	-	-	1.04

Sources: Willan, 1964 (a & b); Wood (1964)

2.514 West Africa

2.514.1 Republic of Cameroun and Nigeria

Cameroun possesses the only mountains in western equatorial Africa of sufficient height and with adequate rainfall to support the growth of P. patula. These mountains go up to 2500 m in altitude and plantations of the species have been established. The western flanks of these mountains are in Nigeria, but altitudes are too low and the climate is too arid for satisfactory growth of P. patula, though experimental plots have been established on the Mambilla plateau and also on the Jos plateau.

2.514.2 Republic of Zaire

The eastern boundary of Zaire bordering Uganda, Rwanda and Burundi has several areas of highlands, such as the western slopes of the Ruwenzoni mountains, which should provide suitable sites for the growth of P. patula. However information on the extent of P. patula plantations is not available.

Wood (1971) reported excellent conditions for growing P. patula at Mulungu, on the western shore of Lake Kivu. Commercial planting had not been undertaken, but he measured one trial plot of P. patula which at thirteen years had a mean height of 28 m, and diameter of 22.9 cm and basal area of 31 m^2.

2.52 New Zealand and Australia

2.521 New Zealand

The first P. patula planted was probably brought into the country about 1877 (Adams, 1915). Subsequent introduction to 1915 were from Mexico. From 1916 to 1947 all seed was obtained from South Africa and in all amounted to 430 kg. From 1948 onwards seed was obtained from New Zealand plantations, except for a lot bought from South Africa in 1967 in anticipation of an increase in the P. patula planting programme, which did not in fact come about.

The average annual planting rate in the 1950s reached about 60 hectares, but the species is not planted at all now, and has never accounted for as much as 1 percent of the area under exotic softwoods. The area under P. patula reached a maximum of 1125 hectares, nearly all of which was planted in North Island, in 1968, but this area has now decreased to 870 hectares and the policy is to cut it out completely by 1990 (Weston, 1973). Growth is good, as can be judged from the statistics given in Table 2.521.1.

2.521.1 Table. Growth statistics of P. patula at Whakarenwarewa (Weston, 1973)

Age	Stems/ hectare	Top height m	Dbh cm	Standing Vol/ha m^3	Thinning Vol/ha m^3	Tot Vol/ha m^3	MAI m^3/ha
42	270	31.7	43.9	592	381	973	23.17

It may seem somewhat surprising that a species, which gives higher yields than any other exotic conifer except P. radiata, is no longer planted. But it grows on the same sites as P. radiata and is considered so inferior both in growth rate and wood quality to that species that there is no point in planting it, whereas Douglas fir (Pseudotsuga menziesii) and Corsican pine (Pinus nigra), which can utilise sites not suited to P. radiata, are planted to some extent.

In 1972 a ten year old trial of five provenances of P. patula was assessed. The provenances included one New Zealand provenance from Rotoehu Forest, three from Mexico of the typical variety and one from Oaxaca of P. patula var longipedunculata. The local provenance proved to be about 9 percent superior in height than the combined Mexican provenances and also very much superior in stem form, though the P. patula var longipedunculata was slightly better in terms of stem straightness. However, P. radiata on the same site was 22 percent taller than the New Zealand provenance of P. patula. (Thulin and Firth, 1973).

2.522 Queensland

P. patula was first introduced in 1923 from South Africa. It is planted on a small scale only - some 25 ha were planted in 1970/71 (Queensland, 1974) and the total area at that date only amounted to 1670 hectares; this represented less than 5 percent of the area planted to softwoods, which is dominated by Araucaria cunninghamii.

2.523 New South Wales

In the 1970/71 Annual report of the New South Wales Forest Department less than 50 ha of P. patula plantations are listed. However, Burgess (1972) considered that the Mexican pines should be well adapted for the north of New South Wales and would be capable of producing large volumes of cellulose.

2.524 Papua and New Guinea

280 hectares of P. patula had been planted in 1970 and the annual planting programme was predicted to be 120 hectares up to 1975 (Nikles, 1973). It would appear that some interest is being shown in P. patula though the scale of the planting in relation to other species is not known.

2.53 Asia

2.531 India

P. patula is not widely planted in India. It has been planted on a small scale in West Bengal since the early 1930s. Guhathakurta (1972) considered that it could be grown from 700 m to 2,300 m altitude and in rainfalls from 2,500 mm to 8,000 mm. He gave the following growth data for West Bengal:-

Age	Height m	dbh cm
11	10.4	19.3
21	21.0	27.3
30	22.0	40.0

Joshi and Pande (1972) considered P. patula with P. pseudostrobus to be promising exotics to replace P. roxburghii (Chir pine) in the Chir pine/oak/rhododendron forests at 2000 mm altitude in the middle Himalayan hill zone of Uttar Pradesh, and quoted a height of 6.7 m in eight years for P. patula as against 2.2 m for P. roxburghii. Trials of P. patula were established at Devikulam in Kerala in 1968 and 1969 and Nair (1972) recommended the species for planting at altitudes above 1100 m. Seth (1972) recommended P. patula for the Himalayan region, for the subtropical Himalayan region and for the southern tropical and subtropical zones in Kerala and on the Palni Hills in Madras. He considered that optimum growth would be achieved above 1700 m. Lamb (1973) considered P. patula to be the species most likely to succeed on the high moist plateau-grasslands of the Nilgri Palni Hills and Eastern Himalayan foothills over 1200 m.

2.532 Sri Lanka

Pines are not planted extensively in Sri Lanka; in 1970 the area of pine plantations of all species was less than 1000 hectares as against nearly 30 thousand of teak, 19 thousand of mahogany and 7 thousand of various species of eucalyptus. Trees raised from seed obtained from local P. patula plantations were reported to be doing well in both the wet and the dry mountain zones, according to Reports of Conservator of Forests of 1965-70. Lamb (1970) considered that P. patula could have an important part to play in providing a source of long-fibred pulp, if planted on the wetter hills. He noted that the P. patula in the arboretum at Ohiya (1525 m altitude, 2080 mm rainfall), planted between 1931 and 1934 was heavily branched and prone to nodal swelling; the seed had come from South Africa and the poor form may be a heritable trait that can be overcome by more careful selection of seed trees. He also considered that this species could be planted at altitudes as low as 1300 m in the wet zone, but noted that above Badulla at 1100 m in the winter rainfall zone it was not at all vigorous.

2.54 South America

2.541 Argentina

Pines, mostly P. elliottii and P. taeda are mainly planted in the warm temperate to subtropical north-eastern provinces of Misiones, Corrientes and Entre Rios. These pine plantations amounting to 65 thousand hectares (Barrett, 1971) have been established since 1950 and mostly after 1960. P. patula has been tested in species trials at Cerro Azul, Bella Vista, Gob. Vira Saro. and Concordia; at eight years of age growth of P. patula from Perote, Vera Cruz in Mexico compared

well with that of P. elliottii var elliottii from Baker County, Georgia. The Perote provenance was 10 percent larger than the provenance of Aytola in Puebla. However, the stem form was poor, the branching was dense and on some sites P. patula was heavily attacked by fungi - Hendorsonia sp. and Pestalozzia sp. (Golfari, 1970). P. caribaea (vars hondurensis and caribaea) and P. elliottii var densa were considered to be superior to P. patula, and at altitudes of only 300 m or less in a warm humid climate, probably comparable to the Natal coast, this is not surprising. Barrett (1974) did not recommend P. patula for the north-east region but some sixteen provenances collected in Mexico in 1971 (Barrett, 1972) are currently being tried in the monsoon forests in the mountains of the north-west region.

2.542 Brazil

The first plantations of P. patula were only planted in 1957 (Golfari, 1973); the seed origin is unknown, but since then introductions have been made from Mexico and South Africa. The South African provenances are considered superior in growth, form and uniformity. The sites suited to P. patula in Brazil are very limited, because there is little land of sufficient altitude (over 1000 m). However, in the Serra da Mantiqueira on the borders of Minas Gerais and Sao Paulo states the Companhia Melhoramentos de Sao Paulo had established 2000 ha of P. patula by 1973 and considered it to have a better potential than Araucaria angustifolia, Cupressus lusitanica or Cunninghamia lanceolata.

The growth of P. patula on the latosol soils of Serra Mantiquera is good with a mean annual increment of 21 m^3/ha as an average and maxima as high as 36 m^3/ha. Golfari estimated that 10 thousand hectares of P. patula might be planted over the next ten years at Serra Mantiqueira. This is of course a small fraction of the hundred thousand or more hectares planted annually to softwoods in Brazil.

Golfari (1970) also noted Monte Allegre and the "altiplano" above 1000 m altitude of north-east Parana as being areas with some potential for P. patula pulpwood plantations.

2.543 Other South American countries

2.543.1 Venezuela, Colombia and Ecuador

There is little information available from these countries; conditions of temperature (altitude) and rainfall should be adequate for P. patula growth but, as with other equatorial countries such as Kenya, these conditions are also suitable for the growth of P. radiata. In Venezuela pines were introduced in the 1950s. The main emphasis has been on planting P. radiata, but the form of that species is so bad that Melchior and Quijada (1972) have suggested that more emphasis should be put on other pine species. They gave preliminary results of some species and provenance trials in which the survival and growth of P. patula, though not outstanding, is as far as can be judged at such an early age, adequate at 1800 m. The outstanding performance of P. greggii is of interest.

P. patula has been introduced into Colombia from both South Africa and Mexico. Plantations have been established and it is anticipated that 1000 hectares will be planted over the next five years (Raigosa, pers. comm.). Miller (1973) has reported that trials of the species will shortly be made in Ecuador at altitudes of 3200 to 4000 m; individual trees observed at altitudes of 2500 to 3000 m appeared vigorous though at the higher altitudes it gave the impression of doing little better than P. radiata.

2.55 The Caribbean

2.551 Jamaica

Gray (1972) noted that between 1950 and 1955 180 hectares of P. patula had been established in Jamaica and that yields of from 8.5 to 16.4 m^3/ha a year compared favourably with yields from P. caribaea var hondurensis. However, P. caribaea has been widely planted whereas no further plantings of P. patula have been made since 1955.

3 Silviculture

3.1 Flowering and fruiting

3.11 Age

P. patula flowers early. In Rhodesia female flowers have been found on two year old plants in the nursery (Barrett and Mullin, 1966). They noted that in plantations female flowers are common by the third year, male flowers usually appear a year later and viable seed is being set in the fifth year. By the age of eight or ten years annual cone production is usually heavy. This pattern is typical for stands throughout East, Central and South Africa, from latitudes 2° North to 28° South. In Northern India Joshi and Pande (1972) reported the production of female flowers at the age of four, whereas Righter (1939) recorded female flowers in a seven year old tree at Placerville, California (latitude 39° North).

In Africa P. patula appears to flower and set seed freely every year, though Weston (1973) reported that good seed crops are borne at most once every three years in New Zealand.

3.12 Altitude

At low altitudes seed set is not satisfactory. Denison (1973a) stated that in South Africa seed production has been unsatisfactory in orchards at 900 m to 1500 m altitude. He noted that ovulate strobili abort; the probable reason for this is that at low altitudes there is poor synchronisation of the maturation of male and female flowers (see 1.222). Absence of cones has also been noted in Rhodesia below 1200 m (Barrett and Mullin, 1966), in Kenya at 1700 m in Kakamega (Ochieng, 1969c), in Malawi below about 1000 m (Foot, 1967).

3.13 Position on the tree

Female flowers are usually borne in the upper crown, while male flowers are borne in the lower crown.

3.14 Seeding

The cones develop over a period of 22 months (Barnes and Mullin, 1974) to 30 months (Dyson and Paterson, 1966), but as the cones are serotinous, that is they remain on the tree unopened for one or two years after ripening, the date of seed ripening is not critical. Seed collection can be deferred to a convenient season; Weston (1973) has stated that seed may remain in the cone for seven years with no more than 40 percent loss in viability. In Kenya collections are made from October to March in order to take advantage of the dry season for extracting seed. Other dates for collecting cones have been given as March to May in Madagascar (Nanson, 1973) and October at Mufindi in Tanzania (Kimber, 1963).

3.15 Seed production

3.151 Cones

In Madagascar in seed stands with a stocking of 500-700 stems to the hectare the harvest of cones is 1.0 to 1.5 tonnes a hectare which, as the cones weigh about 50 grams each, implies a harvest of about 40 cones from each tree. The certificate for seed lot 383 collected from near Pinal de Amoles, Queretaro in Mexico in February, 1972 gives a mean weight of 36.8 gm for each cone.

3.152 The number of seeds in a cone

Geary and Pattinson (1969) calculated that the Rhodesian material on which they were working had a potential for 200 to 300 seeds in each cone. In practice only a proportion of the ovules are fertilised and the following counts of viable seed were given.

Country	Seed/Cone	
Rhodesia	45	wind pollination
	57	hand pollination
South Africa	80 1965)	wind pollination with supplementary
	35 1966)	hand pollination
East Africa	75-80	

Pudden (1956a) gave a figure of 93 seeds in each cone and the extraction of 1 lb of seed from 66 lb of cones (i.e. a production of 1.5 percent). Nanson (1973) gave a seed production figure of 1 to 2 percent of cone weight in Madagascar. Barrett (1973) has suggested a similar general production rate of 1 kg of seed from 91 kg of cones for all pines in Rhodesia. The 1972 Mexican collection (seed lot 383) gave 2.155 kg seed from 10440 cones, or only about 22 seeds from each cone.

It is apparent from the South African figures that seed set can vary considerably. It is likely that the two most important factors are pollen production and the weather conditions, which largely control pollen dispersal, at the time that female strobili are receptive. It is also probable that weather conditions are more critical at higher latitudes and altitudes.

3.153 Seed weight

P. patula has a small seed. Stuart (1954) listed the weights of the seed of fourteen species of pine grown in East Africa. Other than P. patula only one, P. leiophylla, had more than 100,000 seeds to the kilogram; the rest had less than 60,000. The following cleaned seed weights have been given.

Seed origin	Seeds/Kg thousands	Source
Mexico	97-158 (Mean 117)	Barrett (1973)
	116-146	Madan Gopal (1973)
	107	Seed lot 383
Kenya	145-166	Stuart (1954)
	147	Pudden (1955)
	125-150	Wood (1965)
	130	Ochieng (1969a)
	110-145	Madan Gopal (1973)
Tanzania	105-127	Wood (1965)
Rhodesia	145	Wood (1965)
	100-150 (Mean 127)	Barrett (1973)
Malawi	110	Madan Gopal (1973)
South Africa	110-130	Pudden (1955)
	72	Wood (1965)
	145	Crowe (1967)
	132	Donald (1968)
Queensland	122-164 (Mean 140)	Queensland (1974)

This represents a wide range of seed sizes, but from the limited data presented here it is not possible to detect any correlation between seed size and latitude. It is probable that annual climate fluctuations and local site condition affecting the vigour of the mother tree would mask any generalised climatic effect. Barrett (1973) obtained the heaviest seed from El Madrono at the northern end of the range; the collections from Oaxaca tended to have light seed.

3.154 Seed stands

In most African countries it appears that local collections were initially made without any attempt at selecting the stand or the mother trees. Because there were few mature plantations from which to select, this lack of selectivity was almost inevitable. However a general lack of control did tend to encourage collection from trees that were most accessible, which in effect meant coarse, open grown trees or thinnings. Foot (1967) has suggested that the poor form of P. patula planted in Malawi before 1957 may be attributed to the fact that the seed was obtained from thinnings and unselected clearfellings in South Africa.

Seed stands are commercial stands which are of superior growth, which may have been heavily thinned to encourage seed production, and which have been selected for seed collection. These have been used in some countries as an interim measure, while seed orchards are being established.

In Kenya in 1966, 1478 seed trees were selected within 265 hectares (that is about 5 or 6 to the hectare), from these it was planned to collect 167 kg of seed. This amounted to 113 gms per tree. A further 380 kg was to be obtained by way of a general collection from 115 hectares (Smart, 1966). The overall yield of nearly 4 kg per hectare from 14 to 25 years old plantations should be compared with estimated yields of 23 kg a hectare from seed orchards (see 7.324). In Madagascar Nanson (1973) expected to collect 920 kg a year from 46 hectares of seed stands which had been thinned to 500 to 700 stems per hectare. In Malawi Marshall (1967) set aside 17 hectares from each of which he expected to collect 15 kg of seed. Marshall describes a system of scoring trees for defects as a means of selecting the best stands. The plantations were initially selected for superior height growth, after which straightness and absence of forking were considered the most important characteristics as being those that are most clearly genetically controlled. However in Rhodesia the system has been to select superior trees as seed trees at an intensity of about 12 trees a hectare, but paying no regard to the general quality of the stand (Barrett and Mullin, 1966).

The genetic improvement possible with the use of seed collected from seed stands is, of course, limited but, as an interim measure until demand can be met from seed orchards, controlled collection from seed stands is much to be preferred to indiscriminate collecting. Furthermore it does not cost very much more to organise.

3.155 Seed collection

Because the cones are serotinous they must be removed in the closed state from the trees; there appear to be no records of tree shakers being used, and because the cones are persistent on the branches it is unlikely that they would be effective.

In seed stands there are three main options open. First to collect the cones individually; this must be done by climbing the tree and has the disadvantage that beside the difficulty of getting into the crown, it is almost impossible not to break some branches and to waste the next two or three years' production from that tree but the system has been used successfully in Kenya without apparently adversely affecting the next year's crop. Secondly, it is possible to high prune selected trees and to collect the cones from the pruned branches. This is a technique that has been used as an interim measure in Rhodesia (Barrett and Mullin, 1966). It has the disadvantage that, except on very open grown tress, it is unusual for many cones to be produced in the lower crown. Thirdly trees can be felled and stripped of cones. This method has been used in South Africa (Foot, 1967) and though the collection of cones from thinnings is inadvisable, the stripping of clearfelled good quality plantations would be a reasonable method of augmenting seed production.

3.16 Seed extraction and cleaning

3.161 Extraction

The cones open readily with heat. Pudden (1956a) stated that

three days in the sun is sufficient to open cones completely in Kenya. From 1965 onwards the cones were opened by placing them in polythene covered concrete frames. In the dry season the temperature in these frames regularly rose to over 50°C. The seed was extracted by tumbling it in a wire mesh cylinder which allowed the seed to fall through into a trough. The initial drying extracted about 85 percent by weight of the available seed, a further 15 percent could be obtained by wetting and redrying the cones. In Rhodesia artificial heat is used to supplement heat from the sun for opening the cones (Barrett, 1973) and in New Zealand cones are placed on racks in a steam-heated kiln and kept at 66°C for 8 hours (Weston, 1973). In Queensland cones are placed in near boiling water and are then heated over wood fires for about 24 hours. It has been found that when cones have closed after once opening it is very difficult to get them to reopen (Queensland, 1974); Kenya experience (see above) was that cones could be reopened by soaking and redrying.
Where long hours of sunshine and low humidities are predictable sun extraction is much cheaper and is a practical method even for large quantities of seed.

3.162 Dewinging

The wings can be removed by rubbing the seed between the hands. For large quantities the system used by the British Forestry Commission of tumbling seed in a clean cement mixer with a small quantity of water, was found to be successful in Kenya.
This process did not appear to raise the moisture content of the seed unduly. In Rhodesia the use of an air hose in a sack has been found to be very effective.

3.163 Cleaning

Large debris such as broken pine scales can be removed by sieving. Wings and light impurities including empty seeds are often removed by hand winnowing. An electric table fan can be used to remove both unwanted debris and empty seeds.

3.17 Seed storage

P. patula seed stores well and maintains its germination capacity for a year or even longer when stored in open bins at room temperature in Nairobi, Kenya. However, it is advisable to store it in insect proof, air tight containers in a cool place. The most important single factor in storing seed is its moisture content and the humidity of the store. In New Zealand the moisture content is reduced to 5 or 6 percent before storage (Weston, 1973), yet in Kenya no drying, other than that achieved by the sun after dewinging the seed, was found necessary. If the seed is to be stored for more than two years it is advisable to do so in airtight containers at a moisture content of less than 10 percent and in a temperature of about 1° to 4°C.

Gibson (1969) found that seed pelleted with Rhizoctolcombi did not deteriorate when stored for five months at room temperature.

3.2 Natural regeneration and direct sowing

3.21 Natural regeneration

Natural regeneration occurs prolifically in South Africa, Malawi, Rhodesia, Madagascar and New Zealand. However, in East Africa natural regeneration of P. patula unlike that of Cypress, is not common, and what does come up is usually browsed by buck. In no country is natural regeneration now favoured as an afforestation technique for P. patula largely because of the expense of thinning the young saplings. The current move towards the planting of genetically improved seedlings would also tend to militate against a natural regeneration policy.

3.22 Direct sowing in the field

There are no records of this having been tried with success. On many sites it is unlikely that the seedlings would produce a deep enough root system to enable them to survive the first dry season. Though Howland and Hosegood (1965) showed that by placing the P. patula seed in a bamboo sleeve and by concentrating rainfall in the sleeve by means of a conductor stick (a 1 cm x 1.5 cm split bamboo increased the quantity of moisture at its base by 60 percent) the soil moisture deficiency over the critical period could be reduced and seedlings could be successfully raised. However, the fact that seed has until recently been in relatively short supply, combined with the risk of rodent damage, has made this technique unattractive. Finally the technique should have no application where genetically improved seed is used.

3.3 Nurseries

3.30 Siting nurseries

South African Pulp and Paper Industries (S.A.P.P.I.) have sited their nursery at Elandshoogte some 600 to 1200 m lower than the sites considered suitable for planting P. patula (1500 to 2100 m). In this nursery at the warmer lower altitude it is possible to produce P. patula ready for planting (15 to 20 cm) in polythene pots and in beds in seven months. In the past it has been usual to site nurseries near the planting site; this policy was frequently forced on managers by the lack of good roads, particularly in the rains. But with an improvement in roads, it may well pay to raise P. patula in large, centralised nurseries at lower, warmer altitudes and thereby raise better stock in a shorter time. Theron (1972) has commented on the slower growth in high altitude nurseries in Malawi.

The general requirements that nurseries should be level, have an adequate water supply and sufficient area for sheds and for loading trucks and that they should not be sited in frost hollows is generally understood, though Howard (1966) commented on the poor siting of the Nyika nursery in Malawi which suffered from frost.

3.31 Germination

3.311 Germination capacity

Germination capacity is the total number of seedlings germinated at the end of the test period, plus those stained 85 percent or more in a tetrazolium test, expressed as a percentage of the number of full seeds sown. Germination capacities of 75-85 percent are normal. Barrett (1973) gave a figure of 82 percent in forty days in Rhodesia, Crowe (1967) quoted 85-90 percent in South Africa and Nair (1972) 80 percent in Kerala state, India. Donald (1968) in South Africa gave germination capacities of 79-86 percent and also gave figures of 2-16 percent of empty seed.

3.312 Germination energy

This is defined as the number of seedlings that germinate within a given number of days from sowing expressed as a percentage of the number of full seeds in the sample. Germination energy is controlled by the conditions in the seed bed, particularly the temperature, and by the state of dormancy of the seed. Two types of dormancy are recognised; exogenous relating to the physical impermability of the seed coat and endogenous relating to the chemical composition (inhibitors) in the embryo or the stored food reserves. Donald (1968) stated that dormancy in P. patula and the other pines he investigated was endogenous and that the inhibitor was formed as a result of the treatment the seed received. In tests on samples of P. patula he found the germination energy at 15 days to vary from 27 to 69 percent. In Rhodesia Barrett (1973) gave a regression for the expected germination capacity from 14 to 40 days after sowing; germination energy on the fourteenth day was only 13 percent, rising to about 90 percent on the twenty-seventh day. There are obvious advantages in achieving early and uniform germination of the seed, particularly if the seed is being sown direct into the containers or transplant beds instead of into seed beds. The decision whether to pretreat the seed in order to break dormancy and to hasten germination will depend on individual circumstances. For some nursery men the germination of about 60 to 65 percent of the seed sown in a two week period (the fourteenth to twenty-seventh day, as in Rhodesia) may be quite good enough. However Wood (1965) recorded the following germination periods:-

Kenya	36 to 62 days
Tanzania	25 to 70 days
Rhodesia	15 to 64 days
South Africa	36 to 62 days

which indicate that some pretreatment may be required.

If it is considered that dormancy may be a problem the only way to check is to carry out a germination test to calculate the germinative energy. Cutting tests using tetrazolium bromide will not give the answer.

Donald (1968) has also shown that the depth of sowing has a marked effect on the germination capacity. This is probably a temperature effect.

3.313 Pretreatment

There are three pretreatments that are usually applied to pine seed to break dormancy:

Soaking in water
Soaking in hydrogen peroxide
Stratification (wet, cold storage)

3.313.1 Soaking in water

This is considered effective in breaking exogenous dormancy and if dormancy in P. patula seed is endogenous it is not surprising that Donald found that soaking was slightly deleterious both in terms of germination capacity and germination energy at fourteen days; cold water (18°C) was more harmful than warm water (30°C). However, Barrett (1973) concluded from an experiment on twelve seed lots ranging in age from 16 to 85 months that soaking in cold water was beneficial (germination energy at fourteen days improved from 64 to 80 percent) and that it should always be carried out. Pudden (1955) recommended soaking in cold water for eight days.

3.313.2 Soaking in Hydrogen peroxide

Donald found that this was beneficial; the germinative energy at fourteen days improved from 38 to 74 percent after only two days soaking and up to 86 percent after eight days. Germination capcity was only marginally improved. He recommended soaking 1 kg of seed in 80 litres of 1½ percent hydrogen peroxide for four days if germination energy is less than 60 percent. This only cost £0.20 a kg but for large quantities of seed it is a messy procedure.

3.313.3 Stratification

Donald considered that, if the seed was very dormant, stratification at 2° to 3°C in moist peat for 40 days would improve the germination energy, though the germination capacity was lowered. Barrett found that soaking for 24 hours followed by storage at 3° to 4°C for eight days only improved germinative energy from 80 to 88 percent. Furthermore this length of treatment will frequently be impractical. In general it would appear that the returns from the effort involved in stratifying are so small that the procedure is not justified.

3.313.4 Floating

Floating off the empty seed is worthwhile if the seed is being sown direct into containers. A proportion of full seed is usually floated off with the empties, but the reduction in the number of blanks in the bed can justify the practice.

3.314 Plant production (seedling recovery)

The number of plants produced from a given weight of seed depends not only on the number of seed in that batch of seed and the

germination capacity, but also in the purity of the seed, the conditions in the nursery and the skill of the nursery man. The following plant production rates have been quoted:

Country	Plants/kg thousands	Authority
Kenya	44-80	Pudden (1952) Results of a nursery survey, 40,000 considered reasonable.
	87	Ochieng (1969a)
Tanzania	44	Procter (1963)
Rhodesia	55	Barrett (1973)
Angola	25-35	IIAA (1973)
Madagascar	50	Nanson (1973)
South Africa	44-55	Wood (1965)

From these figures it would appear that one useable plant is obtained for about every three seeds that are sown. This compares well with the British Forestry Commission who have, over the last fifteen years, improved their seedling recovery from one in ten to one in four (Gordon and Tee, 1973).

3.32 Sowing

3.321 Seed beds

3.321.1 Soil

The essential requirement is a light acid soil with good drainage. May (1953) recommended that in East Africa seed beds should be raised 15 cm, to ensure good drainage and should consist of:-

7-8 cm of a 50:50 mixture of sieved forest soil and sharp sand.
2-3 cm of unsieved forest soil.
5 cm of broken stone and rubble.

In fact, if the seedlings are transplanted at an early age, before they start to draw nutrients from the soil, they can be sown into a sterile medium such as pure sand or vermiculite. The use of a sterile medium greatly reduces the risk of losses from damping off, but it is advisable to use 'sharp' sand, which will not form a crust thereby creating a physical barrier to the germinating seedling.

In Angola the soil in seed beds is enriched with phosphorous, potassium, magnesium and with cattle dung, but even though transplanting is delayed until the seedlings are 5 to 7 cm tall, this practice should not normally be advised.

3.321.2 Mulches

Mulches of chopped grass, leaves or of polythene can be used to help retain warmth in the seed bed. The mulch should be removed as soon as the seedlings start to germinate. If polythene is used

particular care must be taken not to over-heat the seedlings and it is advisable either to remove the polythene mulch during the hottest part of the day, or to shade the seed beds. Donald has shown that clear polythene is superior to black polythene. For cold season sowing a mulch is almost certainly worthwhile even if the damping off risk is rather greater.

3.322 Sowing density

Over dense sowing can result in losses caused by early germinated seedlings dislodging and exposing the roots of late germinated seedlings. In addition the risk of damping off is much higher.

The following sowing densities have been recommended:-

Country	Rate given	area in square metres to be sown with 1 kg	Authority
Rhodesia	64 g/m^2	15 m^2	Barrett (1973) broadcast
	13 g/m^2	11 m^2	Barrett in drills at 15 cm spacing
South Africa	200-400 seeds/ft^2	30-60 m^2	Donald (1968)
Kenya	1 lb/300 ft^2	60 m^2	Pudden (1952)
Tanzania	1 lb/ 6 $yards^2$	11 m^2	Procter (1963)
Angola	30-40 gm/m^2	29 m^2	IIAA (1973)

This gives a wide range of choice and much depends on the size, the germination capacity and germination energy of the seed as well as the size to which the seedlings are to be grown and the damping off risk. If it is assumed that about 100,000 seedlings will germinate from a kilogram of seed, then broadcast sowing one kilogram over 30 m^2 of bed will allow each seedling 3 cm^2 of growing space, that is about the area of a thumb nail. May (1953) made the point that by mixing the seed with twice its volume of fine sand a more even distribution can be obtained in the seed bed.

Rhodesia appears to be the only country in which some nurserymen sow the seed in drills. If there is a weeding problem this may be helpful, but the use of a sterile medium and the practice of transplanting at the earliest opportunity should make the weeding of seedbeds unnecessary.

3.323 Depth of sowing

Seed beds must be absolutely level and well firmed down before sowing or the act of watering will wash all the seed to one side or cause it to be buried too deep. May (1953) recommended covering the seed to a depth of twice its own diameter. Donald (1968) quoted the results of an experiment which showed that germination energy at fourteen days is inversely proportional to the depth of sowing. At 1.25 cm the germination energy was 0 as against 61 percent for surface sown seed. The germination capacity was only slightly affected. He recommended surface sowing if watering can be done by

a mist spray; the covering should never be more than 6 mm.

3.324 Protection

3.324.1 Shade

Pudden (1952) has pointed out that soil temperatures in excess of 55°C (130°F) are not uncommon in full sun in East Africa. Temperatures of this order can kill seedlings; therefore if seed is sown in the hot season shade may be essential. Donald recommended shade if a clear polythene covering (mulch) is used. Care must be taken to ensure that drips from the shade or its supports do not damage the seedlings.

3.324.2 Birds and Rodents (see also 4.32 and 4.33)

Mice and birds can cause havoc in seed beds. Mice can usually be controlled by trapping and poisoning, but these methods are not acceptable or practical for controlling birds. Wire netting can be used but is expensive if there is a large area of seed beds and impractical if the seed is sown directly into the containers (spot sowing). Donald (1968) found that a mixture of Thiram, Endrin and Terolase applied to the seed of P. radiata was effective in discouraging birds.

3.324.3 Damping off (see also 4.21)

The essential conditions for germinating seeds, warmth and damp, are ideal for the growth of damping off fungi (Pythium, Rhizoctonia and Fusarium). However careful preventive measures can reduce the risk of damping off considerably. Several measures have been mentioned already and these can be summarised briefly as:-

1. The use of a sterile or near sterile medium in the seed bed.
2. Maintaining the seed bed in an acid condition.
3. Sowing at a low density and not burying the seed too deep.
4. Being careful not to overwater.
5. Changing the seed bed soil frequently.
6. Applying a fungicide before sowing the seed if there is a liklihood of damping off.

In East Africa it has been found that a copper base fungicide, Perenox, applied as a suspension (2 gm in a litre of water to 2 m^2 of bed) to be effective in preventing damping off, but care has to be taken if the soil is acid. Madan in Uttar Pradesh mentions the use of Thiram at 25 gm to a square metre.

Gibson (1969) has described the effect of pelleting P. patula seed with Rhizoctol-combi. At 0.3 to 1.0 percent strength this gave satisfactory control of the main damping off fungi, but at greater strengths it proved toxic to the seedlings.

The cost of treating seed in 1969 was:-

1 kg Rhizoctol-combi	22.00	Kenya shillings
1.25 kg methofas sticker	17.50	
Labour	27.50	
Total	66.00	

This was sufficient for 125 kg of seed and therefore cost about £0.03 a kilogram. A method of coating seed with Thiram, has already been described in the previous section. Donald (1968) stated that in South Africa damping off fungi are usually seed borne, therefore pelleting should be the most effective countermeasure.

Prevention is easier than cure. Donald found that trials to cure damping off using Thiram, Dratham and Kaptan were ineffective; the control, once the seedling density had been reduced by death, survived as well as the treated plots.

In general P. patula should not suffer badly from damping off as long as correct nursery techniques are used. The use of seed pelleting techniques must not be considered as an alternative to the preventive measures listed above, but they are a useful insurance for expensive seed such as that obtained from seed orchard.

3.325 The timing of sowing

P. patula seed stores well, therefore the timing of the sowing is in no way limited by the need to use fresh seed. The main consideration in deciding the sowing date is the period the seedling needs to remain in the nursery to grow to a plant of the size required for establishment in the field (see 3.36). In general, though germination is quicker, it is inadvisable to sow seed during the hot wet season in South Africa, because of the greater risk of damping off (Donald, 1968). In Malawi the rate of growth of early, March and April, sown seedlings was 10 to 80 percent faster than late sown seedlings; this resulted in plants that were 40 to 140 percent taller at planting (Theron, 1972). An investigation, conducted by the Centre Technique Forestier Tropical (1971) in Madagascar, showed that while shoot elongation during the cold months of May and June was negligible, root elongation and plant weight increment continued actively in this period.

3.326 Direct sowing into containers or beds

The process of transplanting from the seed bed to the transplant bed or container must involve a risk to the health of the seedling. Even with the best nursery staff the growth of the seedling will be checked for a period after transplanting. Bad transplanting can cause permanent damage to the root system. Therefore, if it is necessary to raise plants with the assistance of inexperienced nursery staff, it may well pay to sow direct into the 'transplant' bed or container.

P. patula seed is small, which makes the sowing a fiddling procedure, but the germination is generally so good that it should be possible to sow no more than two seeds in each spot or individual container and still not have an excessive number of blanks to resow. Stubbings (1958) used this technique successfully for raising plants in beds in Melsetter district in Rhodesia.

3.33 Transplants

3.331 Soil

Almost every experienced nurseryman swears by his own particular soil mixture. The ideal soil mixture cannot really exist since every nursery has to make use of that soil which is available in the nursery, or close by, and can only rely on those ingredients to modify it that are, for the most part, to hand locally. In this respect the nurseryman may well be right - in each nursery the mixture developed for that nursery is the best.

The qualities that go to make up a good pine nursery soil are:-

Good drainage
The essential nutrients
A proportion of organic material to retain moisture
Sufficient adhesion to form a root ball
Mycorrhizal fungi
Acidity

The ingredients that can be added to modify the basic soil are:-

Gravel, silt and sand to improve drainage
Artificial and natural fertiliser to provide nutrients
Manure, peat and compost to provide organic material
Clay to improve adhesion
Pine soil to provide mycorrhiza
Chemicals to lower the pH

The proportion in which these are mixed with the basic soil depends on the condition of the basic soil and the availability of the modifying ingredients. Every nurseryman should be encouraged to experiment to find out the best combination.

3.331.1 Structure

To ensure good drainage a basic soil with a good crumb structure is an advantage. It is a great mistake to force the soil through a sieve of too fine a mesh thereby ruining the crumb structure; a 2 to 3 cm mesh is usually quite sufficient for removing stones and roots. The addition of sand and gravel will improve the drainage in heavy soils but will also reduce the adhesive qualities of the soil. The water retaining ability (i.e. in the field capacity) of a soil can be improved by ensuring that the humus content is high. This can be achieved by using humus

rich soils, particularly 'forest soil' as a basic soil or by adding peat or compost. Pudden (1956b) obtained an improvement by using a compost made from Kikuyu grass (Pennisetum clandestinum). It is however important that the vegetative material should be well broken down and to achieve this 'forest soil' must be allowed to mature (while being kept damp and in the shade) before it is used in the transplant beds. Durham (1965) recommended a maturation period of three months, however Robinson et al. (1969) in evaluating the worth of the Muguga mixture found that there was a decrease in the total of soluble salts up to the fourth week of storage. They came to the conclusion that the addition of artificial fertilisers in this period could be harmful and that unsterilised immature soils should be stored for about four weeks.

The 'Muguga mixture' consists of:-

5 parts by volume of forest top soil
2 parts " " " chopped peat
1 part " " " well rotted horse manure
1 part " " " gravel (0.5 cm crushed stone chips)
30 gm NPK to 20 litres of soil

The figures in Table 3.331.11 show that though a very immature soil reduced survival, the effect of maturing the soil for longer than one month was of no benefit even to survival in the pines. It also shows that growth of P. patula in the nursery is slow in comparison to the other coniferous species most often raised in Kenya.

3.331.11 Table. Height (cm) and survival percent (in brackets) at 8½ months of conifer seedlings grown in potting soil stored for different periods before potting off (Robinson et al., 1969).

Soil matured for:-	1 day	1 month	2 months	3 months
P. patula	16.5 (66)	17.7 (99)	18.2 (92)	19.6 (96)
P. radiata	33.3 (64)	38.9 (93)	39.8 (90)	37.4 (90)
C. lusitanica	46.1 (88)	41.5 (98)	38.7 (98)	38.2 (98)

Least significant difference survival (P.001) 14%
height - Pines (P.05) 4.2 cm

3.331.2 Nutrients

3.331.21 Inorganic fertiliser

In East Africa addition of NPK when the soil is made up is standard practice. May (1953) recommended adding 28 gm NPK (3 parts sulphate of ammonia; 3 parts double superphosphate; 1 part sulphate or muriate of potash) to 18 litres of soil which would be sufficient for 50 seedlings grown in a plant box. Donald (1968) noted that in South Africa the use of inorganic fertilisers is rare and often condemned. He himself, working on P. radiata, recommended

N 0.05 gm; P 0.067 gm; K 0.077 gm per plant, which is a lower level than May recommended. Donald further made the point that application of Nitrogen at time of transplanting can be lethal and that it should not be applied until the transplants are well established. Robinson et al. (1969) found that both manure and artificial fertilisers resulted in significant positive responses in height, growth, stage of maturity and plant weight.

In Rhodesia only half the nurserymen consulted in a recent survey used inorganic fertilisers (Barrett, 1973). Theron (1972) in Malawi showed that application of nitrogen by itself not only depressed height growth but also increased the mortality among the seedlings. Application of potassium by itself resulted in a non-significant increase in height. Phosphate by itself generally resulted in a marked increase in height. But there was, in at least one experiment, a marked interaction between the three nutrients. The optimum level of application at Champoyo and Ngoma in Malawi appeared to be N 0.238 gm; P 0.476 gm; K 0.284 gm per plant. He also found that top dressing after establishment in the seed bed was more effective than mixing with the soil before transplanting and that better results were obtained with early sown than with late sown seedlings. He considered that inorganic fertilisers were only needed to hasten the growth of plants on cold sites such as the Viphya plateau.

3.331.22 Organic fertiliser

May (1953) strongly advocated the use of horse and cow manure to improve the structure and fertility of nursery soils. Donald on the other hand considered that even on light sandy soils, where the added organic matter might be expected to be particularly beneficial, the addition of animal manure had little effect on the growth of P. radiata. Frequently animal manure is not available in quantity on forestry projects and the nurserymen must make do without it even if he does subscribe to the 'muck is magic' philosophy. If it is used there is an increased risk of damage to the seedling from cut-worms, and for this reason it is not used at all in P. kesiya nurseries in Zambia (Wood, 1973).

3.331.3 Soil fungi

3.331.31 Mycorrhiza

The history of the introduction of P. patula and other pines into Africa is that introductions were a failure until steps were taken to innoculate the soil with mycorrhizae from pine growing areas. From this it would appear that the correct mycorrhiza are essential for the healthy growth of pines.

In Angola innoculation of the nursery soil is achieved by watering on a suspension of spores from fruiting bodies of the mycorrhizae and as an additional precaution three plants from the previous year's crops are left standing on each five square metres of

bed (IIAA, 1973). But the most usual method of innoculating nursery soil is by introducing soil from the rooting zone of established plantations. In fact in many countries it is standard practice to add a proportion of 'pine soil' to all soil mixtures. The more vigorous growth of plants that have been transplanted early (see 3.333.1) has been shown to be associated with mycorrhizal infection. However there is considerable evidence to show that once pines have become established in an area the presence of mycorrhizae in the nursery can be guaranteed and there is no need to introduce more mycorrhizae. Indeed in some countries such as Madagascar and Malawi (de Vergnette, 1968; Theron, 1972) it has been shown that addition of pine soil can in fact reduce the growth of pine seedlings.

3.331.32 Damping-off fungi

There is little to add to the information already given in section 3.2343. Providing the nursery techniques are good and in particular the plants are not overwatered in the period immediately after transplanting, damping off should not be a problem.

3.331.33 Soil sterilisation

Sterilisation of soil in order to kill pathogens is practised in some countries (Zambia, Rhodesia). However Donald considered that in South Africa soils imported into nurseries were relatively free of pathogens and he found that sterilisation using Methyl Bromide, Formaldehyde and Mylone 85W (manufactured by the Union Carbide Chemical Company) gave little improvement in the number of plants recovered. This was because the controls were so healthy; but in soil with a damping off problem sterilisation may well be justified. However a point to bear in mind is that beneficial mycorrhizae are killed at the same time as the pathogens. Donald found that soils must be free of the fungicide before seed is sown and that it took 8 weeks before the formaldehyde treated soil was fit for sowing.

3.331.4 Acidification

P. patula will not thrive in soils having a high pH. Durham (1965) describes the problems of growing P. patula in areas of alkaline volcanic soil in Tanzania. He found that acidification with aluminium sulphate was cheap and effective. Elsewhere flowers of sulphur have been used.

3.332 Beds and containers

The choice of method for raising plants in the nursery should be determined by two factors. First and most important the weather conditions that can be expected at planting time. The less predictable rain and dull weather is the more care that has to be taken not to expose the plants roots. Secondly the accessibility of the planting site and consequently the ease with which plants can be transported to the site is a factor to be taken into account. Large individual containers can hold a kilogram or more of soil.

P. patula has a relatively delicate root system, much less robust than that of P. radiata or P. elliottii. It is therefore of particular importance that the minimum amount of damage is done to the root system on lifting the young trees for planting. For this reason either the regular and frequent pruning of roots or the raising of plants in individual containers or both techniques are essential in growing P. patula; furthermore lining out beds, as are commonly used in temperate conditions, are not practicable because in lifting the trees for planting so many of the roots are left in the nursery.

3.332.1 Swaziland beds

These are raised beds which can be underpruned using a wire. They have been used very successfully in several countries in Africa. The stock raised in these beds should have a compact fibrous root system. The plants can be transferred to the field in blocks in boxes with very little loss of soil or disturbance of the roots or they can be taken as bare root plants as frequently happened in Kenya. Providing the roots do not dry out very successful establishment can be achieved using Swaziland bed plants.

3.332.2 Open beds

Research in New Zealand into raising good P. radiata planting stock has resulted in the development of a mechanised root pruning technique (see 3.3341) of plants raised in open beds (Van Dorsser and Rook, 1972). This technique involves growing seedlings to approximately the size required for planting out in the field and then by root pruning and repeated wrenching preventing further shoot elongation but encouraging the growth of fibrous roots. This method, if applied correctly, should result in a short, thick plant with a high root to shoot ratio and it is being tried in South Africa for raising P. patula (Denison, 1973b). The chief point of difference between this technique and the Swaziland beds, besides the fact that the root pruning is mechanised, is that the young trees are wrenched, that is the pruning knife is set at an angle so that the plants are lifted and dropped two or three centimetres. This wrenching which is only possible when pruning has been mechanised, appears to be an important factor in developing a good fibrous root system.

3.332.3 Boxes

The size of box used is limited by the fact that it must be possible for one man to carry a box full of plants and soil; sizes vary from 8 to 16 litres. The advantages of using box raised plants are that; first the plant is moved from the nursery to the field with minimum damage to the root system; secondly the trees are planted complete with the nursery soil in which they have been raised; thirdly if the planting site is inaccessible in the rains 'bush nurseries' can easily be erected at the planting site at the end of the dry season. The disadvantages are that boxes are usually shallower than Swaziland beds (10 cm versus 15 cm) and therefore provide less room for root development and secondly that because

large weights of soil must be taken into the field the costs of transport and planting is high.

3.332.4 Polythene sleeves (tubes)

The use of polythene tubes for raising P. patula planting stock is widely practised. Experience has shown that plants so raised are better able to withstand a prolonged dry period after planting.

Sleeves vary in size. At Turbo in Kenya they are 6.4 cm in diameter by 15 cm long, are made of 150 gauge diothene and contain 480 cc of soil. In Rhodesia the container size is usually 250 cc but may be as large as 780 cc (Barrett, 1973). In parts of Swaziland sleeves may contain as little as 120 cc of soil. In Malawi sleeves are made of 250 gauge polythene and can be reused.

The success of stock raised in polythene sleeves appears to depend on establishing the tree with a minimum disturbance to the root system. This can be achieved if the plants do not outgrow the container. Once that happens there is a risk of serious root deformation which can have bad effects that can last for several years (see 3.43).

Finally unless the trees are planted out very small, it will be necessary to prune the tap root to prevent it growing into the soil under the sleeve. Root pruning individual containers is more time consuming than underpruning boxes or Swaziland beds. It is possible to place the sleeves on an impervious base of concrete or polythene but these soon become covered in a layer of soil spilt from the containers and the tap roots grow laterally in the soil. Ball (1973) reported some success using polythene or hessian painted with a copper based marine paint which inhibited root growth. He has also proved that it is possible to underprune sleeves using a taut wire (see plate 8).

3.332.5 Polythene bags (pots)

These are in effect sleeves with their bottoms sealed and, though they are more expensive, gussetted bags are more satisfactory since the plants stand on a firmer, square base. All polythene bags must have drainage holes punched in the lower half. The advantage of bags as against sleeves is that they are much easier to fill and to handle because the soil does not run out; the main disadvantages are that deformation of the tap root is very much more likely than with sleeves and that the penalties for leaving the bag on when planting are even greater.

3.332.6 Fibre pots

Several proprietary brands of pots made of fibre, paper, compressed moss or peat are manufactured. Jiffy pots are probably the best known. In theory because the pot material can be penetrated by the tree roots these types of pot should overcome any of the problems of root deformation caused by the polythene bags. Therefore the

plants and pot can be planted together and the tree should receive no check at planting time. In practice the problem of controlling root growth in the nursery if plants have to be held over and of preventing the pots from disintegrating has proved difficult in the tropics and subtropics and it is doubtful if these pots have been used on anything but an experimental scale.

3.332.7 Other material

In the past pots have been made from many materials; clay, banana leaves, tarred paper, plywood, etc. but the cheapness and convenience of polythene film has in most countries made these materials obsolete. However Vignal (1956) describes the use of clay balls (boulettes d'argille) which are still used in Madagascar. The seedlings roots are encased in a 'sausage' 3-4 cm in diameter by 10 cm long composed of well rotted manure and clay. These boulettes are set out in beds in the nursery and treated much as sleeved plants. However Wood (1971) reported that growth of seedlings. in boulettes was poor. Queensland uses removable metal sleeves.

3.333 Transplanting (Pricking out)

The process of transplanting from the seed bed to the transplant bed is critical; if done badly seedlings can be killed or severely deformed. Donald (1971) estimated that 60 percent of P. radiata in South African nurseries had a kinked root system attributable to poor transplanting. This is one of the most telling arguments in favour of sowing into containers.

3.333.1 Timing

Most countries advocate transplanting at the earliest possible moment. In Kenya the normal practice is to transplant immediately after the seed testa has been shed and this was also recommended by Donald (1968). However, Ball (1973) advocated transplanting with the testa still attached to the seedling; but this practice may lead to losses from seed eating birds. Procter (1963) recommended transplanting 14 days after germination in Tanzania, and in Rhodesia the normal practice is to transplant when the seedlings are 3 to 4 cm high (Barrett, 1973). The reason for early transplanting is that at this stage the seedlings have hardly started to produce lateral roots and so the process is less of a shock for them and, even more important, the tap root is short and less likely to be kinked during the transplanting operation. However in Angola the practice is to delay transplanting until 30 to 40 days after germination when the seedlings are 5 to 7 cm tall (IIAA, 1973). Queensland also has a policy of transplanting late.

3.333.2 Spacing

The most usual spacing to use in transplant beds and boxes is 5.0 to 6.5 cm. Stubbings (1958) mentions 5 cm (2 inches) spacing for direct sowing in Swaziland beds. In Kenya it was considered worthwhile to increase the spacing from 5.0 to 6.35 cm (2 to 2.5 inches) in order to give plants an extra 30 percent rooting space in Swaziland beds.

Individual containers (polythene sleeves and bags) may vary from 5 to 13 cm diameter (3 inch to 8 inch lay flat) but the most usual size appears to be about 6.5 cm diameter (4 inch lay flat).

3.333.3 Techniques

May (1953) makes the following points:-

1. Careful handling is most important because if the stems are damaged this provides an entry point for damping off fungi. For this reason seedlings should always be handled by their cotyledons.

2. The tap root should always be cut back by one third of its length. This is most important if transplanting is delayed; failure to cut back will amost inevitably result in kinked roots.

3. The seedling must be well firmed into the soil to ensure that the root is not left in an air pocket.

3.34 Tending

3.341 Watering

The amount of water that needs to be applied depends on the climatic conditions and the soil type. In South Africa Donald (1971) has used as a criterion the water holding capacity of the soil. Tests were carried out at various nurseries near Stellenbosch to find the weight of a box of plants at field capacity and at temporary wilting point. The difference was found to be 19.9 percent of the weight of the soil at field capacity. Experiments are then conducted to test the effect of allowing the boxes to lose 6.6 percent, 13.2 percent and 19.9 percent by weight (i.e. reach temporary wilting point) before rewatering.

Donald considered that rewatering after 13.2 percent loss was adequate for P. radiata. This implied applying only 20 to 30 mm of water every 4-5 days. Ball (1973) at Turbo, Kenya has calculated the pan evaporation rate as 8 mm a day in the hottest season (in January and February) and 6 mm for November, December and April to June. He has experimented in applying water in multiples from half to four times of this evaporation rate. After three months mortality in the driest treatment (4 mm only) at 8 percent was only just significantly worse than the most favourable treatment (24 mm a day) at 3 percent. There was no difference in height growth. In another experiment he found that applying a quantity of water each day was no more beneficial than applying twice the quantity on alternate days.

The standard practice at Turbo is to apply 15-20 mm water a day; this is considerably more than the 4 to 8 mm that appear to be adequate but allowance has to be made for greater water requirements by older plants and also for water loss before it reaches the soil on hot, windy days.

The humidity at Turbo is higher in the mornings than in the evenings; measurements on 3 dry days in January and February, the hottest time of the year, showed 85 to 90 percent humidity between 6 and 8 a.m. as against 35 to 55 percent humidity between 5 and 7 p.m. From this it was argued that watering in the morning is more effective than evening watering (Ball pers. comm.). However Howard (1966) considered that on the Nyika plateau in Malawi taller plants were produced by evening watering; he considered that 1 gallon of water to 15 ft^2 of bed to be the correct application; this is equivalent to 3.3 mm and agrees well with Barrett (1973) who implies that in Rhodesia 2-3 mm of water a day is sufficient.

In Malawi Theron (1972) has pointed out that over-watering in high altitude, cold nurseries can check growth.

Stubbings (1958) has pointed out that application of water as a light spray is desirable for seedlings but that a heavy spray is required to ensure that the water penetrates through the foliage of older transplants to reach the soil.

In general the impression gained is that, where the water supply is adequate, there is a tendency to overwater. This no doubt is usually a fault on the right side, but beside the deleterious effect described by Theron in cold nurseries, there is also the fact to consider that, if plants are being raised in small containers the nutrients become leached out very much quicker. Donald (1971) has noted the interaction between fertiliser regimes and watering schedules and in particular that an inadequate watering regime combined with fertiliser application can inhibit height growth and increase mortality.

3.341.1 Irrigation systems

Hand watering, using watering cans or at the best hoses, is frequently resorted to in small nurseries. It is unsatisfactory on two counts; it is wasteful of labour and more important, it is impossible to ensure that the water is applied evenly to all parts of the nursery.

In any large permanent nursery it will almost certainly pay to install sprinkler systems. Barrett (1973) recommended perforated aluminium pipes which have a rectangular wetting pattern. These, when erected 30 to 40 cm above ground can apply 16 mm of water an hour to a 12 to 14 metre band. There is much to be said for using easily moveable aluminium pipes in order to facilitate nursery operations and to save on capital, particularly if, as in Rhodesia, the daily requirement of water can be applied in 10 minutes. But the system that is chosen must depend on local conditions and availability of equipment. In Rhodesia installation of irrigation equipment in the nursery has cut the time taken to water by a factor of more than 10 (from 12 man hours to a little over 1 man hour a day), and the capital cost of £60 was recovered by savings on labour in one year (Barrett, 1973).

3.341.2 Mulching

May(1953) strongly recommended mulching with chopped grass, leaves, forest litter or woodshavings in order to conserve moisture in the dry season and to keep the surface of the beds loose but moist. However, Ball (1973) had found that mulches had little effect on tree growth; sawdust and woodshavings were blown or washed away within a few weeks.

Mulching is not a general nursery practice.

3.342 Shade

3.342.1 Sun

It is a general practice to shade plants for a period after transplanting and to reduce the shade and finally remove it about a month after transplanting. Materials used for shade are usually hessian, matting or split bamboos. However at Turbo shade over transplants has been dispensed with (Ball, 1973). Pudden (1955) has pointed out that when raising plants in boxes or Swaziland beds the outside rows of plants tend to become desiccated and he suggested that if sinking the boxes or beds below the general ground level is not possible, the soil should be banked against the outside of the boxes and beds and that this soil should be watered. Ball has shown that the soil in polythene sleeves, if exposed to direct sun, can heat up to 45°C; this was counteracted by providing a ½ inch timber surround to the beds of polythene sleeves.

3.342.2 Frost

Frost is not uncommon at higher altitudes. If severe frost is anticipated seedlings should be shaded. The harmful effects of frost can be reduced by brushing off hoar frost before the plants are touched by the sun (Procter, 1963).

3.342.3 Hail

Throughout Central and South Africa, and to a lesser extent in East Africa, there is a risk of hail damage. If there is a likelihood of hail nursery stock must be protected by screens. Half inch (1.25 cm) wire netting is sufficient to reduce the damage considerably (see plate 7); matting and bamboo can also be used.

3.343 Hardening off

The process of hardening-off which involves the gradual reduction of water given to nursery plants and is often combined with severe rootpruning, is frequently recommended (May, 1953; Barrett, 1973), but is not always put into practice. The effect of hardening-off on plants is not fully understood; the technique was presumably introduced into the tropics and subtropics as an analogy to the temperate zone practice of hardening plants off to prevent damage from early frost. It is known that plants which have been put into a state of water stress do undergo structural changes; the root to shoot ratio

and the venation of leaves may increase, and smaller leaves with thicker cutin may be produced (Kramer, 1969). In addition protoplasmic changes may take place, though very little is known about the phenomenon. The effect of these structural changes is to reduce water loss from transpiration, and it seems reasonable that a tree that has lower water requirements should suffer less shock in the period after planting while it is generating new roots (see 3.43). It is a common observation that trees with soft shoots show signs of wilting after planting out. However there are no records of field experiments to test the effect of hardening off on survival or growth in the field in the tropics, though Miller (1965) has shown that P. taeda in south-east U.S.A., when watered after being under stress, were stimulated to greater growth in height than when grown without stress.

Unfortunately the water stress needed to harden off the plants must also inevitably check the plants' growth. Therefore the reduction in the water supply must be judged to a nicety so as not to debilitate the plants. There appears to be no information on the length of time under water stress that is required to bring about the structural changes. The usual recommendation is that hardening off should start a month before planting but, as on many sites in Africa the rains start about a month before planting, it may be necessary to start the hardening off process much earlier. The nurseryman working to a limited time schedule may well be faced with the dilemma of whether to produce large 'soft' plants or appreciably smaller 'hardened' plants. Frequently the option of increasing the period in the nursery will not be open to him, either because the time of sowing is limited by the rainy season or because, for administrative reasons, he must attempt to limit the period in the nursery to twelve months.

The open bed system combined with intensive root pruning and wrenching relies on maintaining the shoot in a hardened-off condition for a relatively long period while the plant develops a fibrous root system and this system is to be recommended in preference to any method of hardening off that relies primarily on the reduction of water in the nursery.

3.344 Root pruning

At some stage all nursery plants require root pruning. Even trees grown in polythene bags must be checked to ensure that roots are not growing through the drainage holes. For plants raised in Swaziland and open beds and in boxes, (i.e. bare root and ball rooted plants), root pruning is an essential part of the nursery production process. The objective is to raise plants with a dense mat of hair roots confined within a small root ball. If this is achieved the plant can be taken to the field with a root system that has a good potential for regenerating new roots. The risk of producing trees which, on being lifted for planting in the field, leave the most important part of the root system in the nursery has been mentioned in section 3.332.

To be effective root pruning must start early. Stubbings (1958) stated that initially roots grow at the same rate as shoots and that under-pruning should start when the shoots are 12 to 15 cm high. If underpruning is delayed he noted that the tap roots are not cut by the pruning wire; they are only bent and distorted. Stubbings recommended underpruning at monthly intervals in order to ensure that the regenerated tap roots are cut, not bent; he made no mention of vertical pruning between the plants. May (1953) recommended root pruning plants raised in boxes at weekly intervals; first week, vertically in one direction and the second week at right angles; at each pruning all roots appearing through the slats at the bottom of the box to be cut. This became common East African practice and was adapted to Swaziland beds using a four week cycle; underprune, vertical pruning in one direction, vertical pruning at right angles, and one week no pruning.

Root pruning should be followed by a heavy watering unless the plants are being hardened off.

3.344.1 Pruning equipment

Kenya commonly uses a slack wire - piano wire has been found to be most suitable - for underpruning Swaziland beds. This system requires that the beds are revetted. Two men work down a bed sawing the wire from side to side. The depth of pruning is dictated by the depth of the revetting boards under which the wire is passed. The disadvantages of this sytem are that even in beds only 1 m wide the wire tends to prune at a higher level in the middle of the bed, also wire breakages are frequent.

Stubbings described a system for underpruning with a taut wire on a tubular steel frame which can be pushed and pulled by four men. The advantage of this system is that the bed does not necessarily have to be revetted. This technique is in use at Turbo in Kenya (see plate 8).

Vertical prunings should be carried out using large kitchen knives rather than with 'pangas' which are too heavy and clumsy. With plants only 5 to 6 cm apart a good eye and a steady hand is needed to ensure that a line of plants does not end up with virtually no roots at all.

The mechanical pruning machine developed in New Zealand is composed of a reciprocating blade mounted on the power take-off of a tractor (Van Dorsser and Rook, 1972). The machine must be geared to give a fast lateral movement to the blade to ensure a clean cut of the root, it should also be designed so that the blade can be tilted to lift the soil and to wrench the plants. Vertical coulters can also be fitted on the front of the tractor to prune the lateral roots in one direction. This machine is not only more efficient, in terms of labour saving, in large nurseries, but may well also produce a better plant.

3.345 Weeding

It does not appear that any experiments have been conducted to assess the effect of weeds on nursery stock; it is assumed, and reasonably so, that a nursery full of weeds, which must compete with the trees for water, nutrients and light is undesirable. The choice of method employed to control weeds should be influenced both by the amount of weed seed that can be expected in the soil and also by the relative vigour of the weed species, but little is recorded in the literature on the latter point. Sedges and grasses, particularly the rhizomatous ones such as Digitaria spp., are probably the most persistent, the most greedy of water and nutrients, and also do most damage to the trees' root systems when hand weeded. Annual weeds are a simpler problem.

The three most commonly used methods of control are soil sterilisation, hand weeding and the use of weedicides.

3.345.1 Soil sterilisation (see also 3.331.33)

Sterilisation of the soil using Formaldehyde, Methyl bromide or steam has resulted in excellent control of weeds (Barnes, 1969), but Donald (1968) considered that most soils brought into South African nurseries are relatively free of weed seeds, and though soil sterilisation reduced subsequent hand weeding time by up to 95 percent (steam), the total cost, even of the cheapest sterilisation method (formaldehyde; weeding time reduced by 81 percent), was 50 percent greater than the control.

3.345.2 Handweeding

Handweeding will become progressively more expensive as labour rates increase; there is also the risk that if weeding is delayed, the act of pulling out the weeds by their roots may well uproot the transplant as well, particularly if the trees are grown in sleeves or bags. Even in countries where labour is still cheap nurserymen should constantly review and test alternatives to handweeding.

3.345.3 Weedicides

Donald listed the following chemicals as being uneconomic in the nursery either because they are ineffective or, more often, because they are toxic to the transplants: Shell products; Gramoxin, Sodium T.C.A., C.I.P.C., and WL3373, Fison's products: Simazine 50W. However two points must be borne in mind: first, the effectiveness of any weedicide varies from one weed species to another; secondly, the agro-chemical industry is continually producing new weedicides, some of which may well be of use to forestry. Donald reported favourably on the use of white spirits, derived from naphthenic petroleum, as a weedicide. The following schedule of application proved effective.

Age	Spraying interval	Strength
0-10 weeks	twice weekly	110 litre/ha
10-12 weeks	weekly	170 litre/ha
12-20 weeks till plants are dense enough to suppress weeds.	weekly	280 litre/ha

This treatment was costed at R0.80 per 1000 plants, which compared with a cost of R2.17 per 1000 for handweeding three times in this period. He gave a list of weed species treated, most are easily controlled by white spirits, whereas P. radiata transplants were unaffected as long as the white spirits were not applied at full strength to plants less than 6 weeks old from transplanting. Trials on P. patula indicated that they too are unaffected by white spirits.

The stale seed bed technique is used in some nurseries. The seed or transplant bed is made up well before sowing or transplanting and the weed seeds are encouraged to germinate. The weeds can then be killed with paraquat to leave a relatively weed free bed. This technique is simple, cheap, and has been reported to be effective in reducing the time required for subsequent handweeding (Stubbings, 1958; Ball, 1973).

If beds are to be kept free of weeds it is essential that paths and surrounds should also be kept weed free. Paraquat is effective for this purpose, but care has to be taken to ensure that trees are not sprayed as well.

3.35 Storing plants

Storage of P. patula plants between the time of lifting from transplant beds and planting out in the field is not generally undertaken. Plants in boxes or in individual containers may be kept for a week or two in bush nurseries at the planting site, but once removed from the bed, box or container the plants are usually planted as soon as possible. However Denison (pers. comm.) was of the opinion that in the conditions prevailing at Sabie in the East Transvaal it should be possible to keep plants in a cold store after lifting and that there would be advantages in doing so. He was conducting experiments on storing P. patula plants.

Chemicals such as Agricol (Sodium alginate) and Vaporguard which cut down transpiration have been used on a small scale in some South African nurseries but there does not appear to be any clear advantage in their use. In Kenya the use of Agricol was not found to give any advantage (Dyson, 1974; Ball, 1973).

3.36 The quality of nursery stock

The quality of nursery stock is frequently judged by the height of the trees, but this is not a particularly good criterion. A

vigorous thick stemmed plant is to be preferred to a long, drawn-up plant, therefore the root collar diameter which is much more difficult than height to measure should also be considered in assessing the quality of nursery stock. But the most important factor, and the most difficult to measure, is the condition of the root system. To some extent the state of the shoot reflects the condition of the root system, but the appearance of, and size of, the shoot is not by itself an adequate guide to the suitability of the tree for planting. Various attempts have been made to relate the root condition to that of the shoot using the root to shoot weight ratio. Donald (1969) found that the parameter that was best correlated with survival of P. radiata in the field was the height x root-shoot ratio. He considered that for P. radiata raised in boxes a root to shoot ratio of 0.6 was best. Root pruning tends to produce a compact root ball with many feeder roots without the long, twisted, lateral roots which tend to occur in sleeves and bags. It is therefore likely that root to shoot ratios for plants raised in boxes and in polythene pots will differ. Over and above this, if plants with deformed and twisted roots are to be avoided the size of plant that can be raised in an individual container is very much less than one that can be raised in the same volume of soil in a bed or a box. It would appear then that a plant both with a longer shoot and with a higher root to shoot ratio can be raised in beds or boxes than can be raised in individual containers, though it should be noted that the plant produced by the open bed method with pruning and wrenching has a large root system combined with short shoot.

It has been reported from several countries that plants raised in individual containers have had deformed root systems, which after a few years have resulted in serious losses in the plantation. It appears likely that in many instances plants had been raised that were too big for the containers. The limitation on the size of plant than can be raised in small sized containers must be recognised by the nurseryman. Failure to do so will almost certainly result in plants which may be of the right size but which are of poor quality. Practical limits would appear to be in the order of:-

Height of tree	Container size
30 cm or greater	Swaziland beds with 15 cm rooting depth
20-30 cm	Boxes with at least 10 cm rooting depth
15-20 cm	Large sleeves and bags. 10 cm or more in diameter
10-15 cm	Medium size sleeves and bags 6 to 10 cm diameter
less than 10 cm	Small sleeves

3.4 Establishment

3.41 Site preparation

3.411 General

The degree of site preparation undertaken depends both on the need for improving the rooting conditions for the young tree and

also on the advisability of preventing weed growth overtopping and smothering it. In areas subject to a severe dry season intensive cultivation may be necessary to eliminate weeds of any sizes in order to conserve soil moisture during the dry season; at the other extreme on sites having moist deep soils without a dry season it may only be necessary to cut back rank weed growth to prevent the young trees from being suppressed and mechanically damaged by the weeds. In between these two extremes are sites - mainly on high altitude grasslands - where the necessity for site preparation and weeding is minimal, though some cultivation may be advisable to obtain maximum growth. Much of the land afforested with P. patula falls in this category.

3.412 Grasslands

Many of the areas planted to P. patula in South Africa are in the sourveld; in Natal this comprises the Ngongoni veld, the Natal mist belt and to a lesser extent the Highland sourveld. In the Transkei it is mostly on the Dohne sourveld; and in the east Transvaal and Swaziland, on the north-eastern Mountain sourveld (Donald, 1971). The natural climax of these areas is forest but human interference has reduced this to fairly stable grassland. In the Natal Mist belt the grass species to be found are Themeda triandra, Aristida junciforis (Ngongoni), also Monocymbium spp., Trachypogon, Eragrostis, Heteropogon and Andropogon spp. Parry (1952) also mentioned Hyparrhenia hirta at lower elevations. In Malawi on the Viphya and Nyika plateau and in the Southern Highlands of Tanzania grasslands carrying these or similar species are found. In Kenya the dominant grass if often Pennisetum clandestinum; these grasslands have in the past usually been planted to P. radiata, but P. patula has been successfully established on them.

In South Africa wherever possible the ground is ploughed and disced before planting, but this is frequently impossible because of steep or rocky ground (Donald, 1971). Large areas of P. patula plantations have been established successfully in grasslands by planting into pits, though Keet (1967) has noted that on the escarpment of the north Drakensbergs in South Africa there was a marked retardation of growth where pitting had to be substituted for ploughing and harrowing. In Madagascar preparation of grassland sites involves subsoiling to a depth of 50 cm followed by ploughing with a double mould board plough to a depth of 20 cm and a width of 40 cm (Vignal, 1956); de Vergnette et al. (1968) mentioned subsoiling and ridging.

At Turbo in Kenya on sites where P. patula has been planted in to grassland it has been found that couch grass (Digitaria scalarum) can be controlled with the chemical Dalapon (Ball, pers. comm.). Ball (1971) also found that on grassland sites in Uganda Dalapon applied at the rate of 10 kg of the active ingredient to the hectare was highly effective in killing couch grass and Hyparrhenia spp., though rather less effective in controlling Imperata cylindricum and Cymbopogon afronardus. The herbicide treatment was 30 percent more costly than slashing the grass, but it was effective

in killing the grasses whereas slashing was not. A survey at Turbo has also shown that survival in a grassland site was very much better where a mould board plough had been used rather than a chisel plough. Ball (pers. comm.) assumed that this allowed an earlier and more effective development of the trees root system.

3.413 Bushland

In Angola much of the land used for planting P. patula is Brachystegia/Julbernardia savanna woodland or has been recently cleared for agriculture. Angle dozers and rippers are used for clearing vegetation followed by complete ploughing (IIAA, 1973). This technique is very similar to the one used in Zambia for planting P. kesiya; sites requiring such intensive cultivation are not usually considered suitable for P. patula. In Kenya P. patula has been grown successfully on sites carrying heavy bracken (Pteridium aquilinum) on the Machakos hills and here the only site preparation possible has been the digging of pits.

Donald (1971b) mentioned the fact that in the Cape Province of South Africa where labour rates are high and where trees are planted into dense bush the use of herbicides and arboricides is much more prevalent than in Natal and Transvaal where labour is cheap. It is likely that on both bushland and grassland sites the use of chemicals to control natural vegetation will become more common.

In South Africa and Kenya where old wattle (Acacia mearnsii) sites have been planted to pines problems have arisen over competition from the wattle regeneration. Ball (pers. comm.) found that harrowing the regeneration was successful, though large saplings had to be treated with an arboricide.

3.414 Bamboo Forest

On the deep soils of the bamboo forests of Kenya and Tanzania there is little problem of moisture stress in the dry season, but site preparation is essential to eliminate fast growing weed species; in particular the bamboo (Arundinaria alpina) which would otherwise overtop and suppress the trees. The sites are in general too steep for the use of mechanical equipment and afforestation is almost entirely dependent on the shamba cultivators. This variant of the taungya system has been successfully applied in Kenya for over fifty years in bamboo forest when the stocking of trees, mainly East African Cedar (Juniperus procera) and Podocarpus milanjianus, is not too high (Kenya Forest Department, 1967). However the use of the shamba system in the broadleaved forest below the bamboo forest has not been very successful because of the difficulty in getting the cultivators to fell all the trees, the impossibility of getting a clean burn, the poorer agricultural crops obtained and the consequent reluctance of the cultivators to continue cropping and keeping the trees weed free after the first year. The incidence of Armillaria mellea on these sites is also higher because of the number of stumps in the ground. It seems probable that the shamba system as it originated may well be abandoned as living standards improve, though it is to be noted that at Turbo on what had been a grassland savanna

site P. patula is being established into maize crops, but there the maize crop is grown on a large scale by one licensee, rather than on small plots by individual farmers as in the traditional shamba system. As a consequence at Turbo though an agricultural crop is only raised for one year, site preparation and weeding can be done mechanically.

P. patula, because of its habit of producing long branches as a young tree and therefore occupying a site quickly, is well suited for establishment by the shamba method since weeds have little chance to become established after the cessation of cultivation. The agricultural crops themselves, of course, have some effect on the growth of the trees. Griffith and Howland (1958) found that at Muguga, in Kenya (2100 m altitude, 980 mm rainfall) a maize crop resulted in a 15 percent reduction in the height of two year old trees and a bean crop resulted in an 8 percent reduction in comparison with clean weeding. But, since in field conditions it would have been impossible to maintain the plantations in a clean weeded condition, this loss of increment was considered to be more than outweighed by the advantages of the shamba system.

3.42 Planting season

In a climate having a markedly seasonal rainfall it is of importance to get the young trees well established before the onset of the dry season. It is generally recognised that planting early in the rains is advantageous but it is not always easy to recognise the actual start of the rains. In East Africa a soil moisture build up chart devised by Pereira (1955) and McCulloch (1961) took into account potential evaporation and the capacity of the soil to store moisture, as well as the rainfall. Conditions were considered to be right for planting when the top 30 cm of soil had reached field capacity. Field capacity varied from 20 mm for light sandy soils to 50 mm for bamboo forest soils. This chart proved most useful in encouraging foresters not to delay too long in starting their planting, but over-enthusiastic foresters still had to be restrained from planting after the first heavy storms in March, which might be followed by a month or more of dry weather.

Cocheme and Zazzara (1969) have shown that there is some correlation between the rainfall in the Kenya highlands in the period April to June and the rainfall in Iringa in Tanzania in March. Such correlations if developed to give longer term forecasts might help foresters in planning their planting, but for the present the soil moisture build up chart and inspection of the soil on the planting site are the two practical tools in helping a forester to determine when to plant.

3.43 The type and quality of planting stock

In section 3.36 some of the problems of raising good planting stock and the criteria for judging what is good stock have been discussed. Experiments to assess the survival of various types of planting stock have usually used shoot length as the criterion for judging the quality. Ball (1973) and Theron (1972) found that

large plants survive better in competition with weeds; this may be partly at least accounted for by the fact that larger trees are less easily smothered by weeds. Dick (1969a) found that, on friable soils on a site having a low or uncertain rainfall in the Southern Highlands of Tanzania, the height growth of large trees (35 cm v. 28 cm) was improved, but that survival, which was poor , was unaffected. Ball (1973) found on heavy clay soil at Turbo in Kenya that large plants (30 cm v 15 cm) grew faster in the first 6 months but that there was no difference in survival.

Investigation to find the best root condition of planting stock has been very limited. Stone and Jenkinson (1971) found that in California the field survival of P. ponderosa was related to the trees' ability to regenerate new roots. At a time of water stress a tree that had regenerated new laterals was at an advantage because it could draw water from a larger volume of soil. They showed that the root regeneration potential of planting stock was controlled to a large extent by the temperature in the nursery (with P. ponderosa the length of time the plant has been below a limiting temperature appeared to be the significant factor); they also showed that the root regenerating peak occurred just before bud flush and was low during active shoot elongation. Very little experimental work has been conducted on the root regeneration potential of tropical pines. Howland and Griffith (1961) compared the root regeneration of ball rooted and naked rooted P. patula, Cupressus lusitanica and Eucalyptus saligna at Muguga, in Kenya, by observing the elongation of new roots grown behind glass. There was some variation in the results depending on the technique used for viewing the roots but root regeneration in P. patula started within 14 days of planting and had grown 30 cm within 60 days from planting; the roots of ball rooted plants appeared to grow rather faster than those of naked rooted plants. (The growth of C. lusitanica and E. saligna roots was faster and they grew 30 cm in 43 and 18 days respectively.) It was noted that height growth was negligible during this period of root growth though there was considerable production of new foliage and lateral growth of branches; this appears to agree with the above observations on P. ponderosa, and also with findings in Madagascar (see 3.325).

It is possible that in the tropics a hardening-off process may exist which will affect the plants' physiology beneficially, not only to aid it to withstand water stress but also to bring it into a condition to regenerate roots rapidly. The open bed technique, involving severe root pruning and wrenching of the planting stock used in New Zealand and now being introduced experimentally in South Africa, in effect hardens-off the plants at an early stage and maintains them in a carefully controlled hardened-off condition. This technique increases the root to shoot weight ratio; if it also enhances the root regeneration potential of the plants, it should be most suitable for sites where plants can be planted as naked root stock. If it is correctly applied it certainly would appear to have more in its favour than the abitrary reduction of water to check plants just before planting.

There has in recent years been a move to use a much greater proportion of planting stock that has been raised in polythene tubes. In Malawi it was considered that the advantage of using plants raised in polythene tubes was so great (Fuller, 1962) that all the stock for planting on the Viphya plateau was raised in this way. In Rhodesia only about one quarter of the nurserymen used open or ball rooted stock (Barrett, 1973) and by inference the remainder used tubed stock. Usutu Pulp Company in Swaziland now raises nearly all its stock in small size polythene pots and in Kenya a proportion of the trees for the Turbo pulp scheme are raised in polythene tubes. However, there is the possibility that the effect of raising plants in small polythene tubes may cause a serious deformation of the root system leading to root strangulation and later on to windthrow or windsnap. Donald (1968) considered much of P. patula windsnap was caused by root deformation in the nursery. Ball (1973) noted that in one survey 25 percent of P. patula in one area of Turbo had deformed roots, which he attributed to the effects of raising the trees in polythene tubes; a later survey indicated that the proportion suffering from wind damage in a six year old plantation was very much less, and that damage also occurred in plantations established with box raised plants. Nevertheless Evans (1973) could find no evidence that the use of polythene tubes in Swaziland had caused any serious increase in the incidence of windblow. But root deformation does not always become apparent until the age of ten or later.

It is not clear how serious the problem of root deformation and windthrow is. In some areas (e.g. Swaziland - Evans, 1973) the experience to date has been that the incidence is so low that defective trees would be removed in the first thinning. It is also apparent that the roots of some species either are not affected by the small polythene tubes or are sufficiently vigorous to grow out of the problem. It is possible that some species can even be planted without removing the tube, but pines are probably more susceptible to root deformation than other tropical plantation species and P. patula appears to be one of the more susceptible of the pines.

It is certain that root deformation of tubed stock, notably strangulation by the roots growing round each other, can take place and it is advisable to take precautions to minimise this effect, first by removing the polythene tube, and secondly by cutting the root ball vertically in three or four places to cut circling roots. These procedures however tend to make the actual planting process slower and therefore reduce somewhat the advantages of using tubed stock.

Where climatic conditions, chiefly high dry temperatures in the planting season, make it inadvisable to use bare root stock, the use of tubed stock, despite some risk of root deformation, has much to recommend it. However it will be advisable to limit the size of the planting stock, to reduce the risk of root deformation in the tubes (see 3.36) and this may make it necessary to clean the plantation more often. On sites where bare root stock (from open beds) or ball root stock (from Swaziland beds or boxes) can be used careful consideration should be given to doing so, because their relatively high root to shoot ratio may well give these plants an

advantage that more than offsets the problems and expense of transporting the plants to the site.

Research into the type and size of planting stock appears in general to have concentrated on the nursery performance of the trees. Donald (1968) related different pricking out techniques to field survival in P. radiata, but a comprehensive field trial of P. patula planting stock using a criteria other than shoot length has not been reported.

3.44 Planting depth

Dick (1969a), concluded from two experiments in the Southern Highlands of Tanzania that deep planting (the root collar buried 10 cm below the surface) was an advantage of friable soils that tended to dry out, because it improved height growth. In Kenya it was general practice to plant deep on the assumption that in the dry season those trees with deeper roots would be less affected by drying of the surface soil. Griffith (1957) noted that deep planting enhanced growth but had no effect on survival.

3.45 The application of fertiliser at planting

In East Africa the sites on which P. patula is planted mostly have fertile volcanic soils, but on some sites on the basement complex and in South Africa soils tend to be friable, leached and deficient in nutrients. Procter (1967) has reported on the problem of boron deficiency on the fertile volcanic soils of the Southern Highlands of Tanzania; this can easily be corrected by the application of borax at the time of planting (see 4.222). Dick (1969b) found that on the leached soils of Sao Hill the application of neither nitrogen nor phosphorus at the rate of 55 gm to each plant, nor NPK at the rate of 110 gm had any effect on P. radiata and concluded that the doses may have been too small. Van Goor (1966) found that P. patula was relatively more efficient in taking up available nutrients than P. elliottii or P. caribaea var hondurensis in Sao Paulo state in Brazil, and it is possible that growth of P. patula is not greatly improved by the application of fertiliser.

In Swaziland a recent trial has indicated the advantage of both cultivating and of fertilising young P. patula. It appeared that the effect of fertiliser (NPK) was longer lasting than that of cultivation. It is also of interest that the second rotation crops appeared to have better growth than the first rotation crops and that removal of the needle mat had a deleterious effect (Germishuisen, 1974) (see Table 3.451). Preliminary result of an experiment in Madagascar indicated that application of nitrogen at planting increased mortality and depressed growth. Application of phosphate increased growth and decreased variability; potassium had little effect (de Vergnette et al., 1968). At Turbo in Kenya trees planted into maize are treated with nitrogen and phosphorus in the proportion of 1:5 at a rate of 112 kg to the hectare; this is the standard treatment for maize crops, but there has been no report on the effect on the pines. Addition of phosphate is current practice in Queensland.

3.451 Table. Mean Heights and increments (in cm) of a first rotation establishment trial at Usutu (Site B17) in Swaziland (Germishuisen 1974.)

Age 18 months	Height			Increment 6-18 months		
Treatment	No fert.	fert.	Mean	No fert.	fert.	Mean
Control	69	89	79	56	71	64
All ground cover cleared	74	90	82	63	79	71
Ploughed and rotovated	111	132	122	99	116	108
Mean	85	104		73	89	

Age 30 months	Height			Increment 18-30 months		
Treatment	No fert.	fert.	Mean	No fert.	fert.	Mean
Control	183	224	204	114	135	125
All ground cover cleared	189	243	216	115	153	134
Ploughed and rotovated	264	316	290	153	184	169
Mean	212	261		127	157	

Note 1) Information on the variance of the experiment is not available but from visual inspection there appeared to be marked differences between plots.

2) Though the difference in increment in both years is greater between the control and the ploughed treatments than between the control and fertilised treatments, the fertiliser effect has nearly doubled in the second year, while the cultivation effect has remained constant.

3) All plots received an initial light burn.

4) Fertiliser consisted of:-

N = 33.9 gm active ingredient/tree
P = 21.4 gm active ingredient/tree
KCl 28.5 gm active ingredient/tree
B and S; ¼ teaspoonful of borax and elemental sulphur

3.452 Table. Mean Heights and increments (in cm) of a second rotation establishment trial at Usutu (Site B17) in Swaziland (Germishuisen, 1974)

Age 18 months	Height			Increment 6-18 months		
Treatment	No fert.	fert.	Mean	No fert.	fert.	Mean
Control	136	147	142	116	126	121
All ground cover cleared	87	115	101	73	98	85
Ploughed and rotovated	138	143	140	121	125	123
Mean	120	135		103	116	

Age 30 months	Height			Increment 18-30 months		
Treatment	No fert.	fert.	Mean	No fert.	fert.	Mean
Control	281	287	284	145	140	143
All ground cover cleared	209	251	230	122	136	129
Ploughed and rotovated	280	291	286	142	148	148
Mean	257	276		136	141	

Note 1) The second rotation trial was adjacent to but not randomised with the first rotation trial.

2) By the age of 30 months there appears to be little effect as a result of either ploughing or fertilising.

3) Humus removal was deleterious.

4) Though the second rotation crop were superior to the first rotation crop on unfertilised plots there was very little difference on fertilised plots.

3.46 Beating up (Blanking or In-filling)

Because the growth of P. patula, and in particular the growth of the lateral branches, is so vigorous on good sites, late beating up with small stock was considered to be largely a waste of time in Kenya, however Usutu Pulp Company recommended blanking in the second and third year. The use of large stock is usually recommended, though the ability to start growing and to get away is of more importance than the actual size of the stock.

3.47 Weeding

In those areas of East Africa where P. patula is established by the shamba system, weeding should be unnecessary because the licensed cultivator should keep the crop clean at no charge to the Forest Department till canopy closure occurs, but where shambas have been neglected the weed growth must be controlled or the growth of the trees is severaly retarded.

A recent Kenyan establishment experiment emphasises the importance of keeping P. patula weeded in its early years. RE 288 was laid out in order to assess the prospects for establishing plantations in bamboo forest without the aid of shamba cultivators. Even when weed growth was slashed at regular intervals mortality among the P. patula was unacceptably high; spot cultivating was an even more disastrous treatment. The addition of fertiliser had no significant effect on height growth. The P. patula is obviously far more sensitive to competition from bamboo than C. lusitanica.

3.471 Table. Results at 3 years of RE 288 - a Kenyan establishment trial

	P. patula		C. lusitanica	
Treatment	Survival %	Height m	Survival %	Height m
1. Control	-	-	-	-
2. Slashing at frequent intervals	35	4.4	65	4.0
3. = 2 + superphosphate	15	(4.6)	70	3.6
4. Slashing when weeds reached 1.8 m	20	3.6	58	4.2
5. = 4 + superphosphate	25	2.8	75	4.2
6. Spot cultivation for 0.6 m radius	5	(0.9)	60	1.0
7. Clean cultivation	70	4.9	93	4.6
8. = 7 + superphosphate	53	4.2	83	4.3
Least sig. diff. at 95% probability	23	-	28	.98

In Angola P. patula plantations are cultivated mechanically for two or three years, to eliminate all weed competition. Ball (pers. comm.) also considered clean weeding to be essential on relatively shallow soils at Turbo in Kenya; where the trees are planted into maize theywere sprayed with Simazine and Atrazine as part

of the routine treatment for the maize crops. Ball (1974) experiemnted with Atrazine Simazine GS 14259 Ametryn and Desmetryn as wetable powders and Atrazine as a liquid. He considered that Simazine or liquid Atrazine at 3 kg active ingredient to the hectare to be the most effective against Digitaria scalarum, Panicum maximum and Rhyncholytrum roseum. At this rate of application Atrazine affected the pines to some extent, but this was only temporary. Dalapon applied at 7.9 kg/ha after grass cutting controlled the growth of grass upto the end of the dry season, whereas after harrowing grass had regrown entirely. Dalapon cost K Sh. 100.00 a hectare as against K Sh. 45.00 for mechanical weeding. Tordon (Picloram plus 2.4 - D) proved effective against wattle seedlings. Luckhoff (1964) reported that young P. patula roots that had been damaged by cultivation became infected with Helicobasidium compactum.

In the grassland sites weeding is not usually considered necessary for P. patula, but large areas have to be cleaned in South Africa (Donald, 1971). The area cleaned in the P. patula growing areas (East Transvaal, Natal and also Swaziland) amounted to 35 to 45 percent of the total area planted in the five years 1965 to 1969. The weeds beside the shrubby indigenous regrowth included Lantana camara, Rubus cuneifolius (American bramble), Solanum auriculatum, Phytolacca octandra and Caesalpinia sepiaria (Mauritius thorn) which are aggressive exotic weeds. Weeding was still mostly by hand at an average cost of £4.75/ha (R3.21/ac) treated and £0.40/ha (R0.27/ac) planted, and he calculated that the total annual weeding charge in the country amounted to some £420,000 (R700,000). He anticipated that with a rise in labour costs mechanical weeding and the use of herbicides would become much more common; Tordon (2.4.5-T plus chloropicrin) was used to some extent in the Cape and was considered promising.

3.5 Tending

3.51 Spacing and Thinning

3.510 General

In the early years of the century pine plantations in South Africa were established at very close spacing, following the practice in vogue in Europe at that date, and thinning consisted of little more than removing dead trees. By the 1920s the planting espacement had been increased from 1.2 or 1.5 m to 2.1 m and plantations on good sites were thinned relatively heavily, though those on poor sites were still kept dense (de Villiers et al., 1961). In 1939,Craib pointed out that to grow exotic conifers at a profit it was necessary to maximise increment on a few trees and to do this he recommended planting at wide spacing and heavy early thinning. Craib advocated planting espacement of 2.4 m to as wide as 3.7 m in order to produce trees of 46 cm diameter. His recommendations for a second quality site were not so very different from the schedules in use in 1939, except that initial spacing was wider and early thinning was heavier (see Table 3.510.1). What was novel was that he advocated wider

spacing and heavier thinning on lower quality sites than on good quality sites.

3.510.1 Table. 1939 South African Thinning Schedules for P. patula on Site Quality II.

		Standard Practice up to 1939			Craib's recommendations		
Age	Dom. Ht.	Stems/ ha	DBH of Thinnings cm	Volume m^3/ha	Stems/ ha	DBH of Thinnings cm	Volume m^3/ha
0		2200			1335		
6	8.5	1360			740		
9	13.1	815	12.4				
14	19.2	545	18.0		470	12.4	
25	25.9	370	28.2		320	30.5	
35	30.2	0	40.6	749			
40	30.2				0	45.7	693

Though the standard practice in 1939 resulted in a larger volume of timber, Craib calculated that adoption of his schedules would halve the volume of timber of less than 20 cm diameter and would more than double the volume of timber of 30 cm diameter and over.

Craib's arguments were largely accepted in South Africa and also in other African countries that grew exotic softwoods; his recommendations are the basis for much of the modern thinking on thinning in quick growing exotic crops in the tropics and subtropics. In 1947 he revised his prescriptions and the schedules in use in South Africa from 1948 to 1970 are based on his revised recommendations. These schedules are compared with those for other countries and other schedules recommended in South Africa in Table 3.510.2 in Appendix II.

The response of P. patula to release will be discussed in Chapter 5 on Growth and Yield, and the financial aspect in Chapter 8 on Management; comments in this section will be confined primarily to the more silvicultural aspects of thinning and spacing.

3.511 Spacing

Initial espacement in P. patula plantations in most countries varies from about 2.4 m to 2.75 m (1680 to 1330 stems to the hectare); the extremely wide spacings advocated by Craib for low quality sites have been discarded. The most suitable espacement on any one site depends on an interaction of several factors including the necessity for cleaning young crops, the availability and economics of using mechinery for cleaning operations, the cost of planting stock and the planting operation, and finally the economics of early and possibly uneconomical thinnings. These factors vary from one country to another, from one site to another and from year to year.

On bamboo sites in East Africa the controlling factors which have influenced management towards closer spacing (2.4 m - 1680 st/ha) appear to have been that steep slopes have often made the use of machinery impractical and that experience has shown that at a spacing of 2.4 m P. patula covers the site in two years and makes any cleaning operation after the cessation of shamba cultivation unnecessary. The first thinnings, at age seven or eight, have been unsaleable but even so it has been considered preferable to carry out a financially unremunerative first thinning rather than weeding in the third year. Another factor that has influenced management towards closer spacing has been the need to have sufficient stems on the ground from which to select for the final crop and later thinnings; in Kenya early plantation management orders advocated a 9 ft (2.75 m) spacing for P. patula, but this was later reduced to 8 ft (2.4 m) because it was found that crops were too patchy at the wider spacing (Dyson, pers. comm.). In Rhodesia an initial stocking of 1680 stems to the hectare was considered essential in order to allow selection (Banks, 1962).

On grassland sites in Kenya, and at Turbo, plantations have been established at stockings of around 1700 stems to the hectare, but the espacement has been rectangular (2.10 m x 2.75 m at Turbo, Ball pers. comm.) rather than square, in order to make access for machinery easier. In South Africa the initial espacement in plantations grown for sawlog productions has been rather wider (2.85 m, Burgers, 1972); the first thinnings at age six or so have been considered saleable, but nevertheless extensive weeding has often been required in the early years (Donald, 1971b). (See 3.47). Cawse et al. (1972) have shown that in P. patula plantations grown for pulp an initial stocking of about 1680 stems to the hectare (2.4 m spacing) gave a better internal rate of return than either a stocking of 2200 (2.1 m spacing) or 1330 (2.65 m spacing). In Kenya it has been the practice to demarcate the planting espacement with great care, this has involved the expenditure of funds, but has been considered worth while because it has then been possible to mark thinnings on an arithmetical basis - e.g. leave six trees standing on twelve (three by four) planting spots. When planting has been done at an accurate espacement it is very easy to train junior staff to mark thinnings on this basis. It would also facilitate line thinning on the diagonal (see 8.3).

3.512 Thinning

Craib was an advocate of early heavy thinning in order to grow trees from which saw logs could be obtained on as short a rotation as possible. Since Craib's time it has become much easier in South Africa to sell small sized logs and the market for pulp logs has increased considerably and now accounts for about a quarter of the P. patula produced. As a result thinning is delayed in current South African schedules to allow the basal area to build up. Recently Grut (1967) and Burgers (1972) have recommended, on economic grounds, that schedules involving heavy late thinnings should be used. Broadly speaking saw log schedules in current use are designed to produce about 250 trees to the

hectare, having a mean breast height diameter of about 45 cm at rotation age, which has been judged to be about 30 years on class two sites in Kenya and 35 to 40 years in South Africa, though Grut (1967) considered it possible to achieve this size on 160 trees to the hectare in 25 years. For pulp projects, rotations vary from 15 years in Swaziland to a recommendation of 25 years in South Africa, and anticipate growing trees of up to 30 cm diameter at breast height.

3.512.1 Thinning to control wood quality

In East Africa the general objective of plantation forestry has been to maximise output of timber, with little consideration being given to the possibility of using thinning as a tool to control wood quality. However in South Africa much thought has been given to regulating thinnings so as to grow timber of good and uniform quality. Marsh (1963) considered that the ideal to be arrived at was a tree in which wood had been laid down at a uniform rate of 4.2 to 6.3 mm radius a year (4 to 6 rings to the inch). He recognised that the juvenile core of low density wood could not be limited by practical silvicultural techniques and considered that a juvenile core of about 12 cm diameter would have to be accepted. Burgers (1972) pointed out that the 1948 South Africa thinning schedules (see Table 3.510.2) would result in uneven ring sizes and proposed a saw log schedule, very similar to the one advocated by Marsh, which he considered would limit the juvenile core (defined by him as those rings of greater width than 10 mm) to a core of 20 cm diamter. For pulp he considered that by planting at 2800 stems to the hectare the core could be limited to 11 cm. Burgers' definition of the juvenile core appears to assume that the production of this low density weak wood is an effect only of growth rate, in fact he stated that a really fast grown tree of 25 years of age with growth rings of over 10 mm could be considered to be entirely juvenile core. However Turnbull and Du Plessis (1946) and Scott and Stephens (1947) working on South African material were of the opinion that the strength of the juvenile core is not primarily determined by environmental conditions. Fry and Chalk (1957) and Brister (1960) using Kenyan material considered that the increase in wood density, tracheid length and wood strength from pith to bark was to a large extent an effect of age. If this is so, there should be some potential for a policy of restricting the juvenile core by close planting and delayed first thinning, which could then be followed by a period of unrestricted fast growth.

However de Villiers *et al.* (1961) were of the opinion that, in reference to the juvenile core, there was no evidence that changes in silvicultural treatment within the range of densities considered practicable for economic reasons would have any material effect on timber quality. The picture is somewhat confused, but it is unlikely that the juvenile core can be reduced to less than 15 cm diameter now, though tree breeders may eventually be able to improve on this.

Fry and Chalk (1957) observed that in comparison with European grown conifers Kenya grown *P. patula* had a very much smaller difference

between the density of early wood and late wood within any one ring. There appear to be no records of a similar comparison having been made on South African material, but judging by the trouble taken in South Africa by silviculturists to grow timber with uniformly spaced growth rings the differential between early and late wood is considered to be of importance. (See figures 6.211.1 and 6.42 for a comparison of wood densities).

In East Africa an effect of the two peak rainfall and the general lack of soil moisture stress on most sites is that growth rings are indistinct. This combination of poorly defined two-ring to-the-year growth with little differentiation between early and latewood qualities results in the within-ring variation in tropical grown P. patula being very much less than that of trees grown in the subtropics where wet and dry seasons are more clearly differentiated. If this is so there may be very much less reason to worry about a uniform rate of growth in East Africa than in South Africa. Plumptre (1972) noted considerable variation in latewood percent between trees on one site in Uganda and considered that this might be an inherent trait; it is probable that the development of trees with an inherently high proportion of latewood is of greater potential benefit in the tropics than juggling with silvicultural regimes.

3.512.2 Site factors

There are ecological factors which may make heavy late thinning advisable.

Wind damage. It has been observed that twenty year old crops are prone to windsnap (see 4.11). On sites where high winds frequently occur it may then be necessary to keep crops open from the age of fifteen onwards in order to reduce the risk.

Needle mat. Under dense mature crops there is, in South Africa in particular, a considerable accumulation of leaf litter which can lead to the formation of a dense humus mat of 20 to 30 cm depth (see 2.511). This mat can affect both the moisture and the nutrients made available to the trees. Under open stands there is more opportunity for broad leaved ground cover to grow and for the needle mat to disintegrate.

Shallow soils. On shallow soils a situation of moisture stress will occur in the dry season, frequently resulting in poor height growth and stagnation. This moisture stress must inevitably be greater under a dense mature stand and therefore on shallow soils it will probably be necessary to thin heavily in order to keep the final crop trees growing, though if that is necessary it is likely that P. patula should not have been planted in the first place.

3.512.3 Thinning techniques

The Queensland selection system and other techniques for selecting potential final crop trees have been used in some countries.

These systems assume that the final crop trees can be identified at an early age (5 or 6 years) so that they can be given preferential treatment when subsequent thinnings are undertaken.

In Kenya the Queensland selection system as such has been discontinued but the basis of marking thinnings is still an eclectic one with the objective of favouring potential final crop trees. However Veldhoen (1968) in analysing a thinning experiment in Kenya observed that the identities of the largest 250 stems per hectare changed at the rate of 32 trees a year. Kibuku et al. (1972) have confirmed this change in ranking in a study of plus-trees which showed that of 35 selected in 1955 only 3 retained their predominant position in 1971. These observations call in question the practicability, or even advisability of selecting potential final crop trees at an early age. If the uniformity of the crop can be improved by tree breeding it may well be just as efficient in the future to thin mechanically, taking out every alternate or every third tree, depending on the proportion to be removed. It may even be practicable to carry out line thinning (see 8.3). In Kenya it is already the policy to remove every eleventh line of trees at the second thinning (at age 12 approximately) in order to provide extraction tracks (Logie, 1966).

3.52 Pruning

The branches of P. patula are persistent and self pruning hardly occurs (Loock, 1950). Dyson (1961a) noted that in an experiment planted at close spacing (1.8 m) at eight years of age live branches could still be found only one metre above ground level. Pruning is therefore essential if high grade timber is to be produced from plantations established at a wide spacing and subjected to heavy early thinning. Craib (1939) recognised this and insisted on the necessity for pruning young trees.

Low pruning (to about 2 m) is undertaken in most P. patula plantations in order ot provide access and to reduce the fire risk. Pruning to a higher level is undertaken in order to improve timber grades either by the elimination of loose knots which can be achieved by pruning dead branches or to produce clear knot free timber by green pruning. Most pruning schedules advocate green pruning at an early age, but the advantages in greater outturn of higher grade timber are obtained at a cost, both of a higher risk of fungal infection through the pruning scars (e.g. Stereum sanguinolentum; see 4.224) and also in loss of volume increments. High pruning of plantations grown for pulp is not usually considered justifiable, but it is generally accepted that the butt log (5 to 7 metres long) of the final crop saw log trees should be pruned. The advantages of high pruning to 11 or 12 metres are more debatable. The cost of pruning the second log must inevitably be higher and the benefit must be less than for the first log, but though the experimental results discussed in this chapter cannot give a clear verdict on this point the consensus of opinion appears to be that high pruning is justified; a practical example of this is that South African Forest Investments consider pruning the final crop trees to 11 metres to be essential.

3.521 Pruning experiments

There are well documented accounts of pruning experiments on P. patula in South Africa (Luckhoff, 1949 and 1956) and Malawi (Adlard, 1964 and 1969), but though the authors are in general agreement on the short term effects of pruning on tree growth, their interpretation of these effects in terms of yield at the end of the rotation vary. It is apparent from the experiments that severe pruning, as judged by the proportion of crown removed, has a marked effect on tree growth. However Brown (1962) has pointed out that the stocking of the plantation affects the photosynthetic efficiency of the individual tree's crown and that to attempt to assess the effects of pruning on stem increment without taking the stocking of the plantation into consideration can lead to anomalous conclusions. In P. taeda the branches with contribute most to stem increments occur 15 percent of the height, from the top of the tree (Labyak and Schumacher, 1954). In fact the lower 'shade' crown in densely stocked plantations probably contributes little or nothing to the stem increments. Unfortunately in the experiments quoted here, though the stocking of the plots have been given, there is no data available on crown diameters. It has not therefore, been possible to deduce the likely depth of the shade crown and hence the effect of pruning treatments in terms of loss of actively photosynthetic crown as against merely live crown removal.

3.521.1 Effect on height growth

Both Adlard (1964 and 1969) and Luckhoff (1949) noted a small but statistically significant decrease in height growth with very severe pruning (removal of approximately 75 percent of the crown) in the first year after treatment, but by the second year height increments were no longer significantly different.

3.521.2 Effect on breast height diameter and basal area growth

The effect on diameter, and hence basal area, growth has been shown to be greater than on height growth.

3.521.21 Table. Pruning effects on diameter increments: South Africa & Malawi

Treatment LCR*%	South Africa: Luckhoff (1949) 494 st/ha				Malawi Adlard (1969) 613 - 697 st/ha			
	$\bar{h}$	$\bar{h}_{dom}$	V/t *** 6-12 yrs	$\bar{d}$ 12 yrs	$\bar{h}$	$\bar{h}_{dom}$	V/t 8-12 yrs	$\bar{d}$ 12 yrs
0	9.7	-	1.7	24.7	10.8	2.0	1.6	21.3
approx. 25	9.8	2.4	1.6	24.2	10.8	4.5	1.4	20.6
50	9.8	4.9	1.4	22.5	11.9	6.8	1.2	20.5
75	9.7	7.3	1.0	20.2	11.3	8.5	0.7	18.2

* Live Crown Removal
** Pruned Height
*** Periodic Mean Annual Increment

The periodic mean annual increment of the severest pruned treatment over these periods was reduced by over 60 percent and the mean diameter of the severest treatment was significantly smaller than the control at the end of the period, though annual increments ceased to differ after about the third or fourth year. Adlard (1969) found that the difference between the 50 percent treatment and control was not significant after the second year. Luckhoff (1949) found that the absolute difference between the 50 percent treatment and control was significant even after six years, even though the difference in annual increment ceased to be significant after the third year.

These differences between treatments and between sites are explicable if it is assumed that at a mean of 655 stems to the hectare in Malawi (S% = 37) at eight years of age the shade crown commenced at about 5.5 m and as the trees grew taller and the crowns spread the 'shade' crown level was raised to nearer 8.5 m. Whereas in South Africa at 494 trees to the hectare (S% = 49) at six years of age the 'shade' crown presumably started at a lower point, somewhere between 3 and 4 metres, and therefore at this wider spacing the 50 percent treatment involved the removal of a greater volume of photosynthesising needles and had a relatively greater effect on diameter increment.

The cumulative effect on basal area appears even greater, though in Malawi annual increment differences ceased to be statistically significant after the third year. By the fourth year diameter increment, and even basal area increment in the two less severe pruning treatments, exceeded those of the control. Whether this tendency would continue until the basal area of all treatments equalled that of control cannot be deduced from the evidence available. However Luckhoff (1956) could find no significant differences in diameter between trees pruned as follows:-

2.4 m - 6.7 m in one lift age 9
2.4 m - 8.8 m in one lift age 10
2.4 m - 8.8 m in two lifts age 9 and 11
2.4 m - 11.0 m in two lifts age 9 and 11

when measurements were taken four years after initial treatment. He concluded that any effects of pruning to 6.7 m would certainly have disappeared by the end of the rotation.

3.521.22 Table. Basal area increment Malawi pruning experiment

Treatment LCR	Basal Area Increment m^3/ha				G
	Age				
%	8 - 9	9 - 10	10 - 11	11 - 12	t = 12
0	4.02	3.28	3.00	1.91	23.74+
28	3.26**	2.74**	2.89	2.14	23.22
49	2.10**	1.95**	2.62**	2.40	22.44
72	0.58	0.68	1.46**	1.76	15.77+
Least sig. diff.	.77	.55	.28	.64	7.98
** Differences significant at P.01					
+ Differences almost significant at P.05					

3.521.3 Effect on stem taper

Adlard (1969) showed that while severe pruning reduced diameter at breast height it enhanced increment immediately below the pruning point and to a decreasing extent for a distance of about 3 m down the stem. Luckhoff (1949) also stated that severe pruning improved stem taper. However Adlard did not consider that the differences in taper between his 28 percent and 72 percent treatments would make a significant difference to stand volumes.

3.521.4 Effect on volume

Adlard considered that loss of diameter increment resulting from the application of his severe treatment (pruning to 8.5 m) would be the equivalent to two to three years in the length of the rotation when compared with the 28 percent treatment (pruning to 4.5 m). Luckhoff found that early high pruning had a greater effect on increment than late pruning.

3.521.41 Table. Loss in volume after 4 years as a result of pruning (Luckhoff, 1949)

Treatment	Pruning at	
Live crown removed %	4 yrs	8 yrs
50	20%	10%
75	33%	23%

However it is unlikely that volume differences of this order would be statistically significant at rotation age.

Luckhoff also found that if only selected trees in a crop were pruned instead of the whole crop, the recovery period was increased by one or two years. This has been confirmed in New Zealand where it has been found essential to combine selective pruning of P. radiata with a heavy thinning. (Sutton, 1974)

3.521.5 Other effects

3.521.51 Branch size

Luckhoff found that branch size immediately above the pruning point was slightly less on pruned trees than at the same height on unpruned trees. Adlard confirmed this.

3.521.52 Epicormic branching

The initiation of epicormic branches as a result of heavy thinning and the removal of side shade is only a small problem in P. patula. It occurs to some extent but does not require remedial pruning.

3.522.1 Table. Comparison of 3 pruning schedules

Effective Knotty Core	Recommended in Adlard (1969)					Sherry (in Crowe, 1967)					Luckhoff (in Crowe, 1967)				
	15 cm					18 cm					20 cm				
Age	Tree Ht (m)	Pruned Ht (m)	Lift m	LCR %	Crown Depth m	Tree Ht (m)	Pruned Ht (m)	Lift m	LCR %	Crown Depth m	Tree Ht (m)	Pruned Ht (m)	Lift m	LCR %	Crown Depth m
4						4.9	1.8	1.8	37	3.1					
5	5.8	3.4	3.4	59	2.4						6.1	2.1	2.1	35	4.0
6						7.4	3.6	1.8	33	3.8					
7	9.2	6.1	2.7	47	3.1	9.2	5.4	1.8	33	3.8	9.2	4.6	2.5	34	4.6
8						11.0	7.4	2.0	33	3.6					
9											12.2	6.7	2.1	28	4.5
10	13.7	9.8	3.7	49	3.9										
11+											16.8	11.0	4.3	50	4.1

3.521.53 Sun scorch

Luckhoff (1949) stated that sun scorch and desiccation of the soil occurred in one experiment in which severe pruning and heavy thinning were combined. However there were other adverse factors in this experiment including a severe drought and defoliation by Euproctes terminalis. There are no other records of death from sun scorch resulting from heavy pruning.

3.522 Knotty core

The main objective in high pruning is to grow high grade timber, therefore the diameter of the stem in the section to be pruned is an important factor in determining the knotty core and hence the volume of knot free timber that can be laid down over this core in a given rotation, or alternatively the length of rotation needed to achieve a given stem size and therefore dimension of board that can be cut from the clear timber. There are no records in the literature of pruning experiments that have been grown to rotation age and been sawn up to determine the effectiveness of different pruning policies in producing high grade boards. However, if an allowance of 3 to 5 cm diameter is made for grain deflection and branch stubs (Sherry, 1967), the theoretical knotty core at rotation age can easily be calculated from diameter measurements at time of pruning.

Experience has shown that the effective size of the knotty core is usually determined by the stem diameter at the base of the section to be pruned in the final lift. Therefore the earlier this pruning is carried out the smaller the knotty core will be. But because of the presence of an inherently low density, weak juvenile core in P. patula it is pointless to attempt to achieve a knotty core of less diameter than the juvenile core. The size of the width of juvenile core varies considerably from tree to tree, but it seems unlikely that it can with certainty be confined to a core of less than 20 cm diameter. In Table 3.522.1 three pruning schedules designed to produce cores of different sizes and for different log lengths are compared. It can be seen that frequent small lifts will achieve a smaller knotty core but will also result in a more drastic reduction of the crown depth. Crowe (1967) commented that Sherry's low pruning schedule was mainly used by private growers in Natal, whereas Luckhoff's was used in publicly owned plantations, but in 1973 South African Forest Investments at Sabie in the Eastern Transvaal considered pruning to 11 m to be essential.

3.523 Pruning costs

Luckhoff (1956) gave the following costs.

3.523.1 Table. South African pruning costs

Height pruned	Time/tree Minutes	Daily task Trees/manday	Remarks
4.6 - 6.7	7.5	37	Pole saws
4.6 - 8.8	12.0	30	Ladders and handsaws but inexperi-
6.7 - 8.8	16.8	20	enced gangs used in the work study.
6.7 - 11.0	13.9	30	Ladders and handsaws, more experi- enced gangs used.

The study was conducted over several years and results are not fully comparable, but nevertheless give some idea of costs involved in pruning. Luckhoff estimated that at 1956 prices the cost of pruning from 6.7 to 11.0 m would have been less than £0.01 a tree. However Sherry (1967) gave the cost of pruning from 7.3 to 12.2 m as £0.06 (R0.125) a tree.

3.524 Pruning techniques

In South Africa pole saws are used for pruning to 6.7 m (Luckhoff, 1956), thereafter ladders must be employed to get into the crown. In Kenya a single pole bamboo ladder, which is light and essily moved from tree to tree, was found to be quite adequate for climbing up to 10 m of pruned stem. In New Zealand pruning to 6 to 7 m is done using handsaws and a 4 to 5 m aluminium ladder; high pruning to 10 or 12 m is done using a short aluminium ladder and a platform that can be strapped to the tree trunk. In Uganda rope ladders, which with the aid of a light pole can be hooked onto the lowest branch, have been used successfully.

In Rhodesia pruning late in the rains is considered to be harmful, so harmful in fact that deaths in the dry season have been attributed to this practice.

3.525 Financial return

Various predictions have been made on the outturn of clear or high grade timber from different pruning schedules. Adlard (1969) predicted that the experimental treatment which involved pruning to the 8 cm diameter point (8.5 m) at age eight would result in up to 72 percent of the final timber outturn from trees 27.4 m and 51 cm dbh being clears, as against only 44 percent from trees pruned to 4.5 m. From these estimates he argued that severe pruning was justified though he made no attempt to calculate the cost of pruning or the enhanced value of the clear timber. Brown (1965) however commented that, in P. radiata, because of various stem defects, in practice actual outturn of clear boards was never more than 70 percent of the theoretical outturn.

The value attached to clear, knot free timber is difficult to estimate and it must fluctuate with demand. Sherry (1967) calculated that by using his pruning schedule (see Table 3.522.1) 7.5 cm of clean timber would be laid down on the butt log over the knotty core in a rotation of 42 years. This he considered to be the minimum width of clean timber necessary to produce 3.8 x 11.5 cm (1½ x 4½ inch) boards. He further calculated that if the second log were to be pruned to 12.2 m the rotation would have to be lengthened to 55 years in order to obtain this minimum width of clear timber. For this reason he considered that high pruning would be uneconomic; in fact he calculated that the pruning regime which would give the best financial return would be dead branch pruning to 7.3 m. Luckhoff (1956) while also concluding that high pruning to 11 m to produce clear boards would not be economic did consider that such pruning was justified by the increase in timber grades obtained by eliminating dead, loose knots in the second log (7.3 to 12.0 m).

3.526.1 Table. Some pruning schedules for P. patula

	Age	$\bar{h}$	$\bar{h}_{dom}$	Lift	C.D.	LCR%	Stocking	S%
South Africa (Craib, 1939)	6	8.5	2.4	2.4	6.1	28	740	46
	7	10.0	4.6	2.2	5.4	29	740	39
	9	13.1	6.7	2.1	6.4	25	740	30
South Africa (Luckhoff, 1956)	5	6.1	2.1	2.1	4.0	35	1240	50
	7	9.2	4.6	2.5	4.6	34	740	43
	9	12.2	6.7	2.1	5.5	28	740	26
	11+	15.1	11.0	4.3	4.1	50	740	26
South Africa Sherry, 1967)	4	4.9	1.8	1.8	3.1	37	1240	62
	6	7.4	3.6	1.8	3.8	33	740	53
	7	9.2	5.4	1.8	3.8	33	740	43
	8	11.0	7.4	2.0	3.6	33	740	36
Rhodesia (Banks, 1962)	7	9.2	(3.8)	3.8	5.4	41	990	37
	10	14.0	(6.0)	2.2	8.0	22	990	24
	12	17.4	11.0	5.0	6.4	44	740	23
Rhodesia 1967 (Director's Order No.1)	<4	5.6	1.9	1.9	3.7	35	1675	47
	5	7.8	4.7	2.8	3.1	53	1675	34
	<7	10.7	6.7	2.0	4.0	53	990	32
	10+	15.6	11.0	4.3	4.6	46	990	22
Malawi (Marshall & Foot, 1969) A Sites	5	6.1	2.1	2.1	4.0	34	1335	48
	7	11.0	4.6	2.5	6.4	35	860	33
	9	12.2	6.8	2.2	5.4	29	860	30
	12	16.8	11.0	4.2	5.8	42	860	22
Malawi (Adlard, 1969)	5	5.8	3.4	3.4	2.4	59	1335	51
	7	9.2	6.1	2.7	3.1	47	1335	32
	10	13.7	9.8	3.7	3.9	49	860	27
Madagascar	5	6.0	2.7	2.7	3.3	45		
	7	9.0	4.5	1.8	4.5	29		
	9	12.0	6.6	2.1	5.4	28		
Kenya (Technical Order No.34)	4+	6.1	3.4	3.4	2.7	55	1675	43
	6	9.2	4.9	1.5	4.3	32	1675	29
	8	12.2	6.7	1.8	5.5	21	690	34
	12	16.8	10.0	3.3	6.8	22	690	24

C.D. : Crown diameter

3.526 Pruning schedules

Schedules for second quality site classes used in various countries are given in Table 3.526.1. It is unfortunate that it has not been possible to giving stocking in every case. The proportion of live crown removed in one lift varies from as little as 22 percent to as high as 53 percent; final pruning height may be as low as 6.6 m (Madagascar) or as high as 11 m (South Africa, Rhodesia and Malawi); crown depth after pruning may be reduced to as little as 2.7 m (Madagascar). The range of choice is wide.

3.527 Conclusion

The decision to undertake high pruning (from about 6 m to 11 or 12 m) must depend on whether it is considered that at the end of the rotation there will be sufficient demand for knot free timber for it to command a high enough premium to justify the cost of pruning and the possible reduction in yield or lengthening of the rotation. This is very much a matter of crystal ball gazing, but if it is assumed that there will always be a market for clean timber in large sizes and there are good reasons (e.g. Kenya's ability to export Cypress clears to Scandinavia) to believe that this is so, a policy of high pruning some plantations at least would appear to be justified.

Where plantations are maintained at a high stocking the effects on yield of high pruning, involving the reduction of the crown to 50 percent of tree height or even less, may be small. But yields of clear timber are enhanced when high pruning is combined with heavy thinning. Heavy thinning makes it possible to lay on clear timber on the high pruned part of the bole but also results in large branches and a knottier core in low pruned trees. Therefore where a policy of heavy late thinning has been adopted high pruning will be particularly advantageous. It is of interest that in New Zealand, with a change to heavier thinning schedules in P. radiata, it is now considered to be an economic proposition to prune the second log, whereas previously it was not. It is likely that the adoption of thinning schedules of the type advocated by Burgers (1972) which imply relatively light early thinnings and heavy late thinnings would justify a policy of high pruning to 11 or 12 metres.

P. patula has in the past had a, possibly exaggerated, reputation for poor wood quality, but even if this is discounted careful consideration should be given to deciding whether the pruning effort should be devoted to P. patula or whether it should be concentrated on other, possibly more rewarding, species such as C. lusitanica in Kenya, P. taeda in Rhodesia. If it is decided that P. patula justifies high pruning, it is certain that the pruning effort should be concentrated on final crop stems on first quality or good second quality sites. High pruning trees that are scheduled to be removed in thinnings or in plantations on third quality sites will never be an economic proposition.

4.0 Protection

4.1 Atmospheric agencies

4.11 Wind

P. patula is susceptible to wind damage. This damage occurs as a stem breakage and the loss of the tops rather than as an uprooting of the whole tree (as a contrast wind damage in P. radiata, which tends to have a relatively small root system, frequently involves the uprooting of the whole tree). This tendency for the stem to break is exacerbated by previous mechanical damage. Knuffel, (1970) has pointed out that after loss of its leader, which may be caused by hail, buck or monkey damage, or even by the weight of birds perching on it (see 4.323) P. patula often reacts by producing a whorl of heavy branches, one of which takes over as the leader. However, the remaining large laterals at the point of damage partially "strangle" the stem and this point becomes a zone of weakness at which wind break occurs in later years. Le Roux (1955) noted that at Sabie in the East Transvaal 90 percent of wind damage occurred in P. patula plantations and only 10 percent in P. caribaea (sic) - presumably P. elliottii - and P. taeda plantations. Most of this damage occurred as wind break in 20 to 25 year old plantations. Adlard (1973) confirmed Le Roux's findings in his observation that wind break was frequent in P. patula in plantations over 20 years of age on the Aberdare mountains near Nyeri in Kenya. The South African Forest Department Annual Report for 1970/71 recorded that 91,000 m^3 of timber was salvaged from wind damaged P. patula plantations as against only 14,000 m^3 from hail damaged areas. The 1968 report of the Forest Research Institute at Pretoria noted that in the C.C.T. plots at Mac Mac wind damage was worse in the P. patula plots than in P. elliottii or P. taeda. It also noted that in a timber test on P. patula showing surface irregularities 47 percent of the timber failed, because of compression breaks, to reach the merchantable and utility grades. It was considered that these compression breaks were associated with the heavier crown produced by P. patula, as compared with P. elliottii or P. taeda and for that reason that P. patula was not suited to windy areas. Nanni (1960) also attributed the death of young trees at Cathedral Peak to the effect of strong westerly winds which 'rocked' the young trees and caused root deformation.

4.12 Drought

P. patula has a reputation for being drought sensitive, but the evidence on the actual degree of sensitivity relative to other species is conflicting. Ochieng (1969b) stressed that P.patula is so sensitive to rainfall that any extended period of drought usually results in a few deaths. Dyson (1961b) made a survey of the effect of the drought in Kenya in 1960/61 resulting from the failure of the short rains in the latter end of 1960 and the delay to the start of the 1961 long rains. Of 31 plantations in the highlands in which deaths due to drought were recorded 52 percent were P. patula (30 percent cypress, 12 percent hardwoods and 6 percent P. radiata). Only 19 out of 64 forest stations recorded deaths due to drought and overall this did

not represent a very severe loss, though the effect on reduced increment was not assessed. In the lower dry areas it was noted that P. patula was more susceptible than P. elliottii, which in turn was more susceptible than cypress. Poynton (1966), on the basis of a study of the drought in South Africa at the end of 1964 and which followed several dry years, concluded that P. patula together with P. elliottii, P. radiata, P. pseudostrobus and some other species was moderately hardy (P. taeda and P. palustris being classified as somewhat susceptible). He further noted that P. patula was as hardy as, if not hardier than, P. elliottii, which does not agree with the conclusion reached in Kenya nor with the general reputation of these two species in East and Central Africa.

Both Poynton and Ochieng stress the importance of soil depth and its effect on the drought resistance of P. patula. Providing there is an adequate supply of moisture in the soil P. patula can survive periods of several months without rain. This point has been particularly brought home at Turbo in Kenya, where death has occurred in patches in the dry season. These patches have been clearly related to an underlying laterite pan, and the age of the trees at death shows that moisture stress is most acute where the soil is thinnest, (Ball, pers. comm.) It seems likely that P. patula has a good ability to put down roots, which can tap moisture reserves at depth and over a wide area, but that unlike P. radiata and more particularly P. roxburghii it can not make do with a reduced water supply.

Lamb (1973) has pointed out that the ability of plants to withstand drought is affected by the structure of the cuticle of the leaf surface. He investigated the cuticles of P. patula, P. oocarpa var. ochoterenai and P. caribaea var. hondurensis. Of these three P. patula had cuticle and stomata characteristics least adapted to drought resistance: the microscopic projections on the wax surface of the cuticle and stomata are larger in P. patula and therefore allow freer passage of water vapour. Performance of these species on the Jos Plateau in Nigeria where humidity can be as low as 10 percent during the season of the Harmattan winds supports the conclusion drawn from the observations in the cuticle structure, P. oocarpa thrived, P. caribaea var. bahamensis did reasonably well but suffered to some extent from fused needles, but P. patula had branchy crowns with vertically hanging needles and showed obvious signs of stress.

It can be concluded that P. patula should not be planted in climates of extreme aridity and of low humidity. In areas of relative high humidity,especially in areas prone to mist, the species can survive a dry season of several months provided there is sufficient soil depth to allow a build up of soil moisture.

4.13 Fire

P. patula seedlings and saplings have a thin bark and have a reputation for being very sensitive to fire damage.

Fire precautions tend to vary with the risk of combustion. In Angola at Cuima, a site with a severe 3 to 4 month dry season, fifteen

metre fire-breaks are constructed round any 20 hectare block of planting. In South Africa there used to be a policy of planting fire breaks with fast growing species such as Eucalyptus grandis; the intention being that these breaks should arrest sparks and if a policy of sweeping up leaves in the break, possible at a time of cheap labour, was followed ground fires would also be kept out of the plantations. Current thinking has moved away from the static approach to a dynamic one of highly mobile fire crews on 24 hour stand by in the fire season, backed up by an efficient fire lookout network and good communications using shortwave radio and a well designed system of roads. Firebreaks, which are always combined with a road, are 20 to 30 metres wide and enclose an area of 200 or more hectares. At Sabie in the East Transvaal South African Forest Investments (SAFI) are felling the old Eucalyptus fire breaks and filling them in with pine.

4.14 Frost and Snow

Golfari (1970) notes that in Mexico P. patula can withstand up to 10°C of frost. Provided that the tree has hardened off, frost will do little harm, but on sites where frost can cut green succulent shoots damage can occur with only 4 or 5° of frost. Procter (1963) has described how the adverse effects of a hot sun on hoar frosted seedlings in the nursery can be ameliorated by brushing the hoar frost off. In general, frost damage is more likely to occur in nurseries rather than in plantations and intelligent siting of nurseries to avoid frost hollows can prevent damage. However, Pudden (1956c) attributed the splitting of the bark in P. patula leaders to the differential shrinkage resulting from cold nights following hot days in the highlands of Kenya; though Fry (1964) attributed similar symptoms in P. radiata to hail damage.

P. patula is not often planted in areas of heavy snow fall and its horizontal to upward growing branches are not adapted to shedding snow. Reports from South Africa indicate that snowfall without an accompanying wind can result in breakage. Poynton, 1974).

4.15 Hail

Hail storms occur throughout the summer rainfall zone of southern Africa and to a very much lesser extent in East Africa. The main seasons for the hail storms are the beginning and end of the rains with the preponderance in November/December in Swaziland (Murdoch and Venn, 1963). However the worst damage is not from the mechanical wounding caused by the hailstones, serious though that can be, but from the subsequent invasion of the wounds by Diplodia pinea. D. pinea is a relatively weak parastitic fungus but in the warm humid conditions of the seasons in which hail usually occurs, the fungus invades the wounds and multiplies so rapidly (less than 24 hours) that it is not usually possible to mount an operation to spray the affected area from the air in time to prevent infection. Murdoch and Venn mention that some success has been achieved in Swaziland by dispersing hail storms with rockets.

4. 2 Diseases (by I.A.S. Gibson)

4.21 Nursery diseases

Moulds may cause loss to damaged seed in germination beds in the period after sowing and before emergence (Gibson, 1957). This may be prevented by avoidance of damage to the testa and the use of a standard fungicide seed dressing.

P. patula is also subject to pre-and post-emergence seedbed loss from damping-off. The post-emergence symptoms of this disease include a rapid shrivelling of the stem at ground level, after which the seedling falls to the soil surface and dries up. Thanatephorus cucumeris (Frank) Donk (syn. Corticium solani (Prill. and Delacr.) Bourd. and Galz., mycelial state Rhizoctonia solani Kuhn), Fusarium spp. and Pythium spp. (mainly P. ultimum Trow.) are the main pathogens in this disease complex and studies in East Africa have shown that there is an additional wide range of other fungi that may contribute to these losses (Hocking, Setliff and Jaffer, 1968). In Brazil Rhizoctonia spp., Fusarium spp. and Cylindrocladium scoparium Morgan are reported as causes of damping-off in pine nurseries in Sao Paulo, where P. patula is an important species (May, 1964) and losses to P. patula seedlings caused by Pythium and Fusarium spp have been reported from Queensland (Anon., 1957; Wilkes, 1969). Rhizoctonia spp., Alternaria spp., Fusarium oxysporum Schlect and F. solani (Mart.) Sacc. are associated with damping off in Mexico but the pathogenecity of these fungi to P. patula seedlings has not yet been fully evaluated.

P. patula does not appear to be exceptionally susceptible to damping-off and losses are generally slight, providing that over-watering, alkaline soil mixtures with high organic content and high sowing densities are avoided (Gibson, 1956). The chemical control of the disease by soil drenches has been attempted with varying degrees of success in Queensland, East Africa, Malawi and India (Anon., 1957 and 1960; Gibson, 1955; Hocking and Johanns, 1967; Ram Reddy and Misra, 1970) and more recently the pelleting of seeds with Rhizoctol Combi (methyl arsenic sulphide + 4-benzoquinone-N'-benzoyl-hydrazone oxine) has given good control of damping-off losses in Kenya (Gibson and Hudson, 1969). Bakshi and Dobriyal (1970) have shown that the fungicide soil treatments tested by Ram Reddy and Misra (1970) will slow down the rate of mycorrhiza formation in transplants.

Oxenham and Winks (1963) record Phytophthora boehmeriae Sawada as the cause of a root disease of P. patula nursery stock in Queensland.

Sclerotinia fuckeliana (De Bary) Fuckel (imperfect state Botrytis cinerea Fr.) causes dieback in nursery stock in Kenya, Tanzania and Rhodesia. The early symptoms include a water-soaked condition of the stem, which rapidly dies and shrivels, eventually becoming covered with grey-green hyphae and conidiophores (Browne, 1968). Rosellinia necatrix (Hartig) Prill. (imperfect state Dematophora necatrix Hartig) and Heliocobasidium compactum Boedijn have both been

recorded as root pathogens of nursery transplant stock in Africa. R. necatrix forms white to grey mycelial threads on the roots, while H. compactum causes a black, wet rot of the tissues, which may be accompanied by bright purple mycelial mats.

All these diseases are favoured by overcrowded conditions and warm, damp weather.

Thelophora terrestris Fr. is a mycorrhiza forming fungus (see 4.23) but has also caused slight losses by overgrowing and smothering young nursery stock and plantation regeneration in Kenya (Browne, 1968), Madagascar (Brunck, 1964) and Sao Paulo, Brazil (May, 1969). The fungus causes crustose, purplish-brown fruit bodies that are easily removed by hand.

No records of foliage infections of P. patula in the nursery have been found, except a single record from Sweden, where unthrifty plants were found to be attacked by Lophodermium pinastri (Schrad. ex Fr.) Chev. (Klingstrom, 1967).

Nursery stock of P. patula has proved to be resistant to terminal crook disease (Colletotrichum acutatum Simmonds f.sp. pinea) in Kenya (Gibson and Munga, 1969) and New Zealand (Gilmour, 1965; Dingley and Gilmour, 1972).

4.22 Diseases in the plantation

4.221 Foliage Diseases

Lophodermium pinastri (Schrad. ex Fr.) Chev. has been recorded associated with foliage cast of P. patula in plantations in Fiji (Firman, 1972), Rhodesia (Browne, 1968), Brazil - Sao Paulo - (May, 1964), Australia - Canberra - (Stahl, 1969) and Jamaica (Pawsey, 1970). No details are available on the ages of the affected crops but in all cases the damage was slight. A chlorotic and necrotic speckling of needles associated with Naemacyclus niveus (Fr.) Sacc. has been recorded on two occasions in the highlands of Kenya in twelve and fifteen-year-old plantations, but damage was not significant.

Both these pathogens are generally confined to older foliage. L. pinastri forms black, shiny, elongate hysterothecia and N. niveus forms brown, raised, squarish fruit bodies (which later fade) on the host, both of which are just visible to the naked eye. Millar and Watson (1971) have shown that L. pinastri exists as at least two biotypes that differ in pathogenicity.

Mycosphaerella pini-patulae Sechet was observed and described from foliage of P. patula in Madagascar in 1955 (Sechet, 1955). The fungus has not been found elsewhere and there have been no more reports since the original description. Its effects on the host were mild.

A necrotic needle cast, associated with a member of the Hypodermataceae, is reported from the Piedras Blancas (Medellin) region

of Colombia (Garces, 1964).

P. patula is immune in the field to attack in East Africa by Dothistroma pini Hulbary (perfect state, Schirrhia pini Funk and Parker)(Ivory, 1968) and only very light infections by this fungus have been recorded in New Zealand (Gilmour, 1967). It is possible that this slight difference in host reaction may be related to differences in strain of the pathogen (Ivory, 1967). Complete immunity of the species to field attack by Cercospora pini-densiflorae Hori et Nambu has been observed in Tanzania (Gibson, 1966). In Japan Kiyohara and Tokushige (1969) find that P. patula is mildly attacked by the fungus (Ito, 1972).

4.222 Diseases of stem tissues and cones

Tip dieback of branches and cankers of the main stem caused by Diplodia pinea (Desm.) Kickx (syn. Sphaeropsis ellisii Sacc., Macrophoma pinea (Desm.) Petrak and Syd.) occur in Australia, New Zealand, Swaziland, Rhodesia, Tanzania (Browne, 1968), South Africa (Luckhoff, 1964), Brazil (May, 1964) and Madagascar (Brunck, 1964).

The fungus is a facultative pathogen occurring in nearly all, except temperate, regions where pines are native or grown as exotics. It is rare in the highlands of Kenya (Howland and Gibson, 1969). The impact of the disease varies considerably and is probably most serious in Swaziland and South Africa (Transvaal), where it can cause extensive damage in association with hail damage in regions with periods of summer rainfall. It is reported that under these conditions young stands may be completely destroyed and older crops suffer reduction in increment. The fungus may also cause secondary loss by bluestain and through the cost of salvage operations in damaged plantations; control by fungicides has been investigated (Westhuizen, 1968).

D. pinea generally acts as a wound pathogen and Marks and Minko (1969 and 1970) have shown that it will readily invade shoots if it can gain access to the pith. Stahl (1968) has also shown that drought stress predisposes pines to attack.

The fungus may exist in forms that vary in their pathogenicity. Whereas D. pinea generally acts as a wound pathogen, Brookhouser and Peterson (1971) have shown that in the U.S.A. D. pinea does not require predisposing wounds before infection can take place. The results of Magnani (1969) in Italy also suggest that gross wounding is not necessary to establish D. pinea infections in P. patula.

The symptoms may appear as a canker with external gummosis if infection is through pruning scars, or as a necrosis of the leading shoot and upper branch tips. The latter is accompanied by gummosis, bluestain and a tendency for the tip to turn over and 'crook'. Later, minute black pycnidia of the fungus break through the surface of the infected tissue.

Similar damage, without pronounced bluestaining of the tissues can be caused by Fusicoccum tingens Goid. (perfect state

Botryosphaeria ribis Grossenb. and Dugg.) in Kenya (Ivory, 1967a), where it has been shown to be a wound pathogen. The fungus has also been found in association with stem lesions at ground level, where young plants have been growing in hot, dry conditions.

Diplodia natalensis Pole Evans (syn. Botryodiplodia theobromae Pat., perfect state Physalospora rhodina (Berk. and Curt.) Cooke has also been recorded at times from dead leaders of P. patula in East Africa, a condition which is probably due primarily to water stress (Howland and Gibson, 1969; Gibson, 1958).

Magnani (1966) has shown that Coryneum cardinale Wagener may cause a dieback in P. patula.

In Mexico and Guatemala Peridermium conigenum (Pat.) R. Peterson (syn. Cronartium conigenum Hedgc. and Hunt., P. mexicanum Arth. and Kern.) forms rounded, woody galls 3-7cm in diameter on stems (Peterson and Salinas Quinard, 1967 ; Peterson, 1967) and infects cones, preventing the formation of seed. Damage from this rust can be severe but P. patula is considered to be less susceptible than P. pseudostrobus and P. montezumae. The alternate host is oak and the disease is likely to be confined to areas where susceptible pines and oaks occur together.

Boron deficiency, causing death of the terminal buds and producing a chronic, bushy, stunted condition, has been described from Tanzania (Procter, 1967). Borax applied to planting sites at 17 kg/ha is recommended as a preventive measure and some recovery from the disorder may be obtained by a spray made up of 1% zinc sulphate, 0.25% borax and 0.5% lime (Vail, Parry and Calton, 1961). A similar dieback condition has been observed in 8-10 year old P. patula plantations in the Mococan Mucuruba district of Venezuela (2,500 m altitude) by Etheridge (1970).

A fused needle disease, believed to be due to phosphate deficiency, has been recorded from Tanzania by Gill (1963).

In New Zealand a dieback and wilt occurs caused by Amylostereum areolatum (Fr.) Boidin, introduced into the tissues by the wood-wasp Sirex noctilio Fabricio (Gilmour, 1966).

4.223 Root diseases

Reports of attack by Armillariella mellea (Vahl ex Fr.) P. Karst (syn. Armillaria mellea (Vahl ex Fr.) Kummer) in P. patula plantations have been traced from Jamaica (Pawsey, 1970), Brazil (May, 1964), New Zealand (Browne, 1968; Gilmour, 1966), Tanzania and Kenya (Browne, 1968).

The symptoms include the death of the tree with the formation of characteristic thick, white, mycelial sheets under the bark of the roots and the base of the stem. Black bootlace-like rhizomorphs are also often found, either under the bark, on the outside of roots or spreading from there into the soil. The disease may be spread by

these or by root contact between healthy and diseased trees. As a result, deaths occur in patches, with the most recent ones on the outside. The fungus sometimes forms toadstool-like fruit bodies with a honey-coloured cap, white gills and a ring on the stipe. The basidiospores formed by these are airborne but do not appear to be important in spreading the disease.

A. mellea is a widespread fungus which often exists as a harmless associate of the roots of forest trees; however, it will invade the host if it is weakened or cut down. The disease, therefore, is associated with plantations established on exploited forest sites where the fungus is har b oured in stump residues. In South Africa stumps of Parinari mobola frequently form infection centres, from which the disease is spread to P. patula. Damage from A. mellea is seldom severe, except on wet sites with high infestations of the fungus and under adverse conditions of growth for the host.

Pawsey (1970) has described damage by Heterobasidion annosum (Fr.) Bref. (syn. Fomes annosus (Fr.) Cooke) in 14-year-old plantations of P. patula in Jamaica which had been thinned or had sustained windthrow damage. The fungus was observed fruiting at the base of recently killed trees and Pawsey notes also that Dr. J. Rishbeth had recorded fruit bodies of H. annosum growing on P. patula in Jamaica as early as 1951; the fungus was first collected on the island in 1946 (Leathers, 1967). It is clear that P. patula is susceptible to attack by H. annosum and that the course of infection is the normal one through old stumps and other infected woody debris in the soil. The absence of records of this disease from other parts of the world where P. patula has been planted extensively may be attributed to absence of the pathogen rather than to any resistance of the host. This applies in particular to Africa, where the three existing records of H. annosum have been reviewed and shown to be extremely doubtful.

The fungus causes a lethal root disease and also a heart rot. Trees killed by H. annosum have a thin, papery mycelium under the bark and may carry bracket-like fructifications (rich brown on upper surface, creamy-white pore surface underneath) at the base of the stem. These liberate airborne spores that can invade cut stumps in thinned plantations; from these infection centres the disease spreads by root contact.

H. annosum is at present very largely confined to the northern hemisphere, where it causes serious loss to conifer plantations, particularly pines. It is also found in New Zealand, where it does not act as an important pathogen. This fungus might be extremely damaging if introduced into exotic conifer plantations of the tropics and southern hemisphere.

Macrophomina phaseolina (Tassi) Goid. (syn. M. phaseoli (Maubl.) Ashby Rhizoctonia bataticola (Taub.) Butler) a Fusarium species and a Pythium sp. have been associated with a severe root disease of P. patula in Queensland (Wilkes, 1969). Elsewhere in Queensland deaths associated with root infection by Phytophthora boehmeri Sawada have been recorded in a

single locality (Oxenham and Winks, 1963). White root rot caused by Rosellinia radiciperda Massee occurs on P. patula in New Zealand. The disease is associated with poorly-drained, recently-cleared sites, where it causes a slow decline and group dying (Browne, 1968; Gilmour, 1966). Peniophora sacrata G.H. Cunn. also causes a root rot and stem canker to young P. patula in New Zealand; the fungus is a saprophyte on bracken and is associated with native Leptospermum sp. (Browne, 1968; Gilmour, 1966).

Helicobasidium compactum Boedijn has been reported to cause fairly severe losses to young P. patula in the Northern Transvaal (Luckhoff, 1964), which can be controlled to some extent by slashing weed growth and avoiding hoe damage to the roots. This pathogen has also been recorded in Tanzanian plantations (Browne, 1968). The fungus may form purple fruit bodies on infected trees at ground level.

Rhizina undulata Fr. (syn. R. inflata (Schaff.) Quel.), the cause of Group Dying Disease of conifers in Europe and North America, has been found as a root pathogen of young P. patula in Rhodesia (Anon., 1967), Swaziland and South Africa. The fungus can exist as a saprophyte on woody trash, where it may form undulating, lobed, dark brown fruit bodies, mainly on the soil surface; when fresh these have a light-coloured margin.

The root disease caused by R. undulata is always associated with sites that have been burnt-over recently, which stimulates ascospores of the fungus in the soil to germinate. Serious losses from this fungus have occurred in Swaziland, where trash-burning on plantation sites is quickly followed by re-planting. Under these conditions the fungus could be found fruiting freely on the soil and stumps of the previous crop. Control measures depend on the avoidance of burning operations or establishing an extended period between burning and replanting.

Control of root diseases generally relies on the avoidance of sites which carry a high infection risk. It is seldom economically acceptable to attempt any special measures to reduce the amount of inoculum or attempt control by other means.

4.224 Sap stain and heart rot

There are extremely few heart rot conditions recorded for P. patula. Ganoderma applanatum (Wallr.) Pat. is recorded from Australia (Browne, 1968) and in Queensland it causes a rot associated with root attack by termites (Wilkes, 1969). In India Poria monticola Murr. has been recorded in P. patula. The fungus enters through scars in the lower stem and causes a brown cubical heart rot. Affected trees may snap in high winds. The fungus did not form fruiting bodies, but was identified from culture (Bakshi et al., 1972).

In Kenya Stereum sanguinolentum (Alb. and Schw.) Fr. has been found recently invading the species through elephant damage and pruning scars, but it is too early to assess the degree of loss that

will be caused. Colonization of pruning scars by the fungus can be avoided by carrying out this operation in dry weather and elephant damage can be prevented by the establishment of efficient game defences (Gibson, 1966; Griffin, 1969).

Bluestain degrade of freshly felled P. patula timber is caused by D. pinea in Australia, Swaziland, Rhodesia, South Africa (Luckhoff, 1964; Browne, 1968); a similar condition is caused by Curvularia pullescens Boedijn in South Africa (Westhuizen, 1956) and by Fusicoccum tingens in Uganda (Ivory, 1967a).

4.23 Mycorrhiza

Like all pines species, P. patula requires the formation of stable mycorrhizal root associations for normal growth. Little is known of the species of fungi that fill this role in native stands in Central America but Pisolithus tinctorius (Pers.) Coker and Couch probably forms association with P. patula in Surinam (van Suchtelen, 1962). The following species are regularly found fruiting in African pine plantations and probably form mycorrhizae under these conditions:-

Suillus luteus (L. ex Fr.) S.F. Gray
Hebeloma crustuliniforme (Bull. ex St. Amans) Quel.
Thelephora terrestris (Ehrh.) Fr.
Laccaria lateritia Malençon
Scleroderma bovista Fr.
Rhizopogon sp.
Amanita spp.
Cenococcum graniforme (Sow.) Ferd. and Wing.

Inoculation of seedlings at the transplant stage in the nursery is often ensured by the inclusion of a small proportion of pine plantation soil in the soil mixture. Alternatively, 'mycorrhiza mother trees' may be established in the nursery area which provide inoculum to open-ended tube or bedded stock.

Where there are extensive and well established P. patula plantations where mycorrhizal fungi fruit regularly in the proximity of the nursery there is probably little need for extra inoculum, as this will be provided naturally by airborne spores.

Some preliminary investigations by Robinson (1971) have shown that there is a difference between the mycorrhizae of first and second-rotation P. patula in Swaziland plantations. This involves a change in associated fungal species and may be connected with a reduction in growth of second-rotation crops.

A study of mycorrhizae of P. patula in Ceylon has shown that two forms exist; the associated fungi were not identified (Jayasinghe et al., 1969).

4.3 Animals

4.31 Insect pests (by R.F. Lee)

4.310 General

Pinus patula has been extensively planted as an exotic in parts of Africa, Australia, New Zealand and South America and with few exceptions has been remarkably free of persistent damage from pests.

Most forest insects attacking P. patula belong to the orders Coleoptera and Lepidoptera with lesser numbers in the Hemiptera, Hymenoptera, Isoptera and Orthoptera. Rather than reviewing the insect pests of P. patula from a purely entomological standpoint, the review has been classified by damage to the host from the seedling stage through to the mature tree and forest products. Within each category the insects are considered alphabetically by insect order.

The pests of P. patula in its natural range in Mexico are not well documented and it is only where P. patula has been extensively planted as an exotic for a number of years that any surveys of the insect fauna of P. patula have been conducted. Thus, although there are extensive young plantations in South America (Brazil, Argentina, Colombia) it is in Southern and East Africa, Australia and New Zealand where most systematic work on insect problems of P. patula has been carried out. This necessarily puts a strong bias on the following review. Even within Africa there are regional differences. Systematic surveys of the insects of P. patula have been conducted only in East Africa, Malawi and South Africa (Brown, K.W., 1967; Austara and Jones, 1971; Lee, 1971; Anon., 1970). Madagascar, Rhodesia and Swaziland have very large areas of P. patula but only occasional reports on problems associated with specific insects have emerged from these countries (Brunck, 1965; Jones, 1966). In Australia and New Zealand periodic reviews of pests of Pinus spp. including P. patula have been published and several insects causing damage to P. patula have been studied in some depth (Moore, 1962 and 1972; Hadlington, 1966; Zondag, 1965).

4.311 Nursery pests

Nursery pests tend to be ephemeral and very local but hard-hitting. In Africa grasshoppers and crickets are the worst offenders, attacking suddenly in the night and leaving just as suddenly usually before any control measures can be effected. Cutworms are seldom serious in Africa although they frequently cause much damage to seedlings in Australia.

4.3111 Coleoptera

Chafer damage to seedlings has been caused by Mimela mundissima Walk. (Scarabaeidae - Rutelinae) in India and by scarabs such as Trochalus spp. and Lepidiota nitidicollis Kolbe (Scarabaeidae - Melolonthinae) in Malawi and Kenya. Scarabaeidae have caused

negligible damage in Kenya, except when cow manure has been used as a fertilizer.

Some cases of severe defoliation of seedlings by leaf-eating beetles have been reported. Adults of the weevil Entypotrachelus meyeri Kolbe have frequently defoliated seedlings in East African nurseries but never in very large numbers. The larvae live in soil and are not known to be injurious (Browne, 1968).

4.3112 Lepidoptera

The commonest cutworm (Noctuidae) in forest nurseries in East Africa is Euxoa segetis Schiff. and in New South Wales the most important cutworms in pine nurseries are E. radians (Guen.) and Agrotis infusa (Boisd.). The cosmopolitan Agrotis ipsilon Hufnagel which has been recorded from P. radiata nurseries in New Zealand and pine nurseries in Hong Kong is recorded from P. patula nurseries in Colombia (Bustillo and Lara, 1971). The larvae emerge from the soil at night and cut seedlings at ground level and strip buds and leaves. In Uganda, Mocis punctularis Hubn. larvae have been found feeding on P. patula seedlings (Brown, 1967).

Several leaf-rollers (Tortricidae) have been recorded tying together needles of P. patula seedlings and feeding within the webbed needles. Tortrix occidentalis Wlsm. usually webs the leaders of nursery plants in Uganda. Epichorista galeata Meyr. is common in Kenya nurseries up to 3000 m altitude. E. ionephala Meyr. is less common in East Africa. Acropolitis rudisana (Walk.) is of some importance in nurseries in New South Wales.

Other Lepidoptera causing damage in nurseries are defoliators and mainly belong to the families Lasiocampidae, Lymantriidae and Geometridae. Some can be serious on occasion such as Lechriolepis basirufa Strand (Lasiocampidae) which has caused severe local defoliation in nurseries and plantations of P. patula and P. radiata in the Kenya highlands and Buzura edwardsi Prout (Geometridae) which occurs throughout tropical Africa and in Uganda has defoliated nursery stock and plantations. Aroa melanoleuca Hmps. (Lymantriidae) is a polyphagous leaf-feeder in nurseries and plantations and in Rhodesia is usually associated with P. patula in areas of moderate rainfall (1000-1500 mm) but is seldom serious.

4.3113 Orthoptera

Some grasshoppers such as Chrotogonus hemipterus Schaum (Pyrgomorphidae) in East, Central and South Africa and Thericles spp. (Eumastacidae) in Malawi frequently cause some defoliation in P. patula nurseries. However the most injurious Orthoptera are crickets (Gryllidae), especially Brachytrupes membranaceus (Drury) and Gryllus bimaculatus Deg. These are extremely common in Africa and attack almost any seedlings eating roots and cutting stems.

4.312 Plantation pests

The greatest threat to plantations of P. patula comes from defoliating insects. P. patula has relatively succulent needles and is frequently preferred by polyphagous insects to other pines such as P. radiata and P. elliottii. The insect fauna of P. patula plantations is more varied and more numerous than that of other pine species in Malawi, East Africa and South Africa. Sucking insects (Hemiptera) can cause some local damage resulting in die-back of infested leaders and other shoots, loss of photosynthetic area by browsing and premature shedding of needles (e.g. Pineus). Other animals can cause severe damage to individual trees such as leaders damaged by the weight of carton nests of ants (Crematogaster spp.). Although some barkbeetles (Scolytidae) are known to attack P. patula plantations at present.

4.3121 Newly established plantations

Where tubed planting stock have been used, the usual loss is less than 10%. The incidence of insect attack is usually very low during the first year after planting but some damage may result from leaf-tying moths (Tortricidae), sucking insects, termites and local attacks by defoliators especially leaf-eating beetles (Chrysomelidae).

4.31211 Coleoptera

Damage to two year old trees can often be severe although usually very local. The most common damage is complete defoliation by heavy infestations of a few dozen to several hundred trees by adults of leaf-eating beetles (Chrysomelidae) such as Colasposoma ruficolle Bry., Macrocoma aureovillosa Mshl. and other Eumolpinae; Cryptocephalus trisulcatus Suffr. and other Cryptocephalinae ; Crioceris elongata Jac., Bradylema robusta Lac. (Criocerinae); Chrysolagria cyanicollis Borch. and other Lagriinae; and the scarabs Popillia brownii Kolbe and P. bipunctata F. (Rutelinae). Many species of weevils (Curculionidae) are defoliators of these young trees and also cause shoot deformation and die-back by chewing the youngest shoots. In Malawi, the weevils associated with young trees in particular are Systates sexspinosus Mshl., Amphitmetus sp.nov., Diaecoderus ater Mshl. and Dicasticus spp. all of which belong to the subfamily Otiorrhynchinae (Lee, 1971). The tenebrionid beetle Gonocephalua simplex F. causes collar ringing of young pines in plantations in Congo and Gabon (Brunck, 1965).

Adults of the bark beetle (Scolytidae) Hylastes ater Paykull attack roots and bore into and girdle the stems of newly planted P. patula in New Zealand (Weston, 1973). In South Africa and Swaziland adults of H. angustatus Herbst. feed on the bark of seedlings and saplings, girdling the stem near the root collar. It is a major pest of young transplants in Swaziland especially in drought years.

4.31212 Hemiptera

Sucking insects are seldom abundant enough to cause appreciable

damage but there may be some loss of increment due to loss of photosynthetic area as a result of leaf browning and premature needle fall. Such bugs as Homoeocerus sp. indet. and Petascelis remipes F. (Coreidae) have caused this sort of damage in Malawi. Many shield bugs (Pentatomidae) occur on P. patula in Africa, e.g. Atelocera stictica Westw. and other Atelocera spp., Canthecona spp., Nezara spp. in East, Central and Southern Africa and Agonoscelis erosa Westw. in Nigeria. These occur on twigs and suck growing points and bases of young needles, sometimes causing needle fall and, when numerous, defoliation and distortion of young shoots probably resulting in some loss of increment in young trees. Some cicadas such as Melampsalta aethiopica Dist. can cause seasonal damage to aerial parts of young trees in Malawi. In New Zealand, M. cingulata and other Melampsalta spp. are associated with sap sucking and twig breakage (Weston, 1973). In Saissetia spp. which infests the needles of young P. patula but has not yet caused appreciable damage (Bustillo and Lara, 1971).

4.31213 Lepidoptera

Young planted trees are defoliated by some moth species such as the tussock moths Orgyia mixta Snell. and O. hopkinsi Coll. in Africa and O. anartoides Walk. (Lymantriidae) in New South Wales (Moore, 1972); various lappet moths (Lasiocampidae) such as Bombycopsis venosa Butl., Pachypasa papyri Tams, Nadiasa butiti B.-Bak., Streblote tessmanni Strad. and Pseudometa spp. in Malawi and East Africa; many bagworms (Psychidae) including Oiketicus spp. in Colombia, Clania ignobilis Wkr., Hyalarcta hubneri Westw. and Trigonocyttara clandestina in New South Wales and Cryptothelea moddermanni (Heyl.) and Acanthopsyche aethiops Hmps. in Rhodesia, Malawi and East Africa; and leafrollers (Tortricidae) such as Tortrix occidentalis (Wals.) in East Africa. In Colombia a major pest of young trees is Lichnoptera gulo H.-S., a case-bearing noctuid, which is normally adequately controlled by parasitic Hymenoptera and a bacterial disease (Bustillo and Lara, 1971). Helicoverpa (Heliothis) armigera (Hubn.) defoliates young trees in New Zealand (Weston, 1973).

4.31214 Orthoptera

Grasshoppers and locusts of the families Acrididae, Pamphagidae, Pyrgomorphidae and Tettigoniidae are seldom of any importance. Occasional partial defoliation by the longhorn grasshoppers (Tettigioniidae) Tylopsis rubrescens Kirby and Phaneroptera nana Fieb. sparsa Stal has been reported from Malawi (Lee, 1971).

However, there are several genera of Eumastacidae and Lentulidae which have caused much defoliation and even death of young trees in Malawi. Plagiotriptus pinivorus Descamps (in litt.) attacks trees of all ages in Malawi and in the study of an extensive outbreak in Southern Malawi, the first tree mortality occurred in 3 to 4 years old P. patula in "planted firebreaks" after several successive defoliations (Lee, 1972). Mecostibus spp. (Lentulidae) have

occasionally caused severe local defoliation of young P. patula in Rhodesia (Whellan, 1965) and in Malawi (Lee, 1971).

4.3122 Pests of older plantations

In most areas where P. patula has been introduced some true forest insects have adapted to feeding on P. patula after canopy closure has taken place and have become pests or potential pests. The older the tree the more serious the economic consequences become. The majority of the important pests or potential pests are defoliators although some borers are potentially devastating.

4.31221 Coleoptera

In Central and South America, the barkbeetles (Scolytidae) Ips mexicanus Hopkins, I. plastographus Leconte, Dendroctonus frontalis Zimm. and the platypodid Platypus sulcatus in Argentina although seldom if at all recorded from P. patula are serious potential pests of the extensive P. patula plantations that have been established in recent years. In South Africa and Swaziland the cosmopolitan scolytid, Hylurgus ligniperda F. is a pest of unhealthy Pinus spp., the adults attacking the thick bark usually near the base of the stem or large exposed roots and sometimes girdling the stem. In the P. patula range it occurs in Southern Africa, South America and Australia.

There are numerous weevils (Curculionidae) which defoliate P. patula in all of its exotic range. Most records are from Africa where P. patula has been most studied but in Colombia there are several unidentified genera of Curculionidae attacking P. patula and in New South Wales Aoplocnemis rufipes Boh. adults have caused moderate to heavy damage in the highlands to P. patula and other Pinus spp.

The most important weevil defoliators in Africa are Systates surdus Mshl. in East Africa; S. smeei Mshl., S. sexspinosus Mshl. and Amphitmetus sp.nov. in Malawi; Dicasticus funicularis Chevr. in East Africa, Malawi and Rhodesia; and Piezotrachelus spp. in Madagascar (Brunck, 1962).

Aesiotes spp. including the mottled pine bark weevil, A. leucurus Pascoe are fairly important pests of pines in New South Wales but only attack debilitated trees (Taylor, 1948). A. notabilis Pascoe became a primary pest of Araucaria and Pinus spp. including P. patula in Queensland when plantations were established (Brimblecombe, 1945).

4.31222 Hemiptera

The most important pest of exotic pines to occur in Africa in this order of insects is the pine woolly aphid, Pineus laevis Maskell (Adelgidae). This insect occurs in South America, Australia, New Zealand, South Africa, Rhodesia, Tanzania and Kenya although there is still some disagreement about the specific identity of the East Africa and Rhodesian Pineus. Well established infestations of Pineus

were found in Rhodesia in 1968 and in Kenya in 1969. The life cycle of this aphid is probably anholocyclic (i.e. the number of changes in bodyform is incomplete) throughout its range and is exclusively associated with Pinus spp. In Queensland, South Australia and Rhodesia it is mainly associated with P. patula. Damage, which consists of death of terminal buds leading to malformation, stunting, suppression and even death of the whole tree, is most evident on trees on poor sites. The European station of the Commonwealth Institute of Biological Control, sponsored by E.A.A.F.R.O., began a search for possible predators in 1971.

Shield bugs (Pentatomidae) are common on P. patula in Africa but are seldom numerous enough to cause appreciable damage to larger trees but there are a few records of malformation of leaders and shoots of older trees caused by Atelocera stictica Westw. in Malawi, Calidea dregei Germ. in Malawi and Rhodesia, C. bohemani Stal in Uganda and Agonoscelis versicolor F. in Kenya.

4.31223 Hymenoptera

Sirex noctilio F. (Siricidae), the Steelblue Woodwasp, an insect indigenous to the temperate regions of the northern hemisphere, was introduced into New Zealand and Australia where it is a major pest of P. radiata although relatively unimportant elsewhere. It has caused some damage to P. patula in New Zealand frequently resulting in windbreak of the stem at the point of heaviest attack. However, Sirex populations have been considerably reduced by biological control (Weston, 1973).

4.31224 Lepidoptera

The great majority of the injurious defoliators are in this order. Most pests belong to the families Arctiidae, Geometridae, Lasiocampidae, Lymantriidae, Psychidae, Saturniidae and Tortricidae.

In Malawi the arctiids Diacrisia spp., including D. investigatorum Karsch, and Dionychopus similis Möschl which are widespread in areas over 300 m altitude have occasionally caused appreciable defoliation of P. patula and other trees. These two genera could become serious plantation pests under favourable climatic conditions in East or Southern Africa.

Chenuala heliaspis Meyr. (Anthelidae) occurs in Eastern Australia. The larvae are polyphagous and have caused slight to moderate defoliation of P. patula, P. engelmannii, P. radiata and Eucalyptus spp. in the highlands of New South Wales. It is thought to be a potential plantation pest.

In the family Geometridae, Neocleora herbuloti (Fletch.) is a Central Africa moth which has become a serious pest of P. patula and Eucalyptus spp. in South Africa (Northern Transvaal). In 1962, following severe drought, 1600 ha of P. patula were defoliated,

necessitating some very heavy thinning and even premature felling. This is potentially the most serious defoliator in South Africa since it causes damage more quickly than any other important defoliator (Hepburn and Loedolff, 1964). N. herbuloti has also been recorded from Malawi, Tanzania, Kenya, Uganda, Congo and Cameroon.

Buzura abruptaria Walk. stringeri Prout (Geometridae) is an occasionally important defoliator of P. patula in Malawi and Rhodesia, of Cupressus lusitanica in Uganda and of Eucalyptus saligna in Angola. The Malawi outbreak was on 10 year old trees and was less severe and less extensive than Xanthisthisa (see below) and only recorded in 1961-62 as causing any noticeable damage. The loss of increment in that season was 100% loss in height and 73% loss in diameter. There was some loss of increment in the year preceding defoliation possibly due to the build-up of the looper population. A large area of P. patula on a private estate in the Melsetter area of Rhodesia was severely defoliated in 1965-66. B. edwardsi Prout completely defoliated about 3 ha of 10 year old P. patula in Uganda in 1961 and several hundred trees died (Brown, 1967).

Xanthisthisa tarsispina Warren was associated with the Buzura outbreaks in Malawi and Uganda and in the case of the Malawi outbreak in 1963 caused more severe damage over a wider area than Buzura. The Malawi population crashed with very high mortality of larvae and pupae within a few days probably as a result of a polyhedrosis disease. X. tarsispina has been recorded as causing slight damage in other parts of Uganda and Malawi and in Kenya and Tanzania.

Other geometrids such as Ectropis ocellata Warr. in Kenya and Cleora betularia (Warr.) in Malawi have been recorded causing slight defoliation of P. patula. In Colombia, the geometrid Glena bisulca is an important pest of cypress and pines. Many cypress died but the P. patula survived the defoliation (Raigosa, 1973). This family undoubtedly contains some potentially dangerous pests in other continents.

Lappet moths (Lasiocampidae) are seldom numerous and from the economic viewpoint have the advantage of a long life-cycle often including a long pupal period. However, the large size of the larvae means that appreciable defoliation may be caused by very few larvae. Pachypasa capensis L. is the most important species in South Africa. P. patula is one of its many hosts and often it occurs in the same plantation as Euproctis terminalis (see below). The larval period is about ten months and a pupal period of one month. Larval and pupal parasites which include the tachinids Sturmia convergens Weid. and Thrycolyga sorbillans Weid. and the ichneumonids Erymotylus druryi Kriechl. and Amblyteles spp. can cause up to 20% mortality and a larval virus disease can cause up to 70% mortality under favourable conditions (van Dyk, 1969. P. paphyroides attacks Pinus spp in Angola (Carvalho, 1971).

Gonometa podocarpi Aur. severely defoliated about 20 ha of 10 year old P. patula in Uganda despite heavy parasitism by tachinids. A larval non-inclusion virus disease was introduced into another area to prevent an outbreak. Six weeks after introduction of the virus, larval mortality was close to 100% (Brown, 1967; Austara, 1971) G. regia Aur. and G. nysa Druce have also caused slight defoliation of P. patula in Uganda.

In Malawi two more lasiocampid moths, Bombycopsis venosa Butl. and Nadiasa nyassanum Strand caused some defoliation in a P. patula seed orchard in 1969-70 but both species were well-parasitized by Meteorus spp. (Braconidae) and recovery of the trees was complete. Other Nadiasa app. and Streblote spp. such as N. singulare Aur. in Malawi, S. livida Holl. in Uganda and S. aculeata (Walk.) which occurs from Rhodesia to East Africa are all minor defoliators but are potential pests of some importance. Schaussina affinis Aur. in East and Central Africa, Streblote cuneatum Dist. in East Africa, Nadiasa concolor Walk. and Braura truncata Walk. in South Africa and Swaziland are all minor pests usually well controlled by parasites but occasionally causing severe local defoliation. Pachymetana sanguicincta Aur. is a serious pest of P. patula in Uganda. Lechriolepis nephopyropa Tams caused severe local defoliation of P. patula and other pines in Rhodesia in 1960 but is not considered to be a major pest. L. basirufa Strand has caused severe local defoliation in nurseries and plantations of P. patula and P. radiata in the Kenya highlands.

Eutachyptera psidii (Sallé) is a Mexican tent caterpillar (Lasiocampidae) attacking guava, Quercus and P. patula in the Necaxa region. It has an annual cycle with no diapause and six larval instars lasting ten months and certainly causes much loss of increment and favours secondary attack by other insects. Larval parasites include Enicospilus spp. (Ichneumonidae) and a tachinid (Gonzalez, 1964).

Borocera spp. (Lasiocampidae) are defoliators of several conifers including P. patula in Madagascar (Brunck, 1965).

The tussock moths (Lymantriidae) have much shorter life-cycles than Lasiocampidae and although few extensive outbreaks have occurred, notable exceptions being Euproctis terminalis and Orgyia basalis, they present a much more serious threat to exotic pine plantations. The cosmopolitan genus Orgyia contains some serious pests. O. basalis Walk., which is found throughout Tropical Africa, severely defoliated 800 ha of P. patula in Rhodesia in 1961-62 and has caused partial defoliation of P. patula in Malawi on two occasions. O. mixta Snell., which has been recorded from P. patula in Malawi, caused locally severe defoliation in a P. radiata plantation in Kenya in 1966 (Austara and Migunda, 1971). O. mixta has up to 6 overlapping generations per year and Austara and Migunda found that 20 to 25 larvae per metre of branch could cause complete defoliation. Younger plantations were found to be more vulnerable than older ones. O. hopkinsi Coll. reached epidemic proportions in P. patula and P. radiata in Turbo,

Kenya in 1969. This species was found to have a slightly longer life-cycle than O. mixta with 4 overlapping generations (Odera, 1972). O. australis Walk. is an occasional pest of P. radiata and P. taeda in Queensland and has been recorded from P. patula.

Euproctis terminalis Walk. is a serious pest in South Africa and Swaziland where the preferred host is P. patula (Hepburn, 1965). The indigenous host is Acacia but the moth has readily adapted to pine foliage. There is one generation a year. The female lays 100 to 300 eggs in a long cluster usually on the upperside of a twig. Young larvae are gregarious, feeding on foliage and spinning threads from twig to twig. Pupation is in cocoons in soil litter. Epidemics occur in South Africa every 6-8 years. In Swaziland up to 25 percent defoliation has occurred in P. patula plantations. Possibly the most important control agent is a nuclear polyhedrosis virus (Grobler, 1957). Euproctis sp.nov. is a defoliator associated with Buzura outbreaks in Malawi.

Other Lymantriidae which have caused some defoliation in Africa are Dasychira spp. and Mylantria xanthospila Pltz. in Uganda; the widely distributed Laelia fracta Schaus. has caused slight defoliation in Kenya, Bracharoa quadripunctata Wllgr. in Tanzania, B. bistigmigera in Angola and Aroa melanoleuca Hmps. is a minor pest of P. patula in Rhodesia.

Ariathisa semiluna Hmps. (Noctuidae) is associated with Buzura outbreaks on Cupressus and P. patula in Uganda (Brown, 1967). A. excisa H.-S. is a minor pest of P. patula plantations in Tanzania. Elaeodes brevicomis Walk. has defoliated some P. patula in Uganda but is probably of negligible importance.

Few bagworms (Psychidae) are of economic importance to P. patula. The New Zealand Liothula omnivora Fereday is polyphagous and will attack trees of almost any age and is common but of minor importance in nurseries. It is mainly a pest of P. radiata which may merely reflect the abundance of P. radiata compared with P. patula in New Zealand (Zondag, 1965). Outbreaks have occurred but is is normally well contained by indigenous parasites (Rawlings, 1962). Deborrea spp. are occasionally important in P. patula plantations in Madagascar (Brunck, 1965). Other psychids in Africa and Australia are usually confined to young plantations.

The Saturniidae, a family of large moths, contains a few recorded pests and many potential pests. In South Africa and Swaziland the most important persistent pest of P. patula plantations is the pine tree emperor moth, Nudaurelia cytherea F. capensis Stoll. Although there is only one generation a year and several normally efficient parasites together with a polyhedal virus occur in N. cytherea populations (Tripconey, 1970) large epidemics occur with extensive defoliation of P. patula especially in Swaziland. North of South Africa N. cytherea has not been recorded as a serious pest.

Other saturniid moths of potential importance and which have been recorded defoliating P. patula include N. tyrrhea Cr. in South Africa, East and East Central Africa; N. dione (F.) in Malawi; N. gueinzii Staud. in East Africa; N. rhodina Roths, in Kenya and Ubaena dolabella Druce in Tanzania. Imbrasia macrops is a potential defoliator of P. patula in Angola.

The Tortricidae attacking P. patula are represented by Archips occidentalis (Wals.) and Tortrix spp. in Africa. A. occidentalis has a wide distribution throughout tropical Africa and is mainly a pest of young trees and nursery stock although found in small numbers on older P. patula in Malawi. Tortrix spp. in Uganda and Kenya webs needles together and browses on them (Brown, 1967). The European pine shoot moth. Rhyacionia buoliana D. & S. might well become a pest of P. patula in Northern provinces of Argentina since this species attacks many species of pines. Similarly, R. frustrana Comst. might well attack P. patula in Central America.

4.31225 Orthoptera

The only grasshoppers recorded as pests of older P. patula plantations are a few species in the families Eumastacidae and Lentulidae. Populations of grasshoppers in these two families in indigenous forests are usually very low indeed and only in Malawi (and in one case Rhodesia) have serious outbreaks occurred in pines. The main species is Plagiotriptus pinivorus Descamps (in litt.), a robust eumastacid which caused such severe defoliation in Chambe Forest in Malawi that over 40 ha of 16 to 18 year old P. patula were killed. P. pinivorus is highly polyphagous but P. patula has become the preferred host. In the north of Malawi where the great majority of P. patula is planted (Vipya Pulpwood Scheme) P. pinivorus is replaced by the smaller, less virulent, less fecund Plagiotriptus leci Descamps (in litt.). Damage by P. leei has been virtually negligible. In southern Tanzania an even smaller species P. alca (C. Bol.) occurs on Mount Rungwe (Kipengere Range) on indigenous trees and shrubs. In Kenya P. hippiscus Gerst. is a large species which appears not to have adapted to pines. All Plagiotriptus spp. are almost identical in appearance with very similar habits and are very difficult to separate taxonomically and so the genus as a whole should be regarded as potentially important throughout its range. The reasons for the Malawi epidemic were probably the expanded available food supply (changing from grassland with isolated evergreen patches to planted pines with evergreen patches), two or three wet years following on several years of relative drought combined with a failure of the parasite complex. The parasite complex Metacemyia setosa Crosskey (Tachinidae), Poecilometopa spilogaster Wied. (Sarcophagidae), Oreiscelio spp. nr. seychellensis Kieff. (Chalicidae) almost certainly failed because of the paucity of flowering plants within the plantations which were required as nectar sources by the adult parasites. Defoliation opened up the plantations to recolonization by flowering plants and parasitism of Plagiotriptus increased rapidly

thereafter. A detailed study of the life-history of Plagiotriptus was carried out by Lee (1972).

Other Eumastacidae occasionally causing slight defoliation are Euschmidtia sansibarica Karsch and Lophothericles malawi Descamps (in litt.) in Malawi. The lentulidae recorded from P. patula include Malawia leei Dirsh, Mecostibus sp. including one species which caused extensive local damage in Rhodesia mainly on saplings (Whellan, 1965), Nyassacris spp nov and Basutacris sp nov. Malawia may compete with Plagiotriptus under conditions of extreme crowding and a single case of Plagiotriptus nymphs being killed and eaten by Malawia was observed. Other lentulids are of negligible importance.

Stick insects (Phasmidae) occasionally cause appreciable defoliation of P. patula in New Zealand.

4.313 Cone and seed insects

Presumably P. patula in its natural range in Mexico supports a variety of cone and seed insects but fortunately these have not been introduced into other countries along with seed imports. An instance of Chlorophorus carinatus Aur. (Cerambycidae) in cones of P. patula is on record (Curry, 1965) but damage to seeds was very slight. A number of records of minor damage to stored seeds exist from South Africa, Malawi and East Africa such as the beetles Cryptolestes minutus Ol., C. pusillus (Schonh.) and Oryzaephilus surinamensis (L.) (Cucujidae); Stegobium paniceum L. and Lasioderma serricorne F. (Anobiidae); and Tribolium confusum (Dv.) and T. castaneum (Hbst.) (Tenebrionidae), all of which are common pests of stored products. Amongst the moths, only Plodia interpunctella Hb. (Pyralidae) has been recorded in stored seed. In Malawi dead adults of two species of seed chalicids (Hymenoptera: Chalcidae) were recovered from P. patula seed collected in Mexico in 1968 but unfortunately the specimens were lost in transit to the British Museum before determinations could be made

4.314 Pests of timber and wood products

Healthy trees are seldom attacked by woodborers. The Southern Pine Beetle, Dendroctonus frontalis Zimm. (Scolytidae) which occurs in North and Central America, south to Nicaragua is polyphagous and normally breeds in overmature or sickly trees. In the natural P. patula range there is presumably a continuous succession of overlapping generations. In Mexico about 90 percent of insect damage to pines is caused by D. frontalis. Ips bonanseai (Hopk.) is the most abundant competitor of D. frontalis. The most important parasites of D. frontalis are Cecidostiba spp., Medetera aldrichii Wheeler and Tomicobia tibialis Ashm. and several species of Lonchaeidae (Rodriguez, 1967).

Chlorophorus carinatus Aur. which occurs in Malawi and East Africa attacks mainly Cupressus spp. but also other conifers, breeding

in dying trees and logs. Damage is never extensive. Other cerambycid borers, Arhopalus syriacus (Reitt.) in New South Wales and A. ferus in New Zealand are introduced longhorn beetles which attack unhealthy trees and logs. A. ferus attacks seven species of pine including P. patula and is particularly attracted to fire-killed logs and recently-dead standing trees (Hosking, 1970). The scolytid, Xyleborus sexeseni also attacks firescorched trees in New Zealand (Weston, 1973).

Most other records of Cerambycidae in P. patula refer only to damage found in dead stems or branches and in logs. Most records are from Uganda (Brown, 1967) and include several species of Lamiinae : Ceroplesis calabarica Chevr., Dichostathes collaris Chevr. Idactus usambaricus Hintz, Monochamus ruspator F., Monoxenus decliyvis Hintz and Diaphna spp. Perissus wollastoni Gah. (Cerambyanae) has been found under bark and in sapwood of P. patula logs in Uganda. In Malawi, there are very few records except from Chambe plateau in dead standing trees killed by Plagiotriptus defoliation. The most common species on Chambe is Frea nyassana Aur. with fewer trees attacked by Mecosaspis dives Pasc. and Eriesthis sp. All were found in dead stems and to a lesser extent branches. There are a few records of Ceroplesis militaris Gerst. and a single example of Monochamus ruspator from P. patula in Malawi.

Even fewer instances of flat-headed borer damage to P. patula exist. The same Plagiotriptus - killed trees in Malawi were also frequently attacked by an unidentified genus of buprestid. In Uganda Darmasila aurocincta Kerr., Megactenodes westermanni L. & G. and Sphenoptera priamus Obenb. have all been recorded from logs, dead stems and branches of P. patula. In Angola Psiloptera (Darmasila) plagicollis adults are found relatively often in Pinus spp. (Carvalho, 1971).

Some weevils (Curculionidae) are regularly recorded from P. patula logs in Africa. Stenoscelis podocarpi Mshl. (Cossoninae) is a wound parasite of Cupressus, Juniperus and P. patula in Kenya. Decaying wood is essential for attack by this genus but the weevil bores into the heartwood thus increasing degrade of the wood. S. hylastoides Woll. is a borer of hard and softwoods including P. patula in South Africa and is also found in logs and sawn timber of softwoods and hardwoods in Kenya and Tanzania. Endeochetus turneri Mshl. is recorded from P. patula logs in Tanzania. Hylurgus ligniperda is a minor pest in South Africa.

Jonthocerus conradti Senna is a common Africa brenthid weevil which has occasionally occurred under loose bark of P. patula logs in northern Malawi.

Dry seasoned timber of P. patula is most frequently attacked by powderpost beetles (Bostrychidae) and furniture beetles (Anobiidae) in Africa. There are no records of these insects attacking P. patula in East Africa but in Malawi and South Africa P. patula sawn timber is

frequently attacked by Bostrychopsis villosula Lesne, Bostrychoplites cornutus (Ol.), Heterobostrychus brunneus Murr., Xylion adustus Fhs. and Sinoxylon ruficorne Fhs. (Bostrychidae). However, these species are mainly borers of the sapwood of hardwood timbers and so damage to P. patula is usually very low. The important sapwood borer of hardwoods, Lyctus brunneus Steph. (Lyctidae) occasionally attacks softwood, a notable case being pine blockboard furniture with a hardwood veneer in Malawi in 1971.

In South Africa, the introduced Anobium punctatum Deg. (Anobiidae) is of some importance attacking pine wall panelling, roof timbers and floor joists. Ernobius mollis L. (Anobiidae), which was also introduced into South Africa from Europe is of secondary importance since it only attacks timber that has not been debarked.

The only Hymenoptera which cause damage to P. patula timber in Africa are several species of carpenter bees (Xylocopidae). These large bees which bore cylindrical nest holes in structural timber sometimes occur in sufficient numbers to cause significant structural weakening of the timber. The commonest species is Xylocopa flavorufa Deg.

Records of termite damage to P. patula are few. The Kalotermitidae dry wood termites, are represented in Africa by Cryptotermes brevis which has become established in South Africa and Congo, C. dudleyi Banks established in buildings on the East African coast and C. havilandi (Sjöst) recorded from sound wood in Malawi and East Africa.

Coptotermes sjostedti Holmgren (Rhinotermitidae), a dampwood termite, has been found in roots and stems of recently dead P. patula in Uganda. Among the Termitidae, Macrotermes spp. are voracious pests of indigenous trees in Africa and Australia and have been recorded from softwoods but not specifically from P. patula.

4.315 Conclusion

Since the vast majority of borers only attack dead or very sickly trees, the most important pests of P. patula throughout its exotic range are defoliating insects and of these the Lepidoptera pose the greatest threat by far. Within the Lepidoptera the major defoliators belong to a few families only: Arctiidae, Geometridae, Lasiocampidae, Lymantriidae, Noctuidae, Psychidae, Saturniidae and Tortricidae. In general, those defoliators which have rapid life-cycles with high fecundity e.g. Orgyia spp. (lymantriidae) are potentially more devastating than those insects with long life-cycles and low fecundity e.g. Nudaurelia cytherea (Saturniidae) although the latter may persist at a pest level for several or many seasons.

Predisposing factors for the development of an insect epidemic are poor tree growth, large available food source, one or more wet years following a period of relative drought, fire scorching of trees or failure of the parasite complex to adapt to conditions within the pine plantations or, more likely, a combination of factors as was the case in the Plagiotriptus epidemic in Malawi. The absence of an adequate food

4.3151 Table. Summary of insect pests of P. patula

			Africa	Madagascar	Australia	New Zealand	South America	Central America
Nursery pests	Coleoptera	Scarabaeidae	*					*
	Lepidoptera	Geometridae	*					
		Lasiocampidae	*					
		Lymantriidae	*					
		Noctuidae-Agratis	*		*	*	*	
		Noctuidae-Euxoa	*		*			
		Tortricidae	*		*	*		
	Orthoptera	Eumastacidae	*					
		Gryllidae	*					
Plantation pests (except wood borers)	Coleoptera	Chrysomelidae	*					
		Curculionidae	*	*	*		*	
		Scarabaeidae-Rutelinae	*					
	Hemiptera	Adelgidae-Pineus	*		*	*	?	
		Cicadidae-Melampsala	*			*		
		Coreidae	*					
		Pentatomidae	*					
	Lepidoptera	Arctiidae	*				*	
		Geometridae	*				*	
		Lasicocampidae	*	*				
		Lymantriidae-Orgyia	*		*		?	?
		Lymantriidae-other	*					
		Noctuidae	*			*	*	
		Psychidae	*	*	*	*	*	
		Saturniidae	*					
		Tortricidae	*			*	*	*
		Anthelidae			*			
	Orthoptera	Eumastacidae	*		(other genera)		(other genera)	
		Phasmidae				*		
Timber pest and wood borers	Coleoptera	Anobiidae	*		*			
		Bostrychidae	*					
		Buprestidae	*					
		Cerambycidae-Hylotrupes	*	?	?	?	?	?
		Cerambycidae-other	*		*	*		
		Scolytidae and Platypodidae	*			*	*	*
	Hymenoptera	Siricidae-Sirex	*		*		?	?
	Isoptera	Termites-Cryptotermes	*		*		?	?

supply for adult parasites within pine plantations is a problem of the pine monoculture policy.

Table 4.3151 which summarises the families containing pests of P. patula shows that the majority of pests belong to relatively few insect families. Few genera are cosmopolitan but these are indicated in the table.

4.32 Birds

4.321 Seed eaters

Flocks of finches can cause havoc in the nursery. Seed beds can usually be protected with wire netting, but where a system of direct sowing into containers is practised the use of wire screens becomes impractical and expensive . Donald (1968) noted that canaries (Serinus spp.), cape sparrows (Passer melanurus), cape collared doves (Streptopelia capiciola) and laughing doves (Stigmatopelia senegalensis) caused damage in South African nurseries both by eating the seed and by trampling the newly germinated seedlings. Wire screens proved expensive and both automatic bird scarers and men armed with slings were relatively ineffective. However, repellents proved to be cheap, effective and harmless to the birds. He recommended T.M.T.D. (Trimethylthiruam disulphide) as a repellent; this chemical is also known as Thiram or as Thiurol. Twice as many seedlings were obtained from treated P. radiata seed as from untreated seed. The birds apparently not only avoided the treated seed but also kept off neighbouring untreated beds. The recommended treatment is:-

T.M.T.D.	@ 15% dry seed weight	(TMTD is phytotoxic to seedlings if applied at too high a concentration)
Endrin	@ 25% dry seed weight	(effective against field mice, can be omitted if they are no problem.)
Terolaze	@ 70 cc per kg of seed	(a sticker to prevent TMTD washing off onto seedlings.)

The seed should be soaked in water (if that is considered to improve germination), then put in a plastic bag and shaken up with the sticker; the T.M.T.D. and Endrin should then be added and the bag shaken again; finally the seed should be dried in the sun before sowing. The cost of this treatment was calculated to be R 0.1 per lb (approximately £0.15 per kg).

Donald (1971b) mentioned the damage bush pigeons can do by perching on the leaders of pine trees while visiting plantations to feed on Phytolacca octandra berries.

4.322 Cone eating birds

There appear to be no records of cone eating birds in Africa. However, the galah (Kakatoe roseicapilla) is notorious in Australia for destroying the cones of P. radiata and they probably destroy those of P. patula as well.

4.323 Hawks and buzzards

These birds are beneficial in that they prey on rodents and can be of great use in controlling rat damage (see 4.331). In Kenya legislation was passed to protect the augur buzzard (Buteo rufofuscus) because it was considered to be so beneficial to forestry (Pudden, 1959). The long crested hawk-eagle (Lophoaetus occipitalis) is also often seen near plantations and probably preys on rodents. However it is also true that the augur buzzard, in particular, which will always perch on the highest available tree, can do appreciable damage to the leaders of trees. P. patula has an exceptionally succulent leader and appears to be very much more vulnerable to this sort of damage. This problem was overcome to a certain extent by providing hawk perches - bamboos with a cross tie - at intervals through the young plantations. These were only effective until the crop height reached about 7 or 8 metres, however at this height canopy closure had occurred, rodents moved to areas offering better low cover and the plantations were then less frequented by buzzards.

4.33 Mammals

4.331 Rodents and small mammals

Mice can damage seed in the nursery and also seed that is stored loose in the office or equipment store. These depredations are best countered by protecting the seed beds with wire netting and by using a safe poison such as warfarin. Pine seed in store should always be kept in sealed, mouse and insect proof, containers. An essential preventive measure in the nursery is the maintenance of a clean surround by the removal of weeds; a nursery cat will also deter mice and rats.

Rodent damage to P. patula plantations does not appear to be a serious problem in East Africa. Ball (pers. comm.) reported that rat damage in a species trial at Turbo was much worse in P. oocarpa (23 percent attacked) than in P. kesiya (9 percent attacked) or in P. patula, P. radiata or P. caribaea (only 2 percent attacked). Pudden (1959) noted that in Kenya rodent damage was far worse in cypress than in pine plantations and attributed this in part to the fact that in P. patula and P. radiata the branches grow in whorls which makes it difficult for the rats to climb the trees. Rat damage in cypress can occur at considerable heights up the tree. Damage takes the form of bark gnawing which may penetrate through the cambium into the wood and can be so extensive that young trees may be ring-barked. The chief culprit was identified in Kenya as Otomys elassadon, a short-tailed vole-like rat, with the possibility that Dasymys helukus helukus may also cause damage. The cane-rats (Choeromys spp.),though sometimes suspected by foresters are however not considered to attack trees.

As an emergency measure Pudden recommended driving in stakes on either side of each tree to prevent the rats girdling it. But a far more effective measure is to keep the plantation clear of grass and weeds which give cover to the rats, thus enabling predators (see 4.323) to see the rats.

Instances did occur of rat damage to P. radiata planted into grassland in Kenya, when the site had been prepared for planting by ploughing at 2.7 metres spacing. The grass (Pennisetum clandestinum - Kikuyu grass) tended to grow back over the furrow creating a tunnel which rats could use unobserved by predators. If P. patula is planted into grassland on an extensive scale, the same problem could occur but can be overcome by taking care to keep the furrows clean till the canopy closes and kills out the grass. The use of poison in plantations should only be used as a last resort, though it may be necessary to use it to control population explosions of the genus Rattus, which occur occasionally and which can do considerable damage to shamba crops. Parry (1952) however considered that rodent damage (Otomys spp. and Rhabdomys spp.) was potentially a very serious threat in the East Transvaal and Swaziland. He quoted figures for the Sabie district which showed that as many as 39 percent of the trees were attacked and 22 percent killed. He was also of the opinion that the best preventive measure was to keep the plantations clean in order to reveal the rats and mice to predators, among which he listed shrews, snakes, owls and buzzards. He also noted that after the age of four there was little risk of rodent damage and that damage was less serious in P. patula than in P. elliottii.

Edwards (1956) recommended some more ingenious methods for controlling rats in plantations in Natal; one device involved the rat overbalancing into a drum of water when attempting to reach a maize cob on the end of a see-saw, this was considered to be remarkably effective; a bait of maize meal mixed with cement was also thought to cause the rats considerable discomfort.

Donald (1968) mentions damage caused by the grey squirrel (Sciurus carolinensis) in South Africa, but without a specific reference to P. patula. Porcupines (Hystrix galeata) can be a nuisance in shamba crops in Kenya but cause little damage to trees. As a small bonus Burgess (1972) reported that possums do not attack either P. patula or P. ayacahuite in New South Wales.

4.332 Monkeys

Omar and de Vos (1970) made a study of damage by Sykes monkey (Cercopithecus mitis kolbi) in plantations in the Aberdare Mountains and on Mount Kenya. They found that Sykes monkeys normally feed on indigenous leaves and fruits, but that, where a policy of complete clearing of the indigenous forest and replacement with exotic conifers was followed, these monkeys will damage exotic trees. They also showed a species preference; of the recorded attacks 68 percent were in cypress plantations, 26 percent in P. patula and only 6 percent in P. radiata. The distribution and occurrence of the three tree species was approximately uniform. Damage took the form of bark stripping and though P. patula plantations were less frequently attacked the monkeys showed a greater tendency to ring bark P. patula trees. Attacks occurred most frequently in the season between July and October, this may be because the trees are flushing at this season and the sap is more palatable or else it may be a reflection of the fact that alternative agricultural crops - maize, beans, peas and potatoes - are in short supply.

The incidence of monkey damage has increased steadily in recent years and does not appear to have been controlled by a policy of shooting. Omar and de Vos suggest that better control would be achieved by patrolling the plantation boundaries within the high forest in the early mornings and late evenings during the season of maximum attack (July to October); by planting exotic species in big blocks so that monkeys would not move into the plantations from surrounding indigenous forest; by leaving a grass strip - three metres would be sufficient - between the plantations and the high forest; and finally by planting the apparently less attractive P. patula (P. radiata being unacceptable in these areas because of dothistroma blight) on the edge of the plantation blocks where trees are most vulnerable.

Baboons (Papio anubis doguera) are less widespread than Sykes monkey in the softwood plantation areas of Kenya, and there is no record of them damaging established plantations. However, they can cause considerable damage in shamba crops and have been known to uproot newly planted trees, apparently out of inquisitiveness. The colobus monkey (Colobus polykomos polykomos) occurs throughout the plantation area but does not damage exotic softwood trees. In northern India, apes (Presbytis entellus) cause damage by bending and breaking leaders, (Joshi and Pande, 1972).

4.333 Buck, deer and pigs

The forest duiker (Cephalophus spp.) and bushbuck (Tragelaphus scriptus) cause some damage in East Africa by eating the leaders of young trees. However, this damage is confined to the periphery of the plantation blocks and has in the past been further reduced by the shamba system of estblishment, since the cultivators have both fenced their shambas against small game and carried out their own unauthorised control programmes. Buck damage occurs throughout those areas of Africa in which P. patula is planted; experiments have been made with various buck repellents painted onto the leading shoot, but growth is so fast that the repellent has to be renewed at frequent intervals. The South African Forest Department annual report for 1971/72 notes that the buck repellent used was suspected to be toxic to Mexican pines.

In India deer (Cervus unicolor and Muntiacus muntjak) cause damage to the stems of young trees (Joshi and Pande, 1972).

Wild pig (Potamochoerus porcus) in East Africa on occasion cause a certain amount of damage by rootling in young plantations. Control is effected to some extent by leopards (Panthera pardus) which are protected in the forest. Pig damage is worst in the shamba crops but is never very serious to the trees themselves.

4.334 Big game

In East Africa there are some large herds of elephant (Loxodonta africana) and buffalo (Syncerus caffer) in the forests. The population of these animals has built up considerably since the first decades of this century, when heavy shooting of elephant and rinderpest among the buffalo had reduced populations to a low figure. Holloway (1965)

estimated the elephant population of the Aberdare mountains and Mount Kenya to be about one to the square kilometre, and that of buffalo from 1 to the square kilometre in bamboo to as high as 60 to the square kilometre in one small grassland forest near Nyeri, though the overall population was nearer 1 to the square kilometre. Large herds of buffalo are also found west of the Rift Valley but the elephant population there, except on Mount Elgon, is not large.

As the area of plantations is increased within the natural habitat of these animals it is inevitable that the incidence of intrusion into the plantations will increase, whether for the buffalos to find shelter or for the elephant to obtain access to traditional game trails or, to a lesser extent, for feeding. Damage by elephants can be very serious in mature plantations, bark being stripped off the trees up to a height of 10 metres or more; these wounds then become the foci of infection by fungi, especially Stereum sanguinolentum (see 4.224). Buffalo damage occurs mostly in young plantations up to three or four metres in height; the animals using the trees to rub their horns and scratch their hides. Both species can cause considerable damage to shamba cultivator's crops.

The black rhinoceros (Diceros bicornis) causes little damage to trees, but can be a menace to human life. However, their numbers are small - Holloway (1965) estimated a total population of no more than three hundred for the combined Mount Kenya and Aberdare forests - and their effect on tree growth is minimal.

Until the early 1960s control was achieved by shooting to remove individual animals or to break up herds that were causing damage. However, it was recognised that the forests represented important sanctuaries for these animals and that shooting by itself was not a satisfactory control technique. Experiments were carried out to protect plantation areas by means of ditches. Clark (1965) summarised the experiences of the Kenya Forest Department in using ditches or moats. The main lessons learnt were first that, unless very deep moats as used by the National Parks were constructed, it was necessary to rely on bluff and therefore the moat should be sited in the open so that elephant and buffalo did not blunder into it and through it unawares. Moats only 1.3 metres (4 feet) deep were found to be adequate provided they were covered so that animals could not see the bottom. Secondly, patrolling, maintenance, repair of damage and strengthening (by deepening) weak points proved to be essential. Thirdly , the moat should be aligned to take the maximum advantage of the lie of the land and must take into account the habits of the animals. If necessary game corridors may have to be left on well defined migration routes or to allow access to salt licks, though small salt licks can sometimes be neutralised and new ones established outside the plantation area. With these defensive measures it was possible to reserve shooting as a final resort.

In 1965 the costs of constructing such a game moat was estimated at £90 to £140 a kilometre with a maintenance cost of £9 to £13 a kilometre a year. The cost per hectare of plantation was estimated at £0.25 to 0.40 for construction and about £0.03 a year for maintenance.

Job	Task per man day	Man days per kilometre
Clearing a strip through the forest 18 m wide	18 x 9 m = 162 m^2	111
Digging the moat 1.8 m wide x 1.2 m deep and covering	1.8 x 1.2 x 1 m = 2.16 m^3	1000
Maintenance 1 gang of 4 to be responsible for 8 km	2 km	0.5

The recommended rate of pay for labour in the Nyeri district in 1965 was £0.08 a task plus 25% inducement, but even then rates were higher in other parts of the country and would presumably be much higher now.

Outside East Africa large concentrations of big game do not occur in P. patula growing areas and though there may be occasional damage from buffalo in Southern Africa or elephant in India or Sri Lanka the scale of attack does not warrant expensive deterrents.

5 Growth and yield

5.1 Volume tables

5.11 General volume tables

Several countries have developed tables for estimating volumes of P. patula. Examples from seven countries are given in Appendix III. The availability of advanced computers as a tool has made it possible to devise multiple regressions of considerable complexity. The regression used for the Rhodesian volume tables (Prevost, 1971), for example, employs eight variables. However, it has been found that much of the variance can be accounted for by using models of the form:

$$\text{Log } V = a + b \text{ Log } D + c \text{ Log } H$$

or $V = a + bD + cDH + dD^2H$

(where V = volume, D = diameter breast height, H = height)

In fact in the Rhodesian model over 99 percent of the variance was accounted for by the term D^2H. Despite the availability of advanced computers there are still advantages in employing simple regressions, even at a slight loss in accuracy, since complex regressions can be difficult to handle even on large computers and there are many occasions when calculations need to be made on small computers and on calculators.

5.12 Local volume tables

There is the possibility of creating local volume tables to take account of varying form factors in different localities. However, it seems likely that within fairly broad limits the general shape of P. patula does not vary much. In Kenya, for example, local volume tables covering fifteen site types have been constructed. None have been found to differ significantly from the original volume table based on data from a few highland sites. Therefore a general volume table incorporating all the data and covering the whole country was constructed (Wright, 1974).

In fact the differences in volume estimates to be found between countries such as Kenya, Tanzania and Uganda may well owe more to the different techniques for collecting data than to differences in the basic shape of the trees. However it should be noted that Peak Timbers in Swaziland found a 10 percent discrepancy when the South African alignment chart was used to estimate their P. patula volumes.

The Swaziland volume tables derived for Usutu and given as an example in Appendix III are in fact local volume tables, and furthermore are intended for use over a very limited range of sizes. Such limited range tables are the most accurate since tree form varies with age, position in the crop (dominant or subdominant) and with varying densities. It is possible to derive a multiple regression to take all these factors into account, but for field use the number of tables that would be needed and the inevitable anomalies that arise in matching one table to another make general volume tables a more attractive proposition. However users of general volume tables should recognise that their use to predict volumes for a small size range, particularly towards one end of the table, may lead to inaccuracies. Where volumes of crops of a well defined and limited size range - e.g. pulpwood or possibly thinnings - are frequently being estimated, there is a good case for deriving special volume tables.

Conversely bias can occur as a result of deriving general volume tables from data relating predominantly to one size class. This is illustrated by the Rhodesian tables for which 47 percent of the data used to derive a table to estimate volumes up to more than 5.0 m^3 came from trees of less than 0.14 m^3 in volume.

5.13 Stand volume tables

The use of dominant height and basal area for estimating volume on an area basis have been derived for Malawi (Marshall and Foot, 1969) and for Kenya (Wright, pers. comm.). These tables are useful as quick inventory technique for field foresters. The regressions developed were:

Malawi $V = -4.835 + 0.3936GH_{dom}$

Kenya $V = 20.764 - 1.269G - 1.3601\ H_{dom} + .462275\ GH_{dom}$

(Where V = total volume underbark in m^3/ha, G = basal area in m^2/ha, H_{dom} = dominant height in m. Examples are given in tables 5.131 and 5.132, Appendix III).

5.14 Bark volume

P. patula is a thin barked tree, but nevertheless bark can account for up to 12 percent of the volume of a mature tree. In the Malawi tables bark volume was estimated to be 11.3 percent of the stem volume whatever the size of the tree; in the Kenya tables the bark volume varied from 14.5 percent of small trees (15 cm dbh) to only 9 percent for mature trees. These estimates should be compared with those for P. caribaea (Ackhurst and Micski, 1971b) in which bark may account for up to 19 percent of stem volume on mature trees and up to 33 percent on small trees.

5.15 Form factor

The form factors of the trees used in constructing the Rhodesian volume tables are given in table 5.151.

5.16 A comparison of volume tables

In table 5.161 the volume of trees of a range of sizes have been calculated using different volume tables. In the largest size classes the maximum divergence is only 9 percent from the mean, though this increases to 20 percent in the small sizes. Considering the different standards used in measuring volume it would appear from this table that there is little variation in the form factor of the tree over a wide geographic range.

5.161 Table : Total overbark volume estimates

Size H m	Size D cm	South Africa	Rhodesia*	Malawi	Tanzania	Kenya	Uganda	Swaziland 15-19 yrs	Swaziland 9-10 yrs
10	10	.033	.038	.040	.047	.041	.047	.031	.031
20	30	.563	.763	.646	.647	.626	.704	.588	.412
30	50	2.314	2.502	2.618	2.396	2.544	2.737		
40	60	4.467	5.133	5.145	4.442	4.889	5.086		

* adjusted from underbark values, assuming that bark percent varies from 14 percent on small trees to 9 percent on the largest trees

5.2 Site quality classification

The rate of growth and therefore the yield of P. patula varies considerably depending on the site conditions as well as on management techniques and the genetic quality of the crop. The inherent qualities of the tree are discussed in Chapter 7 and management techniques in Chapter 8. Site quality can be altered to a small extent by fertilising and by controlling weed growth but in general it is a variable over which the forester has little control. It is therefore of importance to recognise site types and to understand their effects on crop yields. Evans (1974) found that about 60 percent of the variation in dominant height of twelve year old P. patula crops in the Usutu plantations in Swaziland could be related to altitude, topographic position (distance from ridge top) and to soil set. Other factors that contributed significantly to explaining dominant height variation were steepness of slope,

5.151 Table. Form factors derived from data used for Rhodesian volume tables (Prevost, 1974)

(Figures in brackets are for classes containing less than 20 trees; classes with less than 10 trees have been omitted.)

$\bar{H}$ \ $\bar{d}$	8.9	11.4	14.0	16.5	19.0	21.6	24.1	26.7	29.2	31.8	34.3	36.8
6.3	.508											
7.8	.482	.453	.424									
9.3	.518	.472	.448	.429	(.415)							
10.9	.497	.470	.456	.438	.409	(.418)						
12.4	.532	.494	.467	.443	.424	.411	(.380)					
13.9	(.500)	(.477)	.473	.453	.429	.409	(.403)					
15.4			.477	.467	.440	.425	(.412)	(.388)				
16.9			.469	.452	.443	.419	.434	(.412)				
18.5				.466	.454	.439	.425	(.396)	(.397)			
19.3				(.468)	.472	.454	.436	.415				
21.5					(.490)	.461	.464	.447	(.425)			
23.3					(.471)	(.483)	(.454)	.453	(.453)	(.445)		
24.6							(.459)	.474	.472	(.462)	(.441)	
26.1							(.484)	(.456)	.459	.462	.451	(.443)
27.3									(.478)	(.458)	.465	(.461)

and the levels of phosphate and potassium in the soil. Castanos (1962) found that in natural stands in northern Oaxaca, if the stands were stratified by age, much of the variation in dominant height could be accounted for by three of the twenty two factors he tested. These three factors were altitude, soil depth and aspect.

In a recent survey in Malawi the importance of site quality is illustrated in the standing volumes given in table 5.21.

5.21 Table: Standing volumes (m^3/ha) by site classes - Viphya plateau Adlard (1973).

Site	Crop age - years		
	6	7	8
Ridge top	15 ± 3.7	51 ± 13.8	91 ± 19.8
Mid slope	38 ± 6.6	99 ± 11.5	125 ± 15.8
Lower slope and valley bottoms	53 ± 14.9	144 ± 20.8	158 ± 22.5

Standing volumes in the lower sites, which had deeper and probably more fertile soils, were less prone to water stress and were less exposed, were up to three times the volumes on ridge top sites.

5.3 Yield classes (see tables 5.31 to 5.34 in Appendix IV)

Yield classes are conventionally classified according to height growth, because height is less affected by management practices than the other most easily measured parameter - diameter at breast height. The South African C.C.T. plots (see 5.4) have shown that mean height is in fact affected by stocking, being reduced both by heavy and (to a lesser extent) by very light stocking, but the differences are not large. Dominant heights would be less affected than mean heights. A comparison of dominant height growth in four countries is given in figure 5.31 in Appendix IV.

Veldhoen (1968) considered that the dominant trees in a P. patula crop in the tropics assert their dominance at an early age and grow at relatively uniform rate within fairly wide ranges of stocking. He suggested that the basal area of the dominants was as good a criterion of yield potential as dominant or mean height. Wright (1974) tested this possibility on permanent sample plot data but found basal area to be a less precise index than dominant height.

The most reliable estimate of yield to be obtained from a site is the maximum volume, or as a second best the maximum basal area, that can be maintained on a site. This requires the maintenance of unthinned plots on all major site types; very few such plots are now

in existence but there is a good case for their establishment. Table 5.32 is a yield table for unthinned crops on the Viphya plateau (Adlard, 1973) the yield class (YC) here being defined as the dominant height reached at age fifteen. However the comparison of growth from widely differing sites using height as the criterion must be made with caution. The height growth in permanent sample plots at two locations in Kenya (Kinale, good rainfall, cooler temperature; Nanyuki, lower rainfall and warmer) were very similar. But it was apparent that, even though stockings were lower at Nanyuki, diameter growth was less and therefore that basal area increment and volume increment was very much lower. It appeared that up to the age of nine years the trees at Nanyuki put on the same height increment as the Kinale trees but were unable to respond to release by putting on greater diameter increment. Marshall and Foot (1969) also noted that in Malawi at low levels height growth might be faster in young stands but that growth culminated much earlier (see Figure 5.31). Thus at low altitudes in young stands height by itself might give a misleading impression of the potential yield.

5.4 Thinning response

Many P. patula thinning experiments have been designed to investigate the effect of maintaining constant stocking or constant basal areas and are in effect spacing experiments. There are few mature experiments in which response to release has been adequately investigated.

5.41 CCT plots

The most comprehensive investigation of the response of P. patula and other subtropical pines has been conducted in South Africa. These trials, which are still extant, consist of a series of constant stocking plots having stockings from 2970 stems per hectare down to only 125 stems; these plots were supplemented by others which were established at 2970 stems per hectare and were then thinned at varying intensities and ages. The object of these trials was both to determine the growth pattern of trees on a range of sites and under varying degrees of suppression and also to test the trees' ability to respond to release after suppression. O'Connor (1935) assumed that there would be a simple correlation between a coefficient of suppression and a coefficient of response. In fact the coefficient of response has proved to be independent of suppression over a wide range of stocking. It soon became apparent that increment response could not be predicted accurately by assuming that growth after thinning would follow the trend of the curve at the lower stocking but of the same age.

However Burgers (1971) has demonstrated a technique whereby the point on the curve of lower stocking is chosen not at the same age, but so as to have the same mean diameter as the thinned stand, after

making an adjustment to allow for the increase in diameter consequent on the removal of small trees as thinnings. Increment can then be predicted reasonably accurately for a minimum period of four years. Burgers (1972) noted that after thinning there was a five year period of large additional increment followed by another five year period of moderate additional increment. Marsh (1957) considered that Craib had misinterpreted the treatments in O'Connor's C.C.T. plots and had consequently prescribed early thinnings before the onset of competition. A stand of a slow growing species such as P. roxburghii would remain permanently in a state of free growth if thinned to Craib's prescriptions. One of the results of the C.C.T. trials has been the appreciation that many of the earlier assumptions on thinning response, reached as a result of analysi of trials in which stocking had varied very little around a mean, were not valid when extreme treatments were introduced. In particular the theory that current annual increment does not vary over a wide range of densities and the view that it was impossible to increase total volume production by thinning were shown to be false (Marsh, 1957).

5.42 Mathematical models

These analyses and interpretations of the C.C.T. trial results provide very useful but essentially empirical techniques for predicting growth. Pienaar (1969) used the C.C.T. results to test a mathematical model based on the Chapman-Richards equation which is a generalised form of Bertalanffy's growth model. The basic model is a three parameter differential equation, which assumes a relationship between growth rate and the quantity of living matter in the stand (Turnbull and Pienaar, 1965). In simple terms it relates growth to two processes; a metabolic or building up process, correlated with the superficial area of the tree representing the photosynthesising surface; and an anabolic or destructive process correlated with the volume of the tree. The resulting asymptotic curves were found to agree closely with the growth trends of the C.C.T. plots. The advantage of this model is that for any one site, provided there is some data on basal area growth trends in unthinned stands, a series of growth curves can be derived for any stocking. It has also been found possible to apply the model to thinned stands, since it was found that for a wide range of thinning regimes the growth rate in a thinned stand is identical with that of an unthinned stand of the same age and the same basal area as the thinned stand (Pienaar and Turnbull, 1973).

There are no doubt improvements that can be made to this model but it would appear that this approach which attempts to quantify the natural growth processes offers in the long run a more practical solution to the understanding of growth responses and to the production of yield tables than the strictly empirical approach used formerly.

5.5 Expected yield

Estimates inevitably vary widely, Adlard et al. (1974) found that on a high rainfall fertile site in southern Tanzania a mean annual increment as high as 40 m^3 per hectare could be achieved in plots that had been maintained at a basal area of about 45 m^2 per hectare. Even

plots that had been kept at a low stocking (15 m^2 per hectare) had a gross mean annual increment of nearly 20 m^2 per hectare. The increment of the heavily stocked plots culminated at about age twelve. The diameter distribution of these plots at age thirteen is given in table 5.51 and clearly show the effect of low stocking on increased diameter growth that Craib found important.

5.51 Diameter frequency distribution Exp. 408 Kiwira (Adlard et al., 1974)

Stems per hectare

	DBH Class									
Treatment	10	12	14	16	18	20	22	24	26	
45 m^2/ha	13	43	113	207	183	273	193	133	73	
30 "	-	-	-	-	33	90	157	113	97	
20 "	-	-	-	-	-	-	-	-	10	
15 "	-	-	-	-	-	-	-	-	7	cont./
Treatment	28	30	32	34	36	38	40	42	44	Total
45 m^2/ha	57	13	7	7	-	-	-	-	-	1315
30 "	70	37	10	13	3	-	-	-	-	623
20 "	43	57	50	23	33	17	13	3	-	249
15 "	7	10	27	17	33	23	30	7	10	171

These yields are from research plots on a particularly fertile site; they would not be representative of the situation in normal production plantations. Adlard (1973) considered that yields on the Viphya plateau might be as high as 29 m^3 per hectare per year in unthinned stands on the best sites, but that overall yields are likely to be 20 m^3 per hectare per year or less. The mean annual increment would culminate at between fourteen and eighteen years of age depending on the site. Marshall (1968) considered that for site index 24 (80 feet at age 20) the gross yield to a 12 cm top diameter in Malawi would be about 18 m^3 per hectare per year for crops felled at age thirty and that it might be as low as 10 m^3 for site index 18.

In Uganda predicted yields varied from 9.9 m^3 per hectare a year on a 35 year rotation for site index 18 (age 20) to as high as 21 m^3 on site index 24; volume to an 8 cm top (Kingston, 1970).

Paterson (1967c) postulated a mean annual increment to a 20 cm top diameter as high as 19 m^3 per hectare per year for the final crop in Kenya at thirty years, standing at 370 stems to the hectare. However he considered that mean diameter at breast height would be less than 40 cm. To achieve a diameter of 50 cm he postulated that the crop would have to stand to thirty five years at a stocking of

only 200 to the hectare, resulting in a mean annual increment of little over 12 m^3 per hectare a year. These estimates are largely theoretical but they do not appear unreasonable when compared with measurements of permanent sample plots on a good site (Kinale). Eighteen year old plots at a stocking of 450/st/ha there had a gross yield of more than 24 m^3 per hectare per year and thirteen year old plots at a stocking of 780 st/ha averaged better than 30.5 m^3 per hectare per year. Unfortunately measurements for a less favourable site are not available for crops older than ten years.

Reference to table 3.510.2 (Appendix II) shows that for saw log regimes gross yields in excess of 20 m^3 per hectare a year culminating at about age twenty are anticipated in South Africa and Rhodesia. For pulpwood regimes yields as high as 28 m^3 per hectare a year have been predicted. However Burgers (1972) applied the following conversion factors in calculating utilisable yield:

Age of thinning	Saw log regime	Pulp regime
10	0.95	0.95
15	0.85	0.95
20	0.70	-
25	0.70	0.75
30	0.70	-
Overall	0.75	0.81

This would imply utilisable sawlog yields of about 15 m^3 per hectare and utilisable pulp yields of about 22.5 m^3 per hectare. These yields agree well with findings in Swaziland that sawlog yields in the Pigg's peak area were not expected to exceed 16 m^3 per hectare a year and for pulpwood at Usutu it was considered that at age fifteen the yield would not exceed 20 m^3 by very much. In Madagascar gross volume yields from 20.3 m^3 per hectare a year at age 10 to as little as 2.3 m^3 per hectare a year have been produced depending on the site (Devillé, 1973).

Because there are so many factors that affect yield it is unwise to generalise on the yields that can be expected. On sites with deep soils and a good rainfall with little or no dry season gross mean annual increments of 35 m^3 per hectare and utilisable yields of 26-27 m^3 per hectare are quite possible in well managed stands providing large dimension timber is not required. Such conditions do not prevail in southern Africa and where the dry season, that is those months in which rainfall is less than about 20 mm, is longer than three months it is probable that gross yields will be 20 m^3 per hectare a year or less.

5.6 Current thinning practices

Thinning practices employed in various African countries are tabulated in Table 3.510.2, Appendix II, they are also shown graphically in figures 3.510.31/2, which give the Hart-Becking line (dominant height on stocking) and in figures 3.510.33/4, which give the Reineke line (mean diameter at breast height on stocking). The shift from the heavy early thinnings followed by relatively lighter thinnings advocated by Craib towards the more delayed early thinnings and heavy late thinnings is apparent from the comparison of the South African 1948 schedule and those advocated by Burgers (1972) for timber, and Cawse et al (1972) for pulp. Whereas the former has a basal area that increases through the rotation in the schedule advocated by Burgers, the basal area decreases. The difference in the timing of the first intervention is particularly clear, the current South African and Rhodesian plantations are first thinned when basal area is less than 25 m^2 whereas Burgers advocated waiting until it has built up to over 40 m^2.

6 Wood Properties (by R.A. Plumptre)

6.1 General

6.11 Wood properties and uses

6.111 Mexico

Very little information has been published regarding the wood properties and uses of P. patula grown in its native Mexico. Loock (1950), visiting Mexico from South Africa, reported that the wood from naturally grown P. patula was sawn for light construction work and for making boxes. The outer parts of logs, where rings were closer than 8 to the centimetre, were used for the manufacture of wood flooring at a plant near Apulco, Hidalgo.

Zobel (1965) visited Mexico and collected cores from naturally grown mother trees and measured density and tracheid length. He found considerable variation between trees but mean values were not markedly different from means for plantation-grown material from other parts of the world.

6.112 South Africa

Scott (1953) reported that the wood was used in South Africa for ceilings, internal joinery work and shelving. By 1953 it was used as pulpwood in South African paper mills. Poynton (1957) also reported that the wood was used for box shooks and pulp and that wood from older trees was used as a substitute for deal in construction work. The timber, he reported, was soft and brittle while nodal swellings in some trees further reduced strength. However dense P. patula timber is considered suitable for flooring (de Villiers and Perry, 1973).

It appears, therefore, that by 1953 the properties of naturally grown P. patula in Mexico, and plantation grown material in South Africa were recognised as similar and the uses to which it was put were also essentially the same.

6.113 East Africa

The timber has not been used much until recently and is mainly used as a general purpose timber similar to Cupressus lusitanica but at present it is less popular than this species. As a higher proportion of mature timber of the species comes on to the market the prejudice against P. patula is likely to lessen.

A more detailed record of the properties of the wood of the species follows below:-

6.12 Appearance of the timber

The early wood is almost white, while the late wood is pale brown and there are numerous small resin canals. The resin content of the wood is not, however, high and in most trees does not comprise more than 1-3% by weight of the wood (Tissot, 1968). Occasional trees,

however, have up to 40% of resin in clearly marked zones close to the pith (Plumptre, 1972). The resin content is very high in the neighbourhood of game wounding (Kibuku et al. 1972b). An increase in the proportion of late wood and a reduction in ring width, are also visible from the centre of the tree outwards. Heart wood in plantation grown material is not easily distinguishable from sapwood.

6.13 Sawing Properties

The wood can be sawn easily both when green and dry and has little blunting effect on saws. The only limitation to very rapid feed speeds is likely to be the capacity of saw tooth gullets.

6.14 Blue Stain

Both logs and sawn timber are susceptible to blue stain; rapid conversion after felling and anti-stain dipping after conversion are necessary to avoid discolouration.

6.15 Seasoning

6.151 General

Accounts of the response of the timber to seasoning are conflicting. Some publications record that there were no problems in drying the timber and that it dried rapidly with little distortion. According to other reports severe distortion occurred particularly in scantling sizes. This defect is almost certainly related to the age and size of the tree. Scott and Stephens (1947) found that 12 year old material from South Africa tested in 1924 showed considerable distortion, while 30-40 year old material tested in 1944 seasoned well. They also reported that large spiral grain angles were correlated with high distortion. One inch (2.5 cm) thick material dries better than thicker dimensions (Gueneau, 1970).

Seasoning distortion depends on a complicated combination of interrelated factors of which mean grain angle, variations of grain angle within the piece of timber, number and arrangement of knots, radial and tangential shrinkage and the ratio of one to the other, percentage of compression wood, dimensions of the timber and method of sawing (orientation of the piece in the log), all play a part in determining how the timber dries. In the juvenile core grain angle is higher and probably more variable than in the outer wood, rings are more curved (i.e. radial and tangential shrinkage act in a manner more likely to cause distortion), knots are more frequent and sawing is likely to be less exact in orienting the piece of timber relative to the pith. Because of these factors distortion, particularly of timber of nearly square cross section in small dimensions, is normally greater in the juvenile core than further out.

Growth stresses probably also affect distortion, before and during seasoning, particularly in juvenile wood. It is possible that these are modified in older trees by the adult wood laid down round the highly stressed core but little information is available regarding stresses in P. patula.

Very high green moisture contents of between 150% and 200% have been recorded for the species; this is consistent with the low density of the wood and high proportion of early wood with large cell lumens and thin walls.

6.152 Air seasoning

The time taken to season the timber to 20 percent moisture content in the air in Uganda was between 2-3 weeks for one inch (2.5 cm) thick material.

6.153 Kiln seasoning

The timber kiln seasons rapidly and usually without severe degrade. Bryce (1959) reported some distortion, which was reduced by a 24 hour treatment in a saturated atmosphere. Recent South African research (South Africa Report 1969/70) has shown that high temperature drying, of 1½ inch (4 cm) thick tangentially sawn timber, at 88°C resulted in less cupping than drying at 52°C. The drying time was reduced from eight to four days. In this trial the timber was dried in a stack which was weighted; several other authors report that restraint reduces distortion of P. patula during air and kiln drying.

6.2 Physical and mechanical properties

6.21 Variations in properties

While P. patula is not as variable in its properties as some other tropical pines, the variation shown is still considerable and it is useful to examine possible sources of this variation. Variation may be associated with:

Geographical location.
Site conditions.
Between-tree (within site) differences.
Within-tree pattern of wood development.

Geographical sources of variation are concerned with the effects of large climatic and environmental differences such as are exhibited by different latitudes in the same continent or the same latitudes in different continents; for convenience they are considered here as differences between one country and another.

Site sources are distinguished by more localised differences in altitude, soils or climate.

Between-tree (within site) sources of variation are taken to be differences between trees growing in similar macro-environmental conditions of climate, soils and topography but subject to differences in their immediate environment due to competition and other localised site factors. It can be assumed that many, but not all, of the observed differences between trees on the same site can be attributed to genetical differences.

Within-tree sources of variation also are partly the result of the genetic characteristics of trees and partly of the effects of the

environment on the tree.

6.211 Geographical variation

Properties of the wood of P. patula tested in a number of countries are given in table 6.211.1. Examination of the table shows that the age of trees tested affects the average values for the strength of the timber and the fibre length. By comparison the differences between mean values for trees of similar age in widely separated countries such as South Africa, Madagascar and Uganda, which have very different climates and soils, are quite small. Published figures are not available for naturally grown P. patula from Mexico, but it seems likely from the uses to which it is put there, that mean values would not be much greater than for the older plantation-grown material in Africa.

6.212 Site variation

Scott and Stephens (1947) compared the density and bending strength of P. patula wood from three sites from different altitudes with widely differing soils and rainfall. With samples of 42-57 m^3 of timber they found large between-tree differences and large within-tree differences but only quite small between-site differences. There was only a 20 percent difference in site mean values of modulus of rupture between the two extreme sites. Plumptre (1972) analysed timber samples from four sites which differed considerably in altitude and length of dry season and found that site differences accounted for less than 10 percent of the total variation in density and of the main strength properties. Tests seem to have been carried out only in stands of trees which have shown good growth. It is likely therefore that the species has been sampled mainly within the range of sites that are suitable for it; this may, in part, account for the small between-site variations.

6.213 Between-tree variation

By contrast, between-tree variation has been reported to be large by almost all workers. Paterson (1967, 1968a, 1968b and 1969) found large differences between trees and suggested that considerable gains in timber values could be obtained through breeding. Tissot (1968) found an inverse relationship between rate of growth and density. Paterson (1967) and others found similar relationships, but the degree of correlation was low, leading to the conclusion that only a small part of between-tree variation in density can be accounted for by rate of growth and much is due to the individual character of the trees.

6.214 Within-tree variation

6.214.1 Density, strength and fibre length

The within-tree variation of Pinus patula shows a pattern which is typical of most pine species. There are marked gradients of

increasing density, strength and fibre length from the centre of the tree outwards at all heights. Density tends to decrease from the pith outwards for the first few rings but then assumes a steadily increasing trend. Fibre length increases steadily with no initial decrease. Variations of wood density within the stem are shown by the densitometer traces in Figure 6.214. The contrast between the species grown on the equator in Uganda and in a sub-tropical climate in Swaziland is shown by the more pronounced annual rings in the Swaziland material. The Uganda material shows a tendency towards a two peak arrangement.

Turnbull and Du Plessis (1946) and Plumptre (1972) have shown by means of contour diagrams, the distribution of wood densities and strengths within the stem. The increase in strength and density from the centre of the tree outwards coincides with a decrease in width of ring. Turnbull and Du Plessis (1946) and Scott and Stephens (1947) concluded that physiological age, rather than environmental conditions or rate of growth is the major factor affecting strength and density within the stem. Most workers have found little variation of density or strength with height in the tree but Plumptre (1972) found a small, but statistically significant, increase of density and strength with increasing height at one inch from the pith. This suggests that the softest and weakest wood is near the base of the tree in the centre while the strongest and most dense wood is near the outside of the stem but also near the base of the tree.

6.214.2 Grain angle

Several workers (Turnbull (1942), Banks (1956), Paterson (1967) and Paterson and Howland (1971)) have shown that spiral grain is common in P. patula. The grain angle has been found to decrease from the centre of the tree outwards and Paterson showed that it was in the region of two degrees lower near the bark at the base of the tree than near the pith at the same height. He also found good correlations between external grain angles at breast height and weighted whole tree grain angles. Inclination of grain is however very variable around the stem and varies markedly within quite small areas.

Banks (1956) and Paterson (1967) found a moderate positive correlation between rate of growth and grain angle suggesting that with fast growth the inclination of the grain increases. Studies of effects of grain angle on strength of the wood (Brazier (1954) and Plumptre (1972)) suggest that grain angle of over 5-7^{o} has a significant effect on bending strength. Scott and Stephens (1947) have suggested that pruning may reduce grain angles and this was confirmed by Gerischer and de Villiers (1963) working on P. radiata.

6.22 Correlation of morphological characters with wood properties

Density, strength and angle of grain do not appear to be closely related to any externally recognisable morphological characters, but it was found in one investigation that density was slightly but significantly positively correlated with crown diameter (Plumptre, 1972).

6.23 Knots

Several writers have reported that knots seriously reduce the

strength of the timber, particularly where the knots are large and occur in whorls. Banks (1956) showed that nodal swelling, which indicated the presence of large occluded knots, considerably reduced the bending and axial compression strength of the timber.

6.24 Durability and preservation

The wood is not resistant to fungus, insect or termite attack and, in external conditions in the tropics, deteriorates rapidly. It is easy to treat by vacuum-pressure methods (Plumptre and Kasirye, 1969) and complete penetration of preservative into all but the thickest timber sections can be obtained. Shingles pressure-treated with creosote were reported to be in excellent condition after ten years exposure. The timber is also easy to treat by hot and cold tank and by dip diffusion methods. Gueneau (1970) reported that small poles could be treated by sap-displacement methods. Plumptre (1973) however rejected this method of treatment for fence posts after observing large concentrations of preservative in the bottom of the posts, but very little upward transfer of preservative. The use of this method for preserving P. patula was much less satisfactory than for E. grandis poles.

6.25 Use of P. patula for poles

Gueneau (1970) suggested the use of P. patula poles, since the poles are easy to treat, for purposes such as telephone lines where the load carried is small. Campbell (1971) compared standard Eucalyptus saligna transmission poles with 13 year old and 20 year old P. patula poles and found the latter considerably (30-40%) weaker. Knotty poles were weakest and exhibited "carroty" types of fracture at nodes. He concluded that the pine poles were unsuitable for power lines unless carefully selected and that such poles should not normally be taken from plantation thinnings.

6.26 Woodworking

The timber can be sawn without difficulty; it planes and moulds easily. It takes nails easily, without splitting, and glues well. It turns fairly well, but for boring and morticing requires support to avoid breakout at the exit of the tool and it tends to break away at the edges of the hole. The wood is too soft for high class furniture or joinery manufacture unless used in thick sections and coated with a hard finish. It can, however, be used for panelling and decorative purposes and is attractive in appearance because of the colour contrast between early and late wood. Boards containing large knots could produce attractive panelling.

6.27 Use for particle board manufacture

The wood is suitable for particle board manufacture and gives a board of good strength (Parrish, 1958).

6.28 Use for wood-wool-cement board manufacture

The wood does not retard the setting of cement appreciably and

can be used satisfactorily for making wood-wool slabs and boards. It is suggested that this might be a good use for thinnings, which are too small and weak to produce sawn timber.

6.29 Pulp and paper manufacture

The species is used in the manufacture of pulp on a commercial basis in the Usutu paper mill in Swaziland, and in several mills in South Africa. It is proposed that it should be used for the manufacture of pulp in East Africa.

In 1939 Loseby reported the results of a pilot test followed by a more comprehensive test of P. patula for paper making at the Forest Research Institute in South Africa. These tests showed that the species was satisfactory for pulping by the kraft process. They were followed by a pulp and paper making trial at the Premier Paper Mill at Johannesburg in a ½ ton digestor; this indicated that there would be no serious technical problems in using it for making paper on a commercial scale.

Table 6.291 gives results of more recent tests from Usutu in Swaziland, Madagascar, Angola and New Zealand. Fibre lengths for the species vary greatly but normally range between 2 and 5 mm with an average of about 3.2 reported in Kenya (Paterson, 1967).

In Madagascar Tissot (1968) found that, for kraft pulp, cooking for 90 minutes at 170°C produced better pulp than cooking for longer at 155°C. The yield of pulp produced from P. patula was higher than that obtained from P. caribaea and P. oocarpa and it produced a pulp with higher average strength properties. The bleaching properties were also good.

Since tear strength tends to decrease, whereas burst strength and breaking length tend to increase, with beating different beating times have to be selected for each type of paper. Mixtures of lightly beaten P. patula pulp and Eucalyptus pulps such as E. grandis/saligna may be advantageous in order to utilise the high tear strength of the pine pulp and the high burst strength and breaking length of the Eucalyptus.

Tissot also tested P. patula using the Soda (Soude) and the M.S.S.C. (Monosulphite) processes. Yields were 63% in the M.S.S.C. process but strengths were 30% lower than for kraft pulp. He also made Calcium bisulphite and mechanical pulps.

The mechanical pulp properties were as follows:-

Yield	Breaking length	Burst	Tear	Porosity
95%	1730 m	8.9	42	8.9

Tests using different densities of P. patula wood indicated that low density wood produces pulp with higher breaking length, higher burst strength and higher stretch but lower tear strength and lower porosity, whereas denser timber has lower breaking length, burst strength and stretch but higher tear strength and porosity.

6.291 Table. Paper making properties of Pinus patula using the kraft process

Location	Age of trees	Yield	Freeness	Breaking length	Burst factor	Tear	Bulk	Porosity	Stretch	Source of data
	yrs	%	S.R.	m		gm			%	
Angola	15	45	49	7480	64	121	1.48	2.3	2.25	IIAA (1973)
Madagascar	12-31 (6 trees)	45	40	6300	44	140	1.70	2.5	2.2	Tissot (1968)
New Zealand		48	16	7000	57	235	1.62	-	2.5	Uprichard (1970)
Swaziland (Usutu)	6-9	48	40	8600	58	125	1.55	0.5	2.7	Tissot (1968)

The Forestry Division of Technology of the Institute of Agricultural Research in Angola carried out kraft pulping trials under similar conditions to those used by Tissot. They found in the test material marked trends of increasing density and tracheid length from pith to bark (IIAA, 1973). The quality of pulp produced was similar to that reported by Tissot.

Uprichard (1970) carried out tests on P. patula grown in New Zealand. He used the kraft process but the pulps were beaten less than in the other trials reported; higher tear strengths without apparent significant loss of other strength properties were obtained but this may reflect the better density and quality of the wood rather than improved methods of paper making.

Myburgh and Mackenzie (1966) summarising South African experience with P. patula confirmed that low density wood tends to produce pulps having low tear strength and stated that the juvenile core at the base of the tree was less suitable for paper making than the core further up the tree (see 6.2141). Separation of earlywood and latewood resulted in very different pulps; the latewood gave strong unbleached kraft pulp whereas the earlywood produced pulp suitable for bleached fine paper. They suggested that sawmill waste, consisting mainly of the denser outer wood of older trees, should be mixed with young thinnings to produce acceptable pulps and stated that pulp from thinnings under 18 years old was inferior in quality.

The pulps obtained from P. patula are slightly, but not greatly, inferior to Scots pine pulp and are suitable either alone, or in mixture with other species, for making most grades of paper.

6.3 Manipulation and control of wood properties

The problems of the juvenile core wood of P. patula and its undesirable properties have been discussed frequently. It was found by early investigators that faster growth in young trees tended to reduce the density of the core wood. Some recommended that growth should be retarded in the early years by close planting and lighter thinnings to increase the density of the core wood. Turnbull and Du Plessis (1946) and Scott and Stephens (1947) argued forcefully that the strength of the juvenile core is not primarily determined by environmental conditions, but by the age and inherent nature of the tree. They claimed that manipulation of tree spacing to control growth rate in young crops would have little effect on the density of the juvenile core. Furthermore they maintained the greater quantity of denser wood laid down later in the life of fast growing trees was of more value than any increase in density in the core that might be achieved by closer spacing. These conclusions appear to be confirmed by the fact that mean density, strength and fibre lengths do not vary very greatly from place to place throughout the world. This is in striking contrast to P. caribaea and some other tropical pines where response to environment is much more marked in terms of changes in wood properties. A possible explanation is that P. patula will not tolerate as wide a range of growing conditions as a more tolerant species such as P. caribaea and is therefore not subjected to such extremes of environmental influence.

By contrast the between-tree variation is large in P. patula (Paterson, 1967, Plumptre 1972 and Zobel, 1965). This variation is not only in density, fibre dimensions and strength, but also in specific strength (strength per unit of density). Most writers agree that a large component of this variation must be genetically determined and Paterson (1967) and others have attempted to estimate the gains that might be possible by breeding for vigour and wood quality. Although these estimates are not based on breeding trials of P. patula itself, which are not sufficiently advanced, the indications are that appreciable increases in value of sawn timber could be achieved through breeding. Denison (1968) suggested that a more thorough exploration of seed sources in Mexico is required to make use of all the available provenances (but see 7.11). Plumptre (1972) found that the density of wood laid down in the early life of the tree was fairly well correlated with the weighted mean density of 20 year old P. patula trees and this suggests that it may be possible to identify trees of better than average density early in life. This may be a further indication that wood properties may be quite strongly genetically controlled. It, therefore appears that breeding offers considerable opportunities to improve the quality of wood produced while at the same time maintaining, or increasing, the volume and dry weight production.

6.4 Comparison of properties with other Tropical Pines

P. taeda (loblolly pine), P. elliottii (slash pine), and P. radiata (Monterey pine) are three species which grow in similar climatic conditions to P. patula in Africa. Average strength properties taken from Koch (1972) and Bryce (1967) are given in table 6.41. Koch's figures for the loblolly and slash pine are from information obtained for a variety of sites and tree ages and probably include natural stands as well as plantations; this may account for the very high values for slash pine. They are not, therefore, directly comparable with figures for plantation grown P. patula. Information from New Zealand (Weston, 1973), however, showed by stress grading that timber of P. radiata was higher in strength than 31 year old P. patula but the age of the P. radiata was not stated. P. patula had longer fibres but gave a lower pulp yield.

6.41 Table. Average strength properties of Pinus taeda, P. elliottii and P. radiata at 12% MC

Species	Modulus of Rupture	Modulus of Elasticity	Total work to Fracture	Axial Compression Strength	Side hardness
	N/mm^2	N/mm^2	mmN/mm^3	N/mm^2	N
P. taeda[1]	86.9	12070	-	33.2	3070
P. elliottii[1]	112.5	13660	-	43.3	4490
P. radiata[2] (33 yrs old)	82.8	12760	0.104	50.3	-

[1] From Koch (1972) [2] From Bryce (1967)

The figures given in Table 6.42 are all, except for the P. sylvestris, from South Africa and even though the ages of the trees are not given they are much more comparable than those given in Table 6.41. From these figures it can be seen that P. patula is generally stronger than P. elliottii and P. taeda but is weaker both in terms of absolute strength and specific strength than P. radiata. It is also to be noted that P. patula is two to three times as variable as the other three pine species. In these South African data P. patula has nevertheless lower variability than the Cypress; it is however unlikely that this would be the situation in East Africa. In New Zealand P. patula is also considered to be stronger than the southern pines (Weston, 1973).

Much depends on site, and, in the case of P. taeda in particular, provenance but, given the same site and age, P. patula is slightly less dense and strong than P. radiata though there is little to choose between P. patula, P. elliottii and P. taeda.

6.5 Summary of suggested uses for the timber

The timber is low in density and strength compared with most temperate conifers, but the strong gradient of increasing density and strength from the pith outwards shows that the outer wood is of comparable density and quality to a timber such as Scots pine while the inner wood is normally very weak and soft. If the outer and inner woods are separated during sawing the inner can be used for non-structural applications and the outer for structural purposes, joinery, light furniture and even light duty flooring. The juvenile core can be used for purposes such as light box and crate manufacture, panelling, weather boarding, shingles, and cheap joinery where the strength is adequate for the purpose. Because the timber is easy to treat with preservative it can be made durable and suitable for external use. Mechanical stress grading is suggested, where possible, to sort out structural from non-structural timber and since the timber is so variable grading in this way has particular advantages. In South Africa no differentiation is made between the main exotic pine species in marketing timber. The suitability of a piece of timber for structural uses is largely determined by its density, which has been shown to be closely correlated with strength. P. patula usually falls, with P. radiata, P. elliottii, P. taeda and P. roxburghii, into density group I (minimum density of 400 kg/m^3 at 15 percent moisture content), whereas P. pinaster and P. canariensis usually fall into group II (minimum density 480 kg/m^3). However denser specimens of P. patula etc. can fall into group II and be used for structures taking heavy loads.

7 Tree Breeding

7.1 Introduction

7.11 The genetic base of current breeding programmes

The identification and testing of P. patula provenances has only recently been started (see 2.1). In Africa, where breeding programmes are most advanced, the populations from which selections are being made in the current programmes have originated from seed introductions to South Africa and Rhodesia amounting to less than 15 kg. The sources in Mexico are not known for certain, but Los Reyes, Hidalgo was suggested as the main origin by Olesen (1972).

This might appear to be an unfavourable basis for a tree breeding programme, but substantial gains in stem form and branching habit have already been made in the first stage of the current programmes and big gains in volume have been predicted. Barnes (1973) considered that it was quite possible that, even though the weight of seed introduced to Africa had been small and had not covered the full geographic range, it had accounted for a large proportion of the genetic variation in the species. Further introductions from the indigenous population starting with Loock's collecting expedition in 1949, will ensure that the gene base of the African population will cover the full range found in the natural population. These introductions may produce provenances or strains adapted to a wider range of sites than the present African population, but the indications are that the new introductions will not greatly enhance the gains in morphological traits obtainable from the existing population.

7.12 Traits needing improvement

Stem volume. Fast growing trees provide a quicker return on investment; in large trees the loss on conversion is also reduced. It is desirable to confirm that wood quality does not deteriorate if volume is improved. In particular, in pulpwood breeding, volume increases are often offset by decreased density.

Stem form. Straight trees can be transported more cheaply and with less loss than trees having butt sweep and bends; the incidence of compression wood is also lower in straight trees. The elimination of nodal swelling and forking is an objective in tree breeding in P. patula. In stems which were sinuous when young or which are elliptic in cross section or have eccentric pith it is difficult tc cut so as to exclude the juvenile core.

Branch size and habit. Branches in P. patula are produced in clearly defined whorls. The grouping of large knots at the nodes is a point of weakness in the timber and also causes problems in pulping. Therefore the production of multinodal type trees with short intervals between whorls, which Denison (1973) has shown to be correlated with small branches, is desirable. Paterson (1967) argued in favour of uninodal trees because the total number of branches and knots in a tree is less in that type; but the size and distribution of the knots is more important than the number. The following are all

desirable: small diameter branches resulting in smaller knots, and more particularly small branches in relation to stem volume; shorter branches, leading to more efficient crowns; and an horizontal branching habit. The flat branching habit is associated with smaller knots, greater apical dominance and less persistent branches.

Crown size and shape. Narrow, dense, efficient crowns are preferred to wide spreading crowns. In addition symmetrical crowns are desirable, since it is thought that asymmetrical crowns may be associated with leaning trees and the production of compression wood.

Wood quality. A low density weak juvenile core is a serious defect in P. patula. Sprial grain also occurs and, though it is not serious, there is a need to select against it. Tracheid length appears to be adequate but the production of denser and therefore stronger wood will be an advantage. However production of a tree with a shallow density gradient from pith to bark is of more importance than the development of dense wood at the periphery.

7.13 Variation

A knowledge of the variation that occurs within trees, between trees on one site and between sites is necessary for tree breeding work. Paterson (1967) studied variation in twenty six morphological and anatomical characters in East African P. patula. He came to the conclusion that variation due to age, site and management practice is so great that is is meaningless to compare plus trees selected from different plantations. However the comparison of matched pairs of plus trees and neighbour trees on the same microsite was found to be valid as a check on plus tree selection. His work and that of Scott and Stephens (1947) in South Africa and Plumptre (1972) in Uganda tend to show that for morphological characters within tree variation is relatively small and between site variation is large; but for anatomical characters the reverse is true. Between tree variation is high in both sets of characteristics; although some of this is due to micro-environmental variation, the bulk of it is commonly of genetic origin and therefore available to the tree breeder for selective breeding.

7.131 Variation within the tree

Paterson (1967) examined five morphological characters (table 7.131.1) and except for stem/branch ratio found little variation within the tree. He found a significant decrease in the number of knots per whorl between 0.6 and 0.8 of tree height and also a significant difference between the number in the bole and the number in the crown. Internode length tended to increase up to about a height of 11 m and to decrease again above that; though there was no significant difference between mean values at various heights, internodes on individual trees could vary from less than 0.3 m in length to more than 3.0 m. Stem/branch ratio decreased significantly up the tree (that is stems became smaller in relation

7.131.1 Table. Variation within trees for five morphological characters (Paterson, 1967).

Character		Number of trees observed	Mean Value	Variance	Level of significance of differences
Ellipticity		25 random	1.04		N.S.
Knots/whorl	Bole		4.0	0.32	N.S.
	Crown	16 random	3.5	0.24	0.05
Internode	Bole		0.41		N.S.
	Crown	18 random	0.40		N.S.
Stem/branch ratio		22 plus tree	4.54		0.001
		22 random	4.10		0.001
Branch angle (^{o})		21 plus tree	22.1		0.01
		21 random	21.0		N.S.

to branch size). The branch angle in plus trees increased from 19^{o} to the horizontal at 0.5 height to 30^{o} at 0.8 height.

7.132 Variation between trees

Paterson (1967) found that variation of the morphological characters examined was relatively greater between trees than within trees.

7.132.1 Table. Number of samples needed to differentiate between trees for morphological characters for a given precision (95% probability) (Paterson, 1967).

Character		Number of trees observed	Level of significance of difference	Number of samples needed	for a tolerance of
Knots/whorl	Bole	16	N.S.	15	0.43
	Crown		0.05	12	
	Whole tree		0.05	13	
Internode length	Bole	18	0.001	18	0.13
	Crown		0.001	33	
	Whole tree		0.001	26	
Stem/branch ratio	plus tree	22	(0.05)	13	0.45
	random	22	0.001	19	
Branch angle	plus tree	21	(0.01)	34	5^{o}
	random	21	(0.05)	40	

(Figures in brackets indicate that values almost reached significance)

For a discussion on between tree variation of anatomical characters see 6.213.

7.133 Variation between sites

Of the 26 strength characters that Plumptre (1972) examined only 5 varied significantly (95% probability) between sites. Paterson (1967) found that the number of breast height sectors that needed to be sampled to achieve a stated precision was high for comparisons between sites

7.2 Plus trees

7.21 Criteria for selection

The search for superior phenotypes started in Africa in the late 1950's and is continuing. The criteria used in each country for assessing a candidate tree for plus tree status are broadly similar. Some variation occurs in the weight given to some characteristics; in Rhodesia rather greater stress is given to the form of the tree than in East Africa but there is general agreement on the morphological characteristics of a desirable tree. In East and South Africa care is taken to assess the wood quality (grain angle, tracheid length, density and density gradient of the plus trees); in Rhodesia, however, the policy is to concentrate on improving the morphology of the trees while retaining a full range of variation in wood quality characteristics (Barnes, 1974). This policy has partly been dictated by the expense and difficulty of sampling trees adequately for wood qualities. (Paterson, 1967, estimated that it took 14 man days to analyse one core. In addition wood users have not been able to be as precise as silviculturists in defining the qualities they require.

Some tree breeders have attempted to rank plus trees using indices that incorporate all the traits assessed. Denison (1973) used this technique to rank the progenies which he investigated. There are some attractions in this technique in order to obtain an overall picture of the quality of a plus tree, but until, not only the economic importance of each trait, but also its degree of heritability, is known the weighting given to each character must be arbitrary and subjective; furthermore Paterson (1967) has shown that trees grown on different sites can not be compared. Barnes (1973) has stated that, provided the tree comes up to certain minimum requirements, selection should depend on the experience and eye of the tree breeder. In East Africa an assessment is made of the five neighbouring "free growing" trees to the plus tree to ensure that unacceptably large negative selection is not taking place for any measured character. Paterson (1967) graded the East African plus trees in terms of production potential, that is taking into account not only the stem volume, but also the crown spread and hence the potential volume per unit area. Of the sixty two plus trees then selected he calculated that nine, though superior in individual stem volume, would, because of the size of their crowns, give lower yields

per unit area than the 'normal' crop. Ten trees would give approximately the same yield and forty three trees combining large volumes with narrow crowns would give 30 to over 100 percent higher yields than normal. These calculations assumed that trees would be free growing.

7.22 Selection intensity

Selection intensity is a standardised statistic that varies with the proportion of the population selected; high intensity implies that a comparatively small number of the most superior trees were selected from a given population. Selection differential is a measure of the difference between the mean of the population and that of the selected group. Large differentials are therefore associated with high intensities. Selection intensity and heritability are used in formulae for predicting genetic gain. The selection intensity applied at the beginning of breeding programmes has tended to be relatively low mainly because it has been considered desirable to have a certain minimum number of trees for a breeding population and the total population from which to choose has been small. In 1960 the majority of the P. patula plantations were less than twelve years old (see table 2.501) which is the earliest age at which selection has usually been made hitherto. The increase in selection intensity is illustrated by reference to Rhodesia where up to 1963 it had been about 1 : 17,000, increasing to 1 : 100,000 by 1967 and 1 : 300,000 in 1971 (Barnes, 1974). However Burdon and Shelbourne (1971) had pointed out that genetic gain does not increase in direct proportion to the selection differential; in fact the law of diminishing returns applies. Barnes (1974), after preliminary analysis of progeny trials, has recommended that future Rhodesian policy should be to select at a much lower intensity and consequently in the last two years the intensity has decreased to approximately 1 : 20,000 . However the selection of plus trees at a low intensity on a large scale creates problems in the size of progeny tests required and in some countries such as Kenya it is considered that a satisfactory breeding population can be maintained with a high selection intensity providing a check is kept on in-breeding.

The number of plus trees known to have been selected are listed in table 7.221

7.221 Table. P. patula plus trees

1 Country	2 Number	3 Approx. area over 12 yrs age	4 Date	5 Authority
Kenya	64	7000 ha	1971	Dyson (pers. comm.)
Uganda	5	700 ha	1971	"
Tanzania	2	15000 ha	1971	"
Rhodesia	50	19000 ha	1972	Barnes (1973)
	104	19000 ha	1972-74	Barnes (pers. comm.)

Continued/

Continued:

1	2	3	4	5
Malawi	28	5,000 ha	1971	Nikles (1971)
Madagascar	80	14,000 ha	1973	Devillé pers. comm.
S. Africa Forest Dept.	29	50,000 ha	1974	Poynton (1974)
S. Africa Forest Investments	74	1,330 ha	1973	Denison (pers. comm.)

7.3 Seed orchards

7.31 Propagation

7.311 Clonal seed orchards

Experience in Africa has been that the most satisfactory technique for the vegetative propagation of P. patula has been tip cleft grafting. Propagation using cuttings, needle fascicles and air layering (except in special circumstances as described later) has not proved satisfactory. However, though a good proportion of grafts take, incompatibility between scion and stock has caused problems. The fact that the scion is incompatible with the stock may not become apparent for four or five years, and the incidence of incompatibility varies very much from clone to clone; some clones can be so bad that propagation by grafting is nearly impossible. Barnes (1969a) found that it is possible to induce a scion to produce its own roots by air layering in the nursery at the point of union with the stock; deep planting in the field so as to cover the union can enable the scion to establish its own root system, providing it can survive as a graft for long enough.

In East Africa the use of P. radiata stock has dwarfed P. patula scions (Dyson, 1974). Such heteroplastic grafting is generally unsatisfactory and for many coniferous species the use of stocks related to the scion has reduced the frequency of incompatibility failures.

7.312 Seedling seed orchards

Two seedling seed orchards have been established in South Africa (Denison, 1973). It is claimed that seed production will occur earlier in these orchards than in clonal orchards in South Africa, although this is in contrast to usual experience with pine.

7.32 Management

7.321 Flowering time and pollination

Except at low altitudes the main flush of flowers occurs over a short period and the synchronisation of pollen production and the period of receptivity of the female flower is good (see 1.222). Barnes (1974) as a result of a 6 year study involving 13 clones

considered that there was sufficient variation in the periodicity of flowering to make it possible to select some clones producing early male flowers and others producing late female flowers for testers in trials; but that the variation was not so great as to cause concern that the random effects of pollination in a seed orchard might be affected.

However the success of controlled pollination has been found to be both variable and as yet unpredictable. The success rate of controlled pollination in Rhodesia can vary from 7-50 percent (Barnes, 1974). There appear to be two reasons for this. First in controlled pollination it is usually necessary to use stored pollen and the technique for storing pollen has not yet been perfected. Secondly it is essential to ensure that the female flowers are not overheated in the isolation bags. The use of clear polythene or of dark isolation bags can be lethal. East Africa has found that the use of white non-woven terylene bags with the observation window positioned downwards (away from the sun) to be successful (Dyson. 1974). However, trials in North America suggest that some coniferous pollen can penetrate these bags, thus invalidating tests of control pollinated progeny. Elsewhere casein sausage skin bags have been used successfully.

7.322 Techniques to increase flowering

The application of fertiliser has been tried in South Africa but has been shown to be ineffective and the practice has been discontinued (South African Department of Forestry, 1973; Denison, 1973a. Tying down branches also was believed to increase flowering but has proved impracticable (see 6.323).

The use of dwarfing stock may initially result in a better cone crop, but in the long run the heaviest crops will be borne on the trees with the largest surface area. The cost of collecting from large trees may present some problems however. No records of ring barking or root pruning have been found but it is unlikely that these practices will result in any more than a short term increase in flowering.

7.323 Controlling tree growth

The technique of topping trees and of tying down the leaders has been tried in South Africa. Tying down was considered to be of some benefit when extensive hand pollination was being undertaken. But the wire guys cause considerable inconvenience in the orchard; furthermore hand pollination is not necessary on a large scale in a production orchard and what is needed can be achieved within reach of ground level on wide crowned trees; furthermore tying down reduced flower production by 60 percent (Denison, 1973b).

Rhodesian experience is that there is no advantage in controlling the growth in P. patula seed orchards and that there is little problem in collecting seed from trees twenty metres high standing at one hundred to the hectare.

7.324 Seed production in seed orchards

P. patula seed orchards are not yet producing on a large scale. In South Africa the early orchards were established at too low an altitude though an orchard has recently been established at Hartebeestvlakte at 1800 m (South African Department of Forestry, 1973). In East Africa there have been some incompatibility problems and dwarfing effects as a result of using stocks of other species, but the orchard established at Sao Hill in Tanzania in 1967 has a good crop of cones in 1974.

In Rhodesia it is considered that at thirteen years of age a P. patula seed orchard reduced to 100 stems to the hectare should produce about 23 kg of full seed a hectare. (At eight years 200 trees should produce about 8 kg)(Barnes, 1974). Cone production varies very much from clone to clone and at that age can be as low as 40 conelets a tree to as high as 1400, but with an average of about 320.

In 1972 Rhodesia collected some 80 kg of seed from orchards. The South African Department of Forestry reported the collection of 33.1 kg of P. patula seed from orchards in 1970/71 and 16.7 kg in 1971/72. This compares with 774 kg and 1244 kg of P. elliottii for the two years (South African Department of Forestry, 1973).

There are 12 hectares of seed orchards in Rhodesia, 10 hectares in Kenya, 9 hectares in Tanzania and 4 hectares in Uganda, more than 10 hectares in Malawi and about 10 hectares in Madagascar. Details of the area in South Africa have not been received but must amount to another 15 hectares at least, making a total area of seed orchards in Africa of about 70 hectares. A tree breeding programme is also being undertaken in Angola. New Zealand is not undertaking any breeding work. The position in South America is not known.

7.4 Progeny trials

7.41 Introduction

Progeny trials are being undertaken in all six of the African countries having advanced breeding programmes. In East Africa three progeny trials have been established since 1966. Raunio (1973) has reported that in general the progeny of Tanzania plus trees have proved superior in volume production to progenies from Kenyan and Rhodesian plus trees in trials established in Tanzania. Denison (1973) has reported that in progeny trials at Maggsleigh and Rietfontein in South Africa the best South African families tested proved superior in volume production, but not in branching habit or stem form, to the Rhodesian families tested. In Rhodesia six progeny trials covering 33 ha have been established on four sites from 1300 m to 2150 m altitude.

7.42 Family differences

Denison (1973) found that in progeny measured at forty two months from planting there were significant differences in diameter

at breast height, volume and the number of conelets produced. There were lesser but still significant differences in the number of branches in a whorl, branch diameter and crown width. Differences in branch angle, branch length, and the ratio of branch diameter to stem diameter at breast height were all insignificant. Barnes, (1974) from early informal trials noted that plus trees' families were significantly larger and of better form than a select commercial control which in turn was superior to an unselect control.

7.43 General combining ability (G.C.A.)

Barnes (1974) analysed the measurements of forty two families at eighteen months from planting. He found that for stem form and branch disposition, especially internode length and number of branches in a whorl, the G.C.A. differences were highly significant. Crown size and efficiency appeared to be under less genetic control. Branch efficiency (ratio of branch size to stem volume) differences were highly significant for both material and paternal effects and therefore offer considerable opportunities for quantitative genetic control.

7.44 Specific combining ability (S.C.A.)

Barnes (1974) found that S.C.A. differences were high in young nursery plants, but only up to about five months from sowing when a temporary dormancy occurred. By the age of twelve months from sowing S.C.A. effects were insignificant. He also found that in field trials the S.C.A. differences for branch efficiency were significant.

In general in his analysis of the eighteen month old trial he found that S.C.A. effects were low. However at the age of four or five years in the informal trial mentioned in 7.42 there was evidence that Mendelian assortment was occurring, with one quarter of some two parent crosses being highly depressed. It appeared that in these families the parents were heterozygous for a dominant gene controlling vigour. The effect only appeared at the onset of competition and has not been noted in later trials.

7.45 Correlation of characters

Barnes (1974) found there was a close genetic correlation between good stem form and narrow crowns having wide angled small branches and a lack of correlation between large branches and big stem volume. Denison (1973) found a strong negative phenotypic correlation between tree volume and branch diam : dbh ratio; but, because of the unknown environmental effect, this finding cannot be compared with Barnes' observation above. Denison also found a strong phenotypic correlation between height and diameter at breast height. These correlations are advantageous because breeding for one good trait will result in the improvement of another. However some disadvantageous correlations have also been noted; height with poor stem form and sinuosity and possibly phenotypic excellence with poor flower production (Barnes, 1974); stem volume and crown width (Denison, 1973; Paterson, 1967).

7.471 Table. Heritability estimates on an individual tree basis calculated from 3 trials in Rhodesia (Barnes, 1974)

Character	Age Months	Factorial 1968/69		Reciprocal 1968/69		Polycross 1967/68		Polycross 1968/69	
		1675m	1325m	1675m	1325m	1675m	1325m	1675m	1325m
Height	30	.08	.28	.39	.18	.46	.17	.22	.18
Breast height basal area	30	.12	.28	-	-	-	.17	.25	.08
Height increment for planting	18	.07	.26	.37	.12	.35	.21	.17	0
Basal area at quarter height	18	.13	.10	.25	.23				
Volume from factor	18	.03	.09						
Volume	18	.14	.21	.43	.19				
Straightness	18	.05	.09	.05	.08				
Sinuosity	18	.01	.31	.02	.51				
Branch sectional area in the whorl contributing most	18	.36	.21	.43	.22				
Branch length	18	.37	.32	.40	.29				
Branch angle	18	.04	.16	.06	.04				
Internode length	18	.43	.36	.67	.36				
Branches/whorl	18	.46	.43	.11	.14				
Crown width	18	.04	.07	.06	.14				
Crown height	18	.06	.20	.13	.05				

7.472 Table. Heritability estimates on a family mean basis calculated from 3 trials in Rhodesia (Barnes, 1974)

Character	Age Months	Factorial 1968/69		Reciprocal 1968/69		Polycross 1967/68		Polycross 1968/69	
		1675m	1325m	1675m	1325m	1675m	1325m	1675m	1325m
Height	30	.27*	.76	.62	.35	.86	.71	.70	.54
Breast height basal area	30	.39*	.76	-	-	-	.60	.71	.35
Height increment from planting	18	.29*	.74	.66	.23	.81	.74	.60	0
Basal area at quarter height	18	.58	.54	.50	.37				
Volume form factor	18	.28*	.51	.25	.32				
Volume	18	.54*	.70	.61	.32				
Straightness	18	.33	.23	.20	.14				
Sinuosity	18	.04*	.72	.07	.69				
Branch sectorial area in the whorl contributing most	18	.78	.59	.56	.56				
Branch length	18	.79	.71	.73	.48				
Branch angle	18	.18*	.62	.52	.12				
Internode length	18	.83	.82	.74	.57				
Branches/whorl	18	.85	.87	.30	.43				
Crown width	18	.29	.49	.08	.20				
Crown height	18	.38	.72	.32	.10				
Branch/stem basal area index	18	.74	.62	-	-				
Branch efficiency index	18	.77	.62	-	-				

* Estimates affected by bird damage.

Barnes (1974) noted large differences for height in the nursery at twelve months from sowing. He considered that useful correlations may eventually be shown to exist between height and other characteristics in the nursery with mature characteristics.

Plumptre (1972) found good correlation between wood quality, notably density and specific strength, at the centre of seventeen year old trees with that at the periphery.

7.46 Interaction of genotype with the environment

Barnes (1974) comparing two sites one at 1305 m and the other at 1675 m found that at eighteen months from planting there was little interaction between the performance of families and either climate or soil. What interaction there was could mostly be accounted for by bird damage at one site. Denison (1973) however considered that the interaction between families and environment, when comparing performances at Maggsleigh (1360 m, sandy loam soil) and at Rietfontein (1035 m sandy soil), to be of sufficient size to warrant the selection of families for specific sites. The differences between these two findings may in fact be explained by the fact that the Rhodesian trials were only eighteen months old at which age families had not yet expressed any significant reaction to competition. In addition the parent trees of the Rhodesian families had all been selected from high altitude sites, and the stress in the lower Rhodesian site is likely to have been very much less than at the lower South African site.

7.47 Heritability

Barnes (1974) has given heritability estimates based on forty two families at the age of eighteen months. These estimates are reproduced in tables 7.471 and 7.472. Such estimates can not of course be applied directly as they stand to mature trees nor to other populations or sites but they give some idea of the order of magnitude of heritability for each character listed. With regard to juvenile trees he considered that those characteristics related to branching - branch diameter, length, and branches per whorl, internode length and branch efficiency - showed considerable variation under additive genetic control. Stem characteristics such as height, volume and sinuosity could also be improved considerably, but those characteristics related to crown size, shape and symmetry appeared to be under less genetic control.

7.48 Genetic gain

Paterson (1966 and 1968) using estimates of heritability derived from work on other species in other countries calculated possible genetic gains for P. patula in East Africa (see table 7.481). These heritability estimates must be treated with some caution; Barnes (1974) has pointed out that such estimates are specific both to parents and to sites. However, the estimated genetic gains do indicate the amount of improvement hoped for in East Africa.

7.481 Table. Estimates of genetic gain by comparing 26 plus trees and 130 neighbours in East Africa (Paterson, 1966 and 1968)

Character	Herita-bility	Estimated genetic change %	Advantageous (+) Disadvantageous (-)
Height	.31	+ 2	+
DBH	.29	+ 5	+
Volume OB	.26	+11	+
Crown depth		- negligible	-
Crown width	.30	+ 5	-
Internode length (bole)		+ negligible	-*
Stem sinuosity	.50	- 8	+
bow	.50	- 2	+
sweep	.50	- 5	+
bends	.50	- 9	+
nodal swelling	.50	-12	+
forks	.50	- 5	+
Branch angle	.36	+ 6	-
Grain angle at breast height	.46	- 8	+
Ring width	.50	+14	+
Latewood percent	.50	+ 9	+
Basic density	.50	- 4	-
Fibre length	.50	- 1	-
Cellulose production	.50	+11	+

* considered advantageous by Paterson

Paterson (1968b) calculated that as a result of first generation selection the gain in volumes per unit area might be as high as 60 percent and in value as much as 90 percent at current royalty rates. He considered that if 'super class' plus trees were used and silvicultural regimes were adapted to make the most of their potential, the gain might be as much as 100 percent in volume and 150 percent in value. These calculations need to be tested in progeny trials and with only ten super trees there may be problems over the combining ability of the parents.

7.5 Possibilities of hybridisation

P. patula has been successfully crossed with *P. radiata*, *P. greggii*, *P. oocarpa*, *P. teocote* and *P. lawsonii* with *P. patula* as the female; and with *P. silvestris* using *P. patula* as the male. Unsuccessful attempts have been made with *P. yunnanensis*, *P. brutia*, *P. pinaster*, *P. attenuata* and *P. muricata*. Only one seedling survived of the *P. radiata* cross and the *P. silvestris* cross is somewhat dubious. Critchfield (1967) considered that the chances of crossing *P. patula* with other members of the Latin-American closed cone pine groups - *P. oocarpa* and *P. greggii* - were good. The cross with *P. pringlei* does not appear to have been attempted yet. There is some possibility of achieving a cross with *P. teocote* and *P. lawsonii* but very little with *P. radiata*.

7.6 Mating designs and breeding plans

A comparison of various mating designs for P. patula in Rhodesia was made by Burley, Burrows, Armitage and Barnes (1966). Barnes (1974) discussed the relation of mating designs to breeding plans in detail. He concluded that for the assessment of G.C.A. in juvenile characters factorials were more efficient than polycross trials both in their repeatability and in giving smaller variances, especially when heritability is high. Reciprocal trials in diallels proved that S.C.A. effects were not of great importance for juvenile characters except for the first few months in the nursery. (He also found that lattice designs added very little precision and that five tree line plots in six replications were more efficient than ten tree plots in three replications.)

However in designing progeny trials a tree breeder has two conflicting objectives; to rank plus trees for G.C.A. and to provide unrelated material for second and third generation seed orchards. Neither the polycross nor the factorial mating design is suitable for providing second generation breeding material; the risk of a high incidence of half-sib relationships in the polycross design is too great; the number of crosses between individuals of different families in a factorial design is too limited. The reciprocal design provides every combination between the clones used, but in practice only a few clones can be used.

Barnes proposed that for the second generation seed orchard the G.C.A. of new plus tree selections (from the present Rhodesian population but at a lower selection differential) should be assessed by means of open pollinated trials (i.e. using seed collected direct from the plus trees in the field). This he estimated might save up to six years. Trees of proven G.C.A. together with selections from first generation progeny trials would form the second generation seed orchards. Single pair matings, taking into account the combining abilities of the parents, would then be undertaken for the second generation progeny trials. The third generation seed orchards would be established in the same way after open pollination trials of new selections from provenance trials and would be followed by single pair mating progeny trials. Thus at each stage care would be taken to ensure that the breeding population remained unrelated. At the same time trials would be conducted to assess in-breeding effects.

There are other methods of insuring against in-breeding depression, but this plan has the advantage of obtaining a quick estimate of G.C.A. and of using this to plan the controlled single pair crosses to the best advantage. The plan assumes that the variability of the measured traits which was found to be additive (i.e. due to G.C.A. effects) in juvenile characters would also be additive at maturity, secondly that wind pollination trials are an efficient method of testing for G.C.A. in P. patula and thirdly that juvenile/mature genetic correlations are good. If these assumptions hold true Barnes has estimated that the time from first plus tree selection to the establishment of the third generation seed orchards and progeny trials might be forty to fifty years.

7.7 Conclusions

There is considerable variability within the existing African population of P. patula which can be exploited for tree breeding. The evidence from assessment of juvenile characters in progeny trials is that the genetic variability is largely quantitatively determined. Useful gains both in the size and quality of the trees and also in the uniformity of the population can be anticipated over two or three generations of breeding population during the next thirty or so years. The inclusion of new introductions from Mexico though widening the genetic base of the breeding population will probably not greatly enhance the gains already obtainable from the existing African population.

The existence of genotype/environment interaction and hence the desirability of breeding strains for specific environments, is not clear; but suggestions have been made that a strain of narrow crowned high volume trees could be developed.

Despite some indication that selection for fast growth has resulted in negative selection for anatomical traits particularly wood density, there are reasons to believe that there is sufficient variation in P. patula timber qualities to allow for selection for denser timber.

8 Management

8.1 Introduction

The qualities of P. patula that are of particular significance to its management are:-

1) the fact that its growth is fast and in particular that it has the ability to cover the ground quickly as a young tree,
2) but that it is sensitive to competition for light,
3) the fact that it has a relatively large and weak juvenile core,
4) but that the mature tree can produce timber of adequate, if unexceptional, quality.

The dimension in this chapter is primarily centred round these observations. No attempt has been made to compare costs between countries since not only do climate, topography and vegetation vary widely from region to region, but social conditions, political necessity and financial policy also change from country to country.

8.2 Rotation length

The rotation must depend very much on the end use for which the crop is to be grown.

Pulp. Current pulp rotations are fifteen or sixteen years and both Joubert (1966) and Niekerk (1966) considered that to be the financial rotation in South Africa. Crowe (1972) calculated that maximum return on capital occurred at fourteen years for both newsprint (9.5 percent) and chemical pulp (5.5 percent). These calculations appear to tally with Adlard's (1973) observations that in unthinned stands in Southern Tanzania mean annual increment culminates at about twelve years of age.

However Cawse et al. (1972) considered that the best pulp rotation, taking into account both volume production and return on investment, was twenty-five years with thinnings at eleven and eighteen. They made the point that longer rotations are advantageous because the period during which the land is unoccupied by trees is reduced.

Myburgh and Mackenzie (1966) stated that P. patula in Natal gave inferior pulp up to the age of eighteen, though in Eastern Transvaal pulp from young P. patula tended to be superior to that from P. elliottii and P. taeda. Tops of twenty year old trees were preferable to the butts of seven year old trees but they also made the point that for certain qualities of paper e.g. bleached paper, twelve year old trees having a low latewood content would be satisfactory. However the major proportion of the pulp market is for high strength kraft papers, and for these a high proportion of latewood is required and pulp millers will tend to demand older trees. It was suggested that there was a case for specialised silvicultural regimes to produce pulp material of the required quality.

There is then a wide range of recommendations from which to choose

a pulp schedule. Pulp mills usually buy by weight and this fact should tend to favour longer rotations since the weight increment is greater than the volume increment. It appears that economic analyses do not always take this into account and for this reason tend to favour shorter rotations. In the absence of guaranteed supplies of material of one quality, as judged for instance by the proportion of latewood, mills have obtained the required quality of the product by varuing the processing technique. But for kraft, it is likely that longer rotations to give the mills more mature wood should become more acceptable.

Saw and veneer logs. Rotations can vary from as short as eighteen years as suggested by Crowe (1972) to fifty years (Queensland, 1974), but in Africa rotations are seldom planned to exceed thirty five years and more often are nearer thirty.

The presence of a juvenile core of up to 15 cm in diameter makes the clear felling of trees of less than twenty years of age a doubtful proposition. If pruning is carried up to 11 m or 12 m longer rotations, to allow time for clear timber to be laid on the pruned section, are essential. But there is some doubt whether consumers in South Africa are prepared to pay a sufficient by large premium for clear timber to warrant high pruning. In Kenya, where the producer (the government) insists on a premium for pruned logs, high pruning is more likely to be justified. Marsh (1963) recommended that, in order to maintain a uniform ring width, light early thinning should be followed by late heavy thinning. This implies a relatively long rotation of 35 years but Grut (1967) calculated that Marsh's thinning schedule would add 25 percent to the cost of timber grown on the twenty five year rotation that he advocated. The question again arises; will users be prepared to pay this premium for timber of uniform ring width?

There is a market of P. patula veneer logs in South Africa. Burgers (1972) calculated that a thirty five year veneer rotation would give the same rate of financial return as a thirty year saw log rotation and a rather higher mean annual increment (see table). But, in general, since P. patula does not have any very superior veneering qualities it is unlikely that plantations will be grown specifically for veneer production. However selected butt logs from trees as young as twenty five years can be used for veneering.

Pulp and saw log regimes. Young P. patula thinnings are particularly difficult to convert to sawn boards because not only is the timber weak, but also the necessarily included juvenile core causes cupping and twisting in the boards. The unpopularity of P. patula among East African sawmillers can largely be attributed to the fact that they were initially exposed to large volumes of young thinnings. The development of a market for pulp and reconstituted boards is therefore an important aspect of the economics of P. patula growing. The economic analyses of Grut (1967), Burgers (1972) and Crowe (1972) all assume that early thinning and small size logs would go to pulp. Burgers (1972) calculated that 36 percent of the utilisable yield of his best sawlog regime would go for pulp (23 percent in the pulp class and 13 percent in B1) and that regime would in thirty years yield

8.21 Table. Proportion of log out-turn at each harvest
Marsh (1963)

Age		Pulp	B_1	B_2	C_1	C_2	D_1	D_2	
	Small end diam ub (cm)	13-17.9	18-25.9	18-25.9	26-33.9	26-33.9	34+	34+	
	length (m)	2-3	2-3	3+	2-3	3+	2-3	3+	
11	593 Trees removed	82	18						
		(32)	(11)						(10)
14	247	66	29	5					
		(21)	(14)	(5)					(8)
18	124	36	40	24					
		(10)	(17)	(18)					(7)
21	74	27	35	29	4	5			
		(6)	(13)	(18)	(3)	(1)			(6)
24	50	21	31	32	6	10			
		(4)	(9)	(17)	(5)	(3)			(5)
27	50	16	22	26	10	26			
		(5)	(10)	(20)	(11)	(9)			(7)
34	198	10	7	4	9	30	7	33	
		(22)	(26)	(23)	(81)	(87)	(100)	(100)	(57)
		26	16	9	6	20	4	19	

Figures in brackets refer to the relationship that volume of a class at any one thinning bears to the total production of that log class. Thus at eleven years 82 percent of the thinnings were pulp and that represented 32 percent of the total pulp production.

It is to be noted that the utilisable yields Marsh expected - 207 m^3/ha of thinnings, 279 m^3/ha final crop, 486 m^3/ha in all - were rather larger than those predicted by Burgers (1972) for a thirty year rotation - 264 m^3/ha thinnings, 197 m^3/ha final crop, 461 m^3/ha in all. The thinning schedule is also different therefore the proportion in each class can be expected to be somewhat different.

173 m^3 of pulpwood to the hectare as against 355 m^3 in twenty five years from a pulpwood regime. Marsh (1963) (See table 8.21) calculated that pulpwood constituted about 26 percent and class B1 16 percent, of the yield of his sawlog regime. Burgers (1972) further calculated that the financial return from the thirty year sawlog and pulp regime would at 11.2 percent be nearly one fifth higher than from the twenty five year pulp regime (9.5 percent return). Crowe (1972) also showed that the return from sawlog-cum-pulp regimes, particularly for chemical pulp, were higher than from pulp regimes by themselves.

Bearing in mind Myburgh and Mackenzie's (1966) requirements for mature wood to be included in the pulp mix there would appear to be a case for integrated pulp and sawmills and the offcuts from the older trees being used to enhance the quality of the pulp from the younger thinnings. As can be seen from table 8.21 in the regime proposed by Marsh (1963) some 50 percent of the pulp output would be from trees of under fifteen years of age; the necessity for including more mature wood is evident.

However, despite the evidence that a combined sawlog and pulp-regime is more profitable than a pulp only regime, it is to be noted that to date none of the produce of the Usutu plantations goes for sawlogs. Indeed one of the conditions of setting up the mill was that all the plantation produce should go to pulp. The reason for this may have been the necessity to obtain maximum output from the pulpmill as quickly as possible. Current plans in Swaziland to establish government owned plantations which may supply the Usutu mill may provide the extra material which would justify the establishment of a sawmill to be integrated with the pulp mill.

8.3 Spacing and thinning

Current spacing of P. patula at establishment varies from about 2.4 m (1680 trees/ha) to 2.75 m (1320 trees/ha). The reasons for relatively close spacings, despite the trees' ability to cover the ground quickly, are given in section 3. The decision whether to plant at a wide spacing and to defer the first thinning till about age twelve or to plant at a close spacing and possibly carry out one or even two thinnings to waste are primarily economic. Where a market for small size logs exists, where the ground cover consists of tall grasses or weeds, where establishment is by the shamba system and where labour is cheap, establishment at a close spacing is advisable. Where no market exists for early thinnings, where the ground cover consists of short grasses or where mechanical cultivation is possible, where labour is expensive and plantations are inaccessible a wide spacing may be justified (possibly as wide as 3.5 m - 815 trees/ha). P. patula while capable of shading out grasses quickly, is very sensitive to side and overhead shade; therefore vigorous tall weeds must be eliminated, either by weeding or close stocking, but if the latter course is followed it has to be remembered that the young wood is weak and has a very restricted market. Should the tree breeding result, as it ought to, in more uniform, less defective crops it may be possible to increase spacing

even in the less favourable circumstances.

Some P. patula plantation schemes have been initiated without any clear idea of the end use to which the trees are to be put. The intention has been, as on the Viphya in Malawi, to keep open the options for as long as possible in case a pulp project may prove to be feasible. The tendency has been naturally to delay thinning for as long as possible; this accords well with the theory that the basal area should be encouraged to build up as soon as possible. But there are considerable risks of wind blow in the late thinning of overstocked plantations.

The returns from early thinning are low since the unit value is low and the volume obtainable from a given area is relatively small. Therefore the profitability of the operation must depend very much on the efficiency of the harvesting operation. It is likely that line thinning, (i.e. the removal of complete rows of trees) will be much easier and cheaper to undertake than silvicultural thinning in dense crops. However the efficiency of line thinning is dependent on accurate espacement. There are no reports on the effects of line thinning on tree growth, or crop stability, or on the economics of the operation. But if the first thinnings are no delayed too long and if a rectangular spacing can be maintained (by removing diagonal rows), there should be little risk from windblow. Furthermore the reduction of variation within crops as a result of tree breeding will make line thinning a more attractive proposition.

8.4 Prospects for P. patula

The areas under P. patula are listed in table 2.501. This table shows that there has been a tendency in Africa for the proportion of P. patula in relation to other softwoods to fall while the total area planted to the species has continued to rise. This reflects on the one hand a general increase in the area being afforested to exotic softwoods and on the other an awareness of the unsuitability for the species of some sites currently under P. patula. There are indications that these trends will continue.

8.41 South Africa and Swaziland

Kraamwinkel (1973) has calculated that the softwood demand in South Africa and Swaziland will increase from 6,600 million cubic metres in 1973 to 22,500 million in 1998 representing an annual growth rate of 4½ percent. The major increase will be in the demand for pulp (up 600 percent), while that for sawlogs will rise 150 percent. To achieve this increase will entail enlarging the area under softwood from 565 thousand hectares in 1970 to 1800 thousand by the year 2000. If such an increase in the softwood area is undertaken it must involve the afforestation of sites that are unsuitable for P. patula. Nevertheless it is certain that P. patula will still remain one of the most important afforestation species, especially as so much of the demand will be for pulp for which P. patula is a most suitable raw material.

8.42 Kenya

It has been estimated that, with a planting programme of about 6000 hectares a year to achieve a total area of 142000 hectares under softwoods by 1980, there will be a surplus of both pulpwood and sawlogs in 1985 but by the year 2000 demand for pulp will be more than double the supply (Fraser, 1973). The softwood species currently being planted are P. patula and C. lusitanica. The major demand will be for pulp material (1.7 million m^3 as against 1.07 million m^3 for sawlogs and wood based panels in the year 2000). P. patula has been shown to be unsuitable on many sites of the area set aside for the pulp scheme, and will have to be replaced by other species (see 2.513). But it is nevertheless likely to be the species that will form the major constituent of the softwood planting in existing forest reserves outside the pulp scheme. In Kenya, as with many developing countries, social and therefore political pressures will largely determine the sites that will be made available for afforestation. The choice of species must depend on the sites available, but as long as reasonable proportions of the existing forest reserves in the highland areas are retained, P. patula is likely to remain one of the major softwood species to be planted.

8.43 Other African countries

Tanzania and Malawi

In these countries it is understood that plans are being laid for the establishment of pulp mills based on plantations which are predominantly P. patula. In Tanzania these plantations are in the Southern Highlands and the construction of the Tanzania-Zambia-railway must have made a dramatic impact on the profitability of pulp production. In Malawi the transport of both the raw material and the pulp will pose problems. In both countries it is to be assumed that since mills of an economic size will grossly over supply the local market, the pulp production will primarily be for export. The Kenya pulp scheme has been established to satisfy local, East African, demand; in South Africa it was considered by the Association of Pulp, Paper and Board Manufacturers in 1972 that the very large capital outlay in modern pulp and paper manufacturing plant is best employed in specialised production for substantial domestic markets. On the other hand Usutu pulpmill in Swaziland exports all its production, chiefly to the Far East; however for many years it failed to show a profit. The success of any pulp scheme in Tanzania or Malawi will depend very much on a world demand and a high price for long fibre pulp. Any expansion of the Tanzanian planting scheme is likely to involve the establishment of more P. patula plantations. In Malawi the extension of the P. patula plantations on the Viphya plateau is already in progress, but there is a shortage of land suitable for P. patula on that plateau. The only other large area suitable for P. patula in Malawi is on the Nyika plateau which is likely to become a National Park. Therefore it can be expected that despite an increase in P. patula planting in Malawi, the proportion of the species relative to other exotic softwoods will fall.

Rhodesia has a small newsprint mill at Umtali; it is unlikely that local demand would justify the establishment of a large pulp mill. Any expansion of the P. patula planting programme would appear to be dependent on assured export markets for saw timber or pulp. But logistics of the export market are even more difficult than for other landlocked African countries. However considerable volumes of plantation timber, which is mostly P. patula, are thinned to waste and a pulp project would enhance the profitability of the plantations of the Eastern Highlands.

Angola

A big expansion of P. patula planting is envisaged in Angola and it is to be assumed that much of this will be for producing pulp for export. Eucalyptus pulp is already exported profitably and with a ready access to ports it is quite possible that P. patula pulp schemes will be equally successful.

8.44 Countries outside Africa

South America

It is not easy to obtain information on this region. The most likely areas for the development of P. patula plantations are in the Andes from Ecuador northwards and possibly on the eastern side of the southern Andes in Argentina. In these two areas can be found sites combining altitudes of 1000 to 3000 m with a summer rainfall. No information has been obtained on the markets but by analogy with the successful Chilean industry based on P. radiata it is likely that P. patula in the northern Andes could also form the basis for a timber or pulp industry, though for export markets P. radiata timber would be more competitive. It is likely that any P. patula scheme in north-west Argentina would be established to supply local demand rather than for export.

India

The potential for P. patula would appear to be limited to relatively small areas.

Australasia

P. patula has been given no part to play in competition with P. radiata in New Zealand. It is not now being planted there. In Queensland the current planting programme of P. patula is forty hectares a year which is small in comparison to Araucaria cunninhamii and P. elliottii.

8.5 Conclusion

Because young P. patula produces poor quality timber, the most profitable plantation schemes using this species will be those in which sawmilling and pulping can be integrated, so that advantage can be taken of the greater value of saw logs without lowering the quality of the pulp to an unacceptable degree. There are many sites

where, because of its rapid early growth, P. patula can be established relatively cheaply. These plantations can produce pulp, either for export or for the local market or the older trees can be sawn for structural timber or the lower qualities of timber. As a timber P. patula does not compete well with many indigenous timbers (e.g. Juniperus procera, Podocarpus spp., Widdringtoria spp. in Africa, Araucaria cunninghamii in Queensland, A. angustifolia in Brazil and Argentina) or with some exotic softwoods (e.g. P. radiata, P. elliottii, P. taeda). But as demand increases and indigenous supplies are still further reduced, P. patula timber will be valued more highly, particularly if the wood qualities can be made more uniform through tree breeding. It is however unlikely that it will command a premium on the export market. As pulpwood it has a good potential, particularly for schemes with good access to a port.

9 Conclusions

9.1 Seed availability

Though seed is not readily available from Mexico, it is available in large quantities from plantations in Africa. Some countries, such as Kenya, will supply seed from managed seed stands. Within the next five years there should be a good supply of improved seed from seed orchards.

The seed stores well and can be expected to give 70-80 percent germination. Because the seed is small, about 120 thousand to the kilogram, and because it is not too difficult to collect, it is relatively cheap.

9.2 Nursery

P. patula is not difficult to raise in the nursery but care must be taken to prevent damping-off (though no more so than for other pines) and root-pruning schedules must be maintained. Growth in the nursery is rather slower than for some other species (e.g. P. radiata and C. lusitanica) but trees can be raised to establishment size in less than twelve months in nurseries at lower warmer altitudes.

9.3 Establishment

Again as long as reasonable precautions are taken there should be no difficulty in establishing P. patula. The key to successful establishment is to raise vigorous nursery stock with a healthy root system and to plant early in the rains and to take care not to expose the roots.

Ploughing and weed control on grassland sites promotes tree growth but is not essential. Weed control on more fertile sites is essential. The practice of burning before establishing second rotation crops is risky because of the dangers of Rhizina infection and should not be undertaken unless at least six months can be allowed between burning and planting. The tree occupies a site very quickly.

The species does well on acid soils as long as severe or prolonged moisture stress does not occur. Dry periods of upto four months in the cool season can be tolerated, but unless there is good rooting depth the length of dry season quickly becomes critical. Given reasonable rooting conditions the tree can be grown in annual rainfalls above about 750 mm; growth is correlated with moisture availability. There appears to be a critical temperature, possibly the maximum temperature of the hottest month of about 29°C, above which height growth culminates early; within the range of temperatures normally found in highland (above 1000-1200 m) tropical and subtropical sites growth appears to improve with increasing mean annual temperatures.

9.4 Protection

P. patula has remained remarkably disease free in Africa. The two most serious diseases are Rhizina undulata and Diplodia pinea. The latter is only of importance in areas liable to hail storms; in these zones it is not advisable to plant a monoculture of P. patula. Insect pests have caused damage locally and, even though outbreaks have not reached epidemic proportions, it would be unwise to be complacent.

Windsnap can be caused by high winds particularly in mountainous country where winds can locally reach high speeds. In such terrain the thinning of crops of fifteen years or older must be carried out with care.

9.5 Yield

Mean annual increment can vary from about 15 m^3 per hectare to as high as 30 m^3 per hectare, depending largely on soil moisture availability. Low yields can often be traced to shallow soils and a severe dry season, or else to suppression by weeds at establishment. In the first instance consideration should be given to growing other species; in the second, site preparation and maintenance schedules need to be improved.

On comparable sites P. patula gives yields as great as C. lusitanica in East Africa and for the first twenty years probably does better than P. elliottii or P. taeda in southern Africa. By the age of thirty P. taeda on the best sites may outyield it. In East Africa and New Zealand P. radiata has much higher yields, but only when dothistroma needle blight is controlled. Though it has a tendency towards butt sweep, nodal swelling and heavily whorled branches, the form in general compares favourably with other species that might be grown on sites favoured by P. patula; in particular its form is very much better than East African grown P. radiata.

9.6 Wood properties

The timber tends to be light, but the specific strength is good and it can be used for structural work not requiring great strength. The low density relatively weak juvenile core is only a serious problem in the conversion of small diameter logs.

Good quality kraft pulp can be produced from P. patula wood.

9.7 Tree breeding

Sufficient variation has been found it exotic populations in Africa to indicate that there is good opportunity for improvement, not only in volume and stem form, but also in branch characters. Problems have been experienced in some countries in establishing production seed orchards, but providing the orchards are established at high enough altitudes there appears to be no reason why more than adequate quantities of improved seed should not be produced.

9.8 General

There is every prospect that the planting of P. patula will continue to increase in the summer rainfall or monsoonal zones of the tropics and subtropics where maximum temperatures are not too high.

REFERENCES

Ackhurst, R.W. and Micski, J. (1971a) Tanzania standard volume tables for P. patula. Tanzania Ministry of Natural Resouces and Tourism, Forest Division. 58p.

_____ and _____ (1971b) Tanzania standard volume table for P. caribaea. Tanzania Forest Division. 29p.

Adams, T.W. (1915) The species of the genus Pinus now growing in New Zealand, with some notes on their introduction and growth. Trans. R. Soc. N.Z. 48, 216-23.

Adlard, P.G. (1964) Pruning trial Dedza Mountain Forest, Malawi. Commonw. For. Rev. 43(3), 238-43.

_____ (1969) Quantitative effects of pruning P. patula in Malawi. Commonw. For. Rev. 48(4), 339-49.

_____ (1973) Pers. comm.

_____, Wright, H.L. and Kimariyo, P.E. (1974) Stand and tree growth response to the low-thinning of even-aged P. patula stands in Tanzania 1: Kiwira expt. No. 408. Paper 10th Br. Commonw. For. Conf., Oxford.

Anon. (1957) Queensland, Rep. Dir. For. 1956/57.

_____ (1960) Nyasaland, Rep. Dep. For.

_____ (1965) The forest insect situation in New South Wales. FAO/IUFRO Symposium, Oxford II/III.

_____ (1967) Rhodesia, Rep. Soc. Agric. 1965-30, 1966.

_____ (1970) Check list of insects on forest trees and shrubs in South Africa. Plant Protection Res. Inst., Pretoria.

Argyle, M.C. (1971) Treatment of P. patula plantations. Kenya For. Dept. Tech. Ord. 34.

Austara, O. (1971) Gonometa podocarpi Aur. (Lep., Lasiocampidae) a defoliator of exotic softwoods in East Africa. E. Afr. Agric. For. J. 36(3), 275-89.

_____ and Jones, T. (1971) Host list and distributions of lepidopterous defoliators of exotic softwoods in East Africa. East Afr. Agric. For. J. 36(4), 401-13.

_____ and Migunda, J. (1971) Orgyia mixta Snell. (Lep. lymantriidae) a defoliator of exotic softwoods in Kenya. E. Afr. Agric. For. J. 36(3), 298-307.

Bakshi, B.K. and Dobriyal, N.D. (1970) Effects of fungicides to control damping-off in development of mycorrhiza. Indian For. 96, 701-3.

_____, Ram Reddy, N.A., Puri, Y.N. and Sujan Singh. (1972) Forest disease survey (Final technical report, 1967-1972). Forest Research Institute and Colleges, Dehra Dun, India.

Ball, J.B. (1971) Herbicides in Uganda forestry. Uganda For. Dept. Tech. Note 173/71. 6p.

_____ (1974) Weed control on the Turbo afforestation scheme, Kenya. Paper 5th E. Afr. Weed Control Conf.

Ball, J.B. (1973) Personal communication.

Banks, C.H. (1956) Effect of nodal swellings on strength properties of Pinus patula. J. S. Afr. For. Ass., 28, 27-34.

Banks, P.F. (1962) A note on the silvicultural regimes adopted in Southern Rhodesia for fast growing state coniferous plantations. Paper, 8th Br. Commonw. For. Conf., Nairobi.

Barnes, R.D. (1969) The use of methyl bromide soil sterilisation and a course sand mulch in raising pines and eucalypts in the nursery. Rhodesia Science News, Salisbury. 3(4), 99-101.

_____ (1969a) A method of air-layering for overcoming graft incompatibility in pine breeding programmes. Rhodesia Science News, Salisbury. 3(4), 102-7.

_____ (1970) The prospects for re-establishing Pinus radiata as a commercially important species in Rhodesia. S. Afr. For. J. 72, 17-9.

_____ (1974) Personal communication.

_____ and Mullin, L.J. (1974) Flowering, productivity and phenology in clonal seed orchards of P. patula, P. elliottii, P. taeda and P. kesiya in Rhodesia. (In press).

Barrett, R.L. (1973) Forest nursery practice in Rhodesia. Rhod. Bull. For. Res. No. 4.

_____ and Mullin, L.J. (1966) A review of introduction of forest trees in Rhodesia. Rhod. Bull. For. Res. No. 1.

Barrett, W.H.G. (1971) Response of pine species to varied site conditions in northeastern Argentina and in other subtropical regions. Diss. Abstr. Int. B31, 3786-7.

_____ (1972) /Variation of morphological characters in natural populations of Pinus patula in Mexico/. Idia Supl. For. 7, 9-35.

_____ (1974) Personal communication.

Bassett, C. and Zondag, R. (1968) Protection aginst fungal and insect attack in New Zealand Forests. Paper 9th Brit. Commonw. For. Conf., New Delhi.

Brazier, J.D. (1954) Unpublished record of research on the effect of angle of grain on modulus of rupture in Sitka spruce.

Brimblecombe, A.R. (1945) The biology, economic importance and control of the pine bark weevil, Aesiotes notabilis Pasc. Queensland J. Agr. Sci., 2, 1-88.

Brister, G.H. (1960) A study of variations in tracheid length in Pinus radiata and Pinus patula grown in Kenya. Univ. of Oxford. Imp. For. Inst. (Spec. Subj.)

Brookhouser, L.W. and Peterson, G.W. (1971) Infection of Austrian, Scots and ponderosa pines by Diplodia pinea. Phytopathology 61, 409-14.

Brown, G.S. (1962) The importance of stand density in pruning prescriptions. Commonw. For. Rev. 41(3), 246-57.

_____ (1965) The yield of clearwood from pruning: some results with radiata pine. Commonw. For. Rev. 44(3), 197-221.

Brown, K.W. (1967) Forest Insects in Uganda. Uganda, Govt. Printer. 98p.

_____ (1969) The pine wooly aphid, Pineus sp. in East Africa. Commonw. For. Rev., 48(3), 194-5.

Browne, F.G. (1968) Pests and diseases of forest plantation trees. Oxford Clarendon Press. 1330p.

Brunck, F. (1962) Aperçu sur les principales attaques parasitaires observés dans les plantations forestières d'Afrique Tropicale. Centre Technique Forestier Tropical Note Tech. No. 5.

_____ (1964) Compte rendue d'un deplacement effectue a Madagascar du 3 Febrier au 18 Mars 1964. C.T.F.T. Division d'Entomologie et Pathologie Forestiere. (Cyclostyled report).

_____ (1965a) Parasites des plantations forestieres d'Afrique tropical et de Madagascar et mesures de protection. Congres de la protection de Cultures Tropicales, Marseilles, 105-10.

_____ (1965b) Aperçu general des infections parasitaires d'origine animale dans les pays d'Afrique d'Expression Française et à Madagascar. FAO/UNDP Symposium, Oxford, II/III, 1-10.

Bryce, J.M. (1959) Utilisation properties of locally grown Pinus patula and Pinus radiata. Tanganyika For. Dept. Tech. Note 22.

_____ (1967) The commercial timbers of Tanzania. For. Division, Ministry of Agriculture and Co-ops Tanzania. 139p.

Burdon, R.D. and Shelbourne, C.J.A. (1971) Breeding populations for recurrent selection: conflicts and possible solutions. N.Z. J. For. Sci. 1(2), 1974-93.

Burgers, T.F. (1971) The correlated curve trend (CCT) method used in thinned stands of P. patula. Bosbou in Suid Afrika 12, 11-7.

_____ (1972) Growth prediction for sawlog, pulpwood and veneerlog regimes for Pinus patula. Bosbou in Suid Afrika 13, 31-44.

Burgess, I.P. (1972) Trials of exotic conifers on the north coast of New South Wales, Australia. In: "Selection and breeding to improve some tropical conifers", ed. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland Dept. For. Vol. 1, 1373-84.

Burley, J., Burrows, P.M., Armitage, F.B. and Barnes, R.D. (1966) Progeny test designs for P. patula in Rhodesia. Silvae Genet. 15, 166-73.

Bustillo, A. and Lara, L. (1971) Plagas forestales. Boletin de divilgación No. 33. Instituto Colombiano Agropecuario.

Campbell, P.A. (1971) Test on pine and saligna poles. Occasional Paper, Dept. Civil Engineering, Univ. Nairobi, No. 5. 6p.

Carvalho, J.P. de (1971) Introduacao a entomologia forestal de Angola Universidade de Luanda. 314p.

Castanos, M.L.J. (1962) /Assessment of site quality for P. patula in north Oaxaca/. Instituto Nacional de Investigaciones Forestales, Mexico, Bol. Tec. No. 2. 32p.

Cawse, J. et al. (1972) Optimum pulpwood regimes for plantations of P. patula, P. taeda and P. elliottii. Paper, 7th World For. Congr. Buenos Aires.

Choate, T.A.R. (1969) Age and area distribution of plantations in main management units. Kenya For. Dept. Tech. Note 113.

Clark, K. (1965) Game moats. Kenya For. Dept. Tech. Note 99.

Cocheme, J. and Zazzara, G. (1969) A contribution to the forecasting of the early rains at Nairobi. E. Afr. Agric. For. J. 34(3), 312-4.

Craib, I.J. (1939) Thinning, pruning and management studies on the main exotic conifers grown in South Africa. Dept. of Agric. and For. Sci. Bull. 196.

Critchfield, W.B. (1967) Crossability and the relationships of the close-cone pines. Silvae Genet. 16(3), 89-97.

_____ and Little, E.L., Jr. (1966) Geographic distribution of the pines of the world. Misc. Publs. U.S. Dept. Agric. 991. 97p.

Crosskey, R.W. (1973) A new species of Metacemyia (Dipt., Tachinidae) parasitic on Manowia (Orth., Eumastacidae) in Malawi. Bull. Ent. Res., 62, 375-82.

Crowe, N.D. (1967) Growth, yield and economics of P. patula in the Natal midlands. Annele Univ. van Stellenbosch 42(A) 2, 7-1152.

_____ (1972) Pine volumes and economics. Cyclostyled report.

Curry, S.J. (1965) Forest entomology in East Africa. FAO/UNDP Symposium, Oxford II/III ii, 1-4.

Denison, N.P. (1968) Breeding of practices in South Africa for improving pine timber. S. Afr. For. J. 64, 24-31.

_____ (1973) Variation in families of patula pine grown at two locations in the Republic of South Africa. The State University of North Carolina. Thesis submitted for MS degree.

_____ (1973a) The development and a review of tree breeding in the Republic of South Africa. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland Dept. For. Vol. 2, 277-84.

_____ (1973b) Personal communication.

Devillé, F. (1973) Personal communication.

Dick, J.H. (1969a) The effect of planting depth and seedling size on the first year survival and growth of P. patula and P. radiata. Tanzania For. Dept. Silvic. Res. Note 10. 4p.

_____ (1969b) The application of fertiliser at time of planting: a resumé of research in Tanzania 1960-66. Tanzania For. Dept. Silvic. Res. Note 11.

Dingley, J.M. and Gilmour, J.W. (1972) Colletotrichum acutatum Simmonds f.sp. pinea associated with 'Terminal crook' of Pinus spp. N.Z. J. For. Sci. 2, 192-201.

Donald, D.G.M. (1968) Fundamental studies to improve nursery production of P. radiata and other pines. Annale Univ. van Stellenbosch 43(A) 1. 180p.

_____ (1969) Direct sowing as an establishment technique for P. radiata. S. Afr. For. J. 69, 1-10.

_____ (1971) Water requirements in South African nurseries. Bosbou in Suid Afrika 12, 253-33.

_____ (1971a) Cleaning operations in South African Forestry. Bosbou in Suid Afrika 12, 55-65.

_____ (1972) The use of inorganic fertilisers for the production of pines in the forest nursery. S. Afr. For. J. 81, 2-6.

Drew, A.P. (1969) A phenology study of P. patula on the Vipya plateau. Malawi For. Res. Inst. Dedza, Silvic. Res. Rec. No. 30.

Durham, P. (1965) Nursery practice. Tanzania For. Dept. Tech. Note (Silvic.) 80.

Dyk, L.P. van (1969) The biology and control of the wattle lappet moth, Pachypasa capensis L. Bosbou in Suid Afrika, 10, 21-25.

Dyson, W.G. (1961a) Registered Experiment 79: an experiment on initial espacement and early treatment of softwood plantations. Kenya For. Dept. Tech. Note 80.

_____ (1961b) Deaths due to drought in plantations. Kenya For. Dept. Tech. Note 83.

_____ (1962a) P. radiata - interim report and instructions. Kenya For. Dept. Tech. Note 86.

_____ (1962b) Notes on the silviculture of Cypress grown for timber in Kenya. Kenya For. Dept. Tech. Note 84. 6p.

_____ (1974) Personal communication.

_____ and Paterson, D.N. (1966) Seeding and flowering studies. Rec. of Res. Ann. Rep. 1965, 107.

Edwards, J.K. (1956) Forestry in South Africa. Emp. For. Rev. 35(3), 292-301.

Etheridge, D.S. (1970) Personal communication.

Evans, J. (1971) Interim report on the results of comparison of growth between two rotations of P. patula in the Usutu Forest, Swaziland. (Unpublished - restricted).

_____ (1973) A report on a second visit to the Usutu plantations. (unpublished - restricted).

_____ (1974) Some aspects of the growth of P. patula in Swaziland. Commonw. For. Rev. 53(1), 57-62.

FAO. (1973) An annotated bibliography of Pinus patula. FAO, Rome. 88p.

Firman, I.D. (1972) A list of fungi and plant parasitic bacteria, viruses and nematodes in Fiji. CMI Phytopath. Papers No. 15.

Foot, D.L. (1967) Notes on the planted conifers of Malawi. Malawi Silv. Res. Rec. Silv. Res. Sta., Dedza, 9. 53p.

Fraser, A.I. (1973) F.A.O. Manual of management. (Unpublished).

Fry, G. (1964) Personal communication.

Fry, G. and Chalk, L. (1957) Variation of density in the wood of Pinus patula grown in Kenya. Forestry 30(1), 29-45.

Fuller, B.R. (1961) Report on the FAO pine study tour of Mexico and British Honduras. Nyasaland Dept. For.

_____ (1962) The use of polythene tubed nursery stock for afforestation in Nyasaland. Paper, 8th Br. Commonw. For. Conf., Nairobi.

Garces, C. (1964) Las enfermedades do los arboles forestales en la America Latina y su impacto en la produccion forestale. FAO/IUFRO Symposium on Internationally Dangerous Forest Diseases and Insects, Oxford.

Gardner, J.C.M. (1957) An annotated list of East African forest insects. E.A.A.F.R.O. Tech. Note No. 7. 48p.

Geary, T.F. and Pattinson, J.V. (1969) Seed production potential of the cones of P. kesiya and P. patula in central Africa. Rhod. J. Agric. Res. 7.

Gerischer, G.F.R. and de Villiers, A.M. (1963) The effect of heavy pruning on timber properties. Bosb. Suid-Afr. No. 3, 1963.

Germishuisen, P. (1974) Personal communication.

Gibson, I.A.S. (1955) Trials of fungicides for the control of damping-off in pine seedlings. E. Afr. Agric. J. 21, 96-102.

_____ (1956) Sowing density and damping-off in pine seedlings. E. Afr. Agric. J. 21, 183-8.

_____ (1957) Saprophytic fungi as destroyers of germinating pine seed. E. Afr. Agric. J. 221, 203-6.

_____ (1958) Dead top in Kenya pine plantations. E. Afr. Agric. J. 24, 47-52.

_____ (1966) Cercospora blight of pines. E.A.A.F.R.O. Mycological Note No. 30. (Cyclostyled report).

_____ (1969) Seed pelleting of P. patula with Rhizocotol-Combi for the control of damping-off. E.A.A.F.R.O. Tech. Note (Pathology) 23.

_____ and Hudson, J.C. (1969) Pelleting of pine seed with Rhizocotol and other fungicides for control of damping-off in Kenya highland nurseries. E. Afr. Agric. For. J. 35, 99-103.

_____ and Munga, F.M. (1969) A note on terminal crook disease of pines in Kenya. E. Afr. Agric. For. J. 35, 135-40.

Gill, L.S. (1963) Forest Diseases. Report to the Govt. of Tanganyika. FAO. 1697.

Gilmour, J.W. (1965) Personal communication to I.A.S. Gibson.

_____ (1966) The pathology of forest trees in New Zealand. The fungal, bacterial and algal pathogens. N.Z. For. Res. Inst. Tech. Pap. No. 48.

Gilmour, J.W. (1967) Host list for Dothistroma pini in New Zealand. N.Z. For. Res. Notes No. 16.

Golfari, L. (1970) Conifers suitable for reforestation in the states of Parana, Sante Catarina and Rio Grande do Sul. UNDP/FAO Report to the govt. of Brazil TA2858. Rome.

_____ (1972) Responses of some tropical and subtropical conifers to various site conditions in Brazil. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland Dept. For. Vol. 1, 264-73.

Golfari, L. (1973) Personal communication.

Gonzalez, M.L.E. (1964) Biologia de Eutachyptera psidii (Sallé) en las regiones de Necaxa, Puebla y Zacualtipan, Hidalgo. Instituto Nacional de Investigaciones Forestales, Mexico, Bol. Tec. No. 12. 16p.

Gordon, A.G. and Tee, L.A. (1973) Seed and seedling losses in nursery beds. Quart. J. For. 67(2), 150-2.

Gourlay, E.S. (1946) Erechthias fulguritella Walk. (lep., Lyonetiidae) inhabiting pine cones. N.Z. J. Sci. Technol. B27, 243-50.

Gray, K.M. (1972) Potential of P. caribaea var. hondurensis Barr. and Golf. in Jamaica. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept. Vol 1, 235-50.

Griffin, H.D. (1969) Studies on Stereum sanguinolentum in Kenya pine plantations. Cand. J. Bot. 47, 761-71.

Griffith, A.L. (1957) The effects of depth of planting of exotic pines at Muguga (Kenya). E. Afr. Agric. J. 22(4), 175-6.

_____ and Howland, P. (1958) Effect of shamba crops and cultivation. E.A.A.F.R.O. Ann. Rep. 1957, 91.

Grobler, J.H. (1957) Some aspects of the biology, ecology and control of the Pine Brown-tail Moth, Euproctis terminalis Walk. Dept. Agric. For., Union S. Africa, Pretoria. 186p.

Grut, M. (1967) Most profitable silvicultural programme for P. patula and the cost of improving timber by adopting other programmes. Bosbou in Suid Afrika 8, 95-115.

Gueneau, P. (1970) /The characteristics and uses of pines in Madagascar (P. patula and P. khasiya)/ - Bois. For. Trop. 113, 39-51.

Guhathakurta, P. (1972) Introduction trials of pines in North Bengal. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept. Vol. 1, 318-26.

Hadlington, P.W. (1966) Common insect pests of trees. N.S.W. Forest Commission. 37p.

Harrison, S.G. (1966) A handbook of Coniferae and Ginkgoaceae (Revision of the work of Dallimore, W. and Jackson, A.B.) 4th ed. London. Edward Arnold. 729p.

Hepburn, G.A. (1965) The status of forest insects in the Republic of South Africa. FAO/UNDP Symposium, Oxford. II/III, 1-4.

_____ and Loedolff, J. (1964) A new forest pest in South Africa, Neocleora herbuloti Fletch. (Geometridae) Bosbou in Suid Afrika, 4, 1-18.

Hocking, D. and Johanns, J.C. (1967) Damping-off in pine nurseries; combined soil and seed treatments. T.P.R.I. Misc. Rep. No. 604. (Cyclostyled).

_____, Setliff, E.C. and Jaffer, A.A. (1968) Potential pathogenicities of fungi associated with damped-off pine seedlings in East African nurseries. Trans. Brit. Mycol. Soc. 51, 227-32.

Hodgson, L.M. (1963) Initiating a breeding programme with P. patula in southern Rhodesia. Paper FAO World Consul. For Genet., Stockholm. FAO/FORGEN 63-4/3. 7p.

Holloway, C.W. (1965) Big game in the Kenya forests. Commonw. For. Rev. 44(2), 125-39.

Hosking, G.P. (1970) Arhopalus ferus, an introduced cerambycid. N.Z. For. Res. Inst. Bull. No. 29. 4p.

Howard, J.A.C. (1966) Preliminary nursery investigations Nyika plateau (Nyasaland). Emp. For. Rev. 35(3), 302-12.

Howland, A.K. and Gibson, I.A.S. (1969) A note on Diplodia spp. one pines in East Africa. E. Afr. Agric. For. J. 35, 45-8.

Howland, P. and Griffith, A.L. (1961) The root development of transplants after planting in the field. Emp. For. Rev. 40(1), 67-72.

_____ and Hosegood, P.H. (1965) Observations on new techniques for the direct sowing of exotic softwoods in East Africa. Commonw. For. Rev. 44(3), 222-31.

I.I.A.A. (1973) Personal communication from Instituto de Investigaçae Agronomica de Angola.

Ito, K. (1972) Cercospora needle blight of pines. Bull. Gov. For. Exp. Sta. Meguro, No. 246.

Ivory, M.H. (1967) A new variety of Dothistroma pini in Kenya. Trans. Brit. Mycol. Soc. 50, 45-8.

Ivory, M.H. (1967a) Fusicoccum tingens Goid. : a wound pathogen of pines in East Africa. E. Afr. Agric. For. J. 32, 341-3.

_____ (1968) Reaction of pines in Kenya to attack by Dothistroma pini v. keniensis. E. Afr. Agric. For. J. 33, 236-44.

Jayasinghe, L.H., Tambiah, M.S. and Tisseverasinghe, A.E.K. (1969) Observations on the mycorrhizae of Pinus patula and an attempt to culture and identify the fungus. Ceylon For. 9, 15-25.

Jones, T. (1966) Report on a tour of forests and plantations in Malawi, Rhodesia and Swaziland. E.A.A.F.R.O. (Cyclostyled).

Joshi, H.B. and Pande, D.C. (1972) Preliminary trials with tropical conifers in Uttar Pradesh. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland Dept. For. Vol 1, 285-301.

Joubert, A.F. (1966) Some economical aspects of growing pulpwood. S. Afr. For. J. 58, 3-14.

_____ (1966a) Percentage log class utilisation graphs for stands of Pinus patula. Bosbou in Suid Afrika 7, 51-70.

Karani, P.K. (1973) Personal communication.

Keet, J.D.M. (1967) A thinning formula for P. patula. S. Afr. For. J. 62, 9-14.

Kenya Forest Department (1967) Taungya in Kenya: the shamba system. Paper, FAO World Symposium on Man made Forests, Canberra Vol. 2 6/4, 1057-68.

Kibuku, M.D.N. et al. (1972) Selection of parent material for clonal seed sources. E.A.A.F.R.O. Rec. of Res. 1971.

_____ (1972a) Wood property studies. E.A.A.F.R.O. Rec. of Res. 1971, 285.

Kimber, P.C. (1963) Local seed collection. Tanganyika For. Dept. Tech. Note (Silvic.) 29.

Kingston, B. (1970) A provisional yield table for P. patula grown in Uganda and an estimate of the financial rotation. Uganda For. Dept. Tech. Note 166/70.

Kiyohara, T. and Tokushige, Y. (1969) Resistance of exotic pine species to Cercospora needle blight. For. Prot. (Tokyo) 20, 208-13.

Klingstrom, A. (1967) Personal communication to I.A.S. Gibson.

Knuffel, W.E. (1970) Branch whorl strangulation in P. patula. S. Afr. For. J. 73.

Koch, P. (1972) Utilisation of the Southern pines. U.S. Dept. Agric. For. Serv., Agric. Handbook No. 420, Vol. 1.

Kramer, P.J. (1969) Plant and soil water relationships: a modern synthesis. New York, London and Sydney, McGraw Hill Book Co., 376-7.

Kramwinkel, P.O. (1973) Future demand and supply of roundwood in the Republic and Swaziland. South African Dept. of For. Pamphlet 121. 15p.

Labyak, L.F. and Schumacher, F.X. (1954) The contribution of its branches to the main-stem growth of loblolly pine. J. For. 52(5), 333-7.

Lamb, A.F.A. (1970) Impressions of plantation forestry in parts of (northern and eastern) India and Ceylon after visits from Jan. 5th to March 14th, 1970. Oxf., U.K. Commonw. For. Inst. 93p.

_____ (1973) Pinus caribaea. Commonw. For. Inst., Oxford. Fast growing timber trees of the lowland tropics No. 6. 254p.

Leathers, R.I. (1967) A catalogue of some plant diseases and fungi in Jamaica. Bull. Min. Agric. and Lands., Jamaica, No. 61.

Lee, R.F. (1971) A preliminary annotated list of Malawi forest insects. Malawi For. Res. Inst., Res. Rec. No. 40. 132p.

_____ (1972) A preliminary account ofthe biology and ecology of Plagiotriptus spp. (Orth. Eumastacidae). Malawi For. Res. Inst., Res. Rec. No. 48. 100p.

Le Roux, H.H. (1955) Wind damage to Pinus patula. J. S. Afr. For. Ass. 26, 62-6.

Little, E.L., Jr. and Critchfield, W.B. (1969) Subdivisions of the genus Pinus. Misc. Publ. U.S. Dept. Agric. 1144. 51p.

Logie, J.P.W. (1966) Treatment of pulpwood plantations. Kenya For. Dept. Tech. Ord. 37.

_____ (1969) Treatment of P. patula plantations. Kenya For. Dept. Tech. Ord. 43.

Loock, E.E.M. (1950) The pines of Mexico and British Honduras: a report on a reconnaissance of Mexico and British Honduras during 1947. Bull. Dip. For. S. Afr. 35. 244p.

Loseby, P.J.A. (1939) Pulp and paper making as a South African industry. J. S. Afr. For. Ass. 2, 56-69.

Lückhoff, H.A. (1949) The effect of live pruning on the growth of P. patula, P. caribaea and P. taeda. J. S. Afr. For. Ass. 18, 25-55.

_____ (1956) High pruning in P. patula, its feasibility, effect on growth and economics. J. S. Afr. For. Ass. 27, 55-71.

_____ (1964) Diseases of exotic plantation trees in the Republic of South Africa. FAO/IUFRO Symposium on Internationally Dangerous Forest Diseases and Insects, Oxford.

McCulloch, J.S.G. (1961) Soil moisture build up at planting time. Kenya For. Dept. Tech. Note 78.

Madan, Gopal. (1973) Personal communication.

Magnani, G. (1966) Necrosis and dieback in conifers caused by Coryneum cardinale. Publ. Cent. Sper. Agric. For. Roma 8, 285-97.

_____ (1969) Diplodia pinea as a cause of colour change in wood. Cellulosa and Carta 20, 43-5.

Marks, G.C. and Minko, G. (1969) The pathogenicity of Diplodia pinea to P. radiata D. Don. Aust. J. Bot. 17, 1-12.

_____ and _____ (1970) The resistance of P. radiata to infection by Macrophoma pinea. Aust. J. Bot. 18, 55-65.

Marsh, E.K. (1957) Some preliminary results from O'Connor's correlated curve trend (CCT) experiments on thinnings and experiments and their practical significance. Paper, 7th Br. Commonw. For. Conf., New Zealand.

_____ (1963) The possibilities and limitations of silvicultural treatment. S. Afr. For. J. 47, 2-8.

_____ (1972) Some observations on the growth and characteristics of P. kesiya, P. oocarpa and P. merkusii in South Africa. Bosbou in Suid Afrika 13, 31-44.

Marshall, H.G.W. (1967) Selection of P. patula seed stands, Zambia plateau and outer slopes. Malawi Silv. Res. Rec. 15. 5p.

_____ (1968) A preliminary growth study of P. patula in Malawi with a view to improving thinning regimes for production of timber. Malawi For. Res. Inst. Res. Rec. 18. 28p.

_____ and Foot, D.L. (1969) Growth and silviculture of P. patula in Malawi. Malawi For. Res. Inst. Res. Rec. 37. 58p.

Martinez, M. (1940) /Mexican pines; description of several new species and varieties/. An. Inst. Biol. Univ. Mex. II, 57-84.

_____ (1948) /The pines of Mexico/. Edicones Botas, Mexico 2nd ed. 361p.

May, L.C. (1964) Molestias de coniferas ocorrentes no estade de Sao Paulo. Silvicultura 3, 221-45.

_____ (1969) Personal communication.

May, W.B. (1953) Nursery notes. E.A.A.F.R.O. Tech. Note 1.

Melchior, G.H. and Quijada, M. (1972) Preliminary results of species - provenance trials of exotic conifers, in Venezuela. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept. Vol. 1, 251-62.

Milano, V.A. (1948) /A new horticultural variety of P. patula/. Lilloa 17, 145-6.

Millar, C.S. and Watson, A.R. (1971) Two biotypes of Lophodermium pinastri in Scotland. Europ. J. For. Path. 1, 87-93.

Miller, A.D.G. (1973) Personal communication.

Miller, L.N. (1965) Changes in radiosensitivity of pine seedlings subjected to water stress during chronic gamma irradiation. Health Phys. 11, 1653-62.

Mirov, N.T. (1967) The genus Pinus. New York, Ronald Press Co. 602p.

Moore, K.M. (1962) A preliminary list of insects attacking Pinus spp. in New South Wales. Aust. Zool. 13(1), 69-77.

_____ (1963) An indigenous insect, Panacela levinae (Lewin) (Lep., Eupterotidae) attacking exotic Pinus spp. in New South Wales. Aust. Zool. 13(1), 40-5.

_____ (1972) A supplementary list of insects attacking Pinus spp. in New South Wales. Aust. Zool. 17(1), 59-64.

Murdoch, G. and Venn, A.C. (1963) Swaziland versus hail. Swaziland Dept. Agric. Bull. 10.

Myburgh, H.H. and Mackenzie, A.A. (1966) The production of timber for pulpwood. S. Afr. For. J. 58, 21-9.

Nair, P.N. (1972) Preliminary trials with tropical conifers in Kerala state. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept. Vol. 1, 302-17.

Nanni, U.W. (1960) Root distortion of young P. patula trees at Cathedral Peak. J. S. Afr. For. Ass. 34, 13-22.

Nanson, A. (1973) Mise en route du programme d'ammelioration des essences forestieres. UNDP/FAO FO : SF/MAG 8. Tech. Rep.

Niekerk, G.C.O., van (1968) Stumpage value of pulpwood with special reference to site quality and return on capital. S. Afr. For. J. 58, 15.

Nikles, D.G. (1973) Improvement of tropical conifers: report on a questionnaire. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, Oxford, C.F.I. and Queensland For. Dept. Vol. 2, 335-63.

Nikles, D.G. (1974) Personal communication.

Norskov-Lauritsen, G. (1963) Notes on the growth habits of the main pine species of the East Transvaal region. Bosbou in Suid Afrika 3, 67-84.

Ochieng, E.A. (1969a) Seed weights and the expected number of seedlings of tree species growing in Kenya. Kenya For. Dept. Tech. Note 114.

_____ (1969b) Altitudes, temperatures and rainfall of Kenya forests. Kenya For. Dept. Tech. Note 118.

_____ (1969c) Factors affecting the rate of growth and distribution of P. patula in Kenya. Kenya For. Dept. Tech. Note 120.

O'Connor, A.J. (1935) Forest research with special reference to planting distances and thinning. Br. Emp. For. Conf., 1935.

Odera, J.A. (1972) A defoliation of pines, Orgyia hopkinsi Coll. (Lep., Lymantridae) in Turbo, Kenya. Canad. Ent., 104(3), 355-60.

Olesen, P.O. (1972) Collection of forest tree seed in Mexico, 1968. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept. Vol. 1, 24-37.

Omar, A. and de Vos, A. (1970) Damage to exotic softwoods by Sykes Monkeys. E. Afr. Agric. For. J. 35(4), 323-30.

Oxenham, B.L. and Winks, B.L. (1963) Phytophthora root rot of pines in Queensland. Q. J. Agric. Sci. 20, 355-66.

Parrish, J.R. (1958) Particle board from Wattle wood and wattle tannin. J. S. Afr. For. Ass. 32, 26-31.

Parry, M.S. (1952) The softwood plantations of the East Transvaal and Swaziland. E. Afr. Agric. J. 4, 188-200.

Paterson, D.N. (1961) Mechanical and physical properties of Kenya exotic pines. Kenya For. Dept. Tech. Note No. 82.

_____ (1966) Crude estimates of genetic gain from plus trees selected in the East African tree breeding programme. E.A.A.F.R.O. For. Tech. Note 18.

_____ (1967) Variation in P. patula and its application to tree breeding in East Africa. Univ. of E. Afr. 237p. (Ph.D. Thesis).

_____ (1968) Control of wood quality in the East African exotic softwood tree breeding programme. E. Afr. Agric. For. J. 33, 302-15.

_____ (1968a) Spiral grain in East African exotic softwood forest plantations. E. Afr. Agric. For. J. 33, 286-91.

_____ (1968b) Further studies in wood quality, wood quantity, wood value and rotations from core wood analysis. E.A.A.F.R.O. For. Tech. Note 22.

Paterson, D.N. (1968c) Volume and value yields from East African exotic softwood crops in highland sites and a fresh approach to East African silviculture. E.A.A.F.R.O. For. Tech. Note 19.

_____ (1968d) The grading of plus phenotypes, its significance in silviculture and volume yields in East Africa. E.A.A.F.R.O. For. Tech. Note 21.

_____ (1969) Genetic gains predicted for seed to be produced from Malawian seed orchards. Malawi For. Res. Inst. Res. Rec. No. 32.

_____ and Howland, P. (1971) Shrinkage, distortion and density in some Malawian timbers. Malawi For. Res. Inst. Res. Rec. No. 46.

Pawsey, R.G. (1969) Personal communication.

_____ (1970) Forest diseases of Trinidad and Tobago with some observations in Jamaica. Commonw. For. Rev. 49, 64-77.

Pereira, H.G. (1952) Water use by forest covers on the Aberdares. E.A.A.F.R.O. Ann. Rep., 1951.

_____ (1955) Soil moisture criteria for planting dates. Kenya For. Dept. Tech. Note 27.

Peterson, R.S. (1967) The Peridermium spp. on pine stems. Bull. Torr. Bot. Club 84, 511-42.

_____ and Salinas Quinard. (1967) Cronartium conigenum: distribucion y effectos en los pinos. Instituto Nacional de Investigaciones Forestales. Mexico, Bol. Tech. 19.

Pienaar, L.V. (1969) Towards the development of Forest management tables. Bosbou in Suid Afrika 10, 15-19.

_____ and Turnbull, K.J. (1973) The Chapman-Richards generalisation of Von Bertalanffy's model for basal area growth and yield in even-aged stands. For. Sci. 19, 2-22.

Plumptre, R.A. (1968) Results of pilot tests on some Uganda timbers. Uganda For. Dept. Timber Leaflet No. 46.

_____ (1972) Comparison of the anatomical and mechanical properties of the wood of Pinus patula grown in Uganda. Univ. Oxf. (M.Sc. thesis - unpublished).

_____ (1973) Unpublished information from private records.

_____ and Kasirye, B. (1969) The resistance of some Uganda timbers to impregnation with copper-chrome-arsenate wood preservatives. Uganda For. Dept. Bull. No. 10.

Poynton, R.J. (1957) Note on exotic forest trees in South Africa. S. Afr. For. Dept. Bull. No. 38.

Poynton, R.J. (1961) A guide to the characteristics and uses of the trees and shrubs quoted in the price list of the Forest Dept. Bull. Dept. For. Un. S. Afr. No. 39. 50p.

_____ (1966) The drought resistance of commercial timber species in the Transvaal. Bosbou in Suid Afrika 6, 87-106.

_____ (1971) Silvicultural map of Southern Africa. S. Afr. J. Sci. 67(2), 58-60.

_____ (1972) Characteristics and uses of trees and shrubs obtainable from the Forest Department (3rd ed.). Bull. Dept. For. Un. S. Afr. No. 39. 70p.

_____ (1974) Tree planting in Southern Africa. Draft report under preparation for the Southern African Regional Council for the Conservation and Utilization of the soil and for the South African Dept. of For.

Prevôst, M.J. (1971) Volume tables for P. patula, P. elliottii and P. taeda in the Eastern districts of Rhodesia. Rhodesia Bull. of For. Res. No. 3.

Prevost, M,J. (1971) Personal communication.

Procter, J.E.A. (1963) Nursery practice in the Southern Highlands. Tanganyika For. Dept. Tech. Note (Silvic.) 32.

_____ (1967) A nutritional disorder of pine. Commonw. For. Rev. 46, 145-54.

_____ (1968) Tree growth trial plots on the Rondo plateau. Tanzania For. Dept. Silvic. Res. Note 5.

Pudden, H.H.C. (1952) Nursery practice - raising pines. Kenya For. Dept. Tech. Note 6.

_____ (1955) Pine seed germination and pricking out. Kenya For. Dept. Tech. Note 32.

_____ (1956a) Seed collection - P. patula (R.E. 153). Kenya For. Dept. Tech. Notes 38 and 43.

_____ (1956b) Nursery practice - composting. Kenya For. Dept. Tech. Note 46.

_____ (1956c) Splitting of leaders - P. radiata and P. patula. Kenya For. Dept. Tech. Note 48.

_____ (1959) Rodent damage to exotic softwood species. Kenya For. Dept. Tech. Note 63.

Queensland. (1974) Personal communication from the Secretary, Queensland Dept. of For.

Raigosa, J. (1973) Personal communication.

Ram Reddy, M.A. and Misra, V.B.M. (1970) Fungicidal soil treatments to control damping-off diseases in pine. Indian For. 96, 270-75.

Raunio, A.-L. (1973) P. patula international (EAAFRO) progeny trial planted in 1967 at Lushoto, Tanzania. In: "Tropical provenance and progeny research and international cooperation", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept., 481-4.

Rawlings, G.B. (1962) Ecology and control of forest insects in New Zealand. N.Z. Inform. Serv., N.Z. For. Serv. No. 38, 6p., also 8th Br. Commonw. For. Conf., Nairobi.

Righter, F.I. (1939) Early flower production among the pines. J. For. 37(12), 935-8.

Roberts, H. (1969) Forest insects of Nigeria. Inst. Pap. Commonw. For. Inst. No. 44. 206p.

Robinson, J.B.D. (1967) The effects of exotic softwood crops on the chemical fertility of a tropical soil. E. Afr. Agric. For. J. 33(2), 175-89.

_____, Hosegood, P.H. and Dyson, W.G. (1966) A note on the preliminary study of the effects of an East African softwood crop on the physical and chemical condition of a tropical soil. Commonw. For. Rev. 45(4), 359-65.

_____, et al. (1969) The efficiency of Muguga standard potting soil. E. Afr. Agric. For. J. 35(1), 68-77.

Robinson, R.K. (1971) Changes in mycorrhizal flora on roots of Pinus patula in Swaziland. S. Afr. For. J. 78, 14-15.

Rodriguez, L.R. (1967) Observaciones sobre la occurencia de parasitos predadores y competidores de Dendroctonus frontalis Zimm. (Col., Scolytidae) en bosques do pino del Estado de Mexico. VI Congreso Nac. de Ent., Folia ent. mex. No. 18-19. 131p.

Salas, F.I. (1964) Biologia y combate de la gallina ciega. Phyllophaga rubella Bates on San Cayetano, Mexico. Instituto Nacional de Investigaciones Forestales, Mexico, Bol. Tech. No. 13. 23p.

Sands, W.A. and Wilkinson, W. (1954) A report on a survey of termites of Nyasaland. (Cyclostyled, 144p.)

Schonland, R.S. (1964) Retardation of growth in pine economically justified? S. Afr. For. Ass. 49.

Scott, M.H. (1953) Notes on South African timbers. S. Afr. For. Dept. Bull. No. 36.

_____ and Stephens, R.P. (1947) The quality of mature P. patula and P. insignis timber grown in South Africa. Paper, 5th Br. Commonw. For. Conf. and J. S. Afr. For. Ass. 15, 46-68.

Sechet, M. (1955) Un champignon parasite des feuilles de pine. Bull. de Madagascar, 113.

Seth, S.K. (1972) An analysis on the performance of some tropical and subtropical pine in India. In: "Selection and breeding to improve some tropical conifers", eds. J. Burley and D.G. Nikles, C.F.I., Oxford and Queensland For. Dept. Vol. 1, 327-50.

Shaw, G.R. (1914) The genus Pinus. Publication No. 5 of the Arnold Arboretum. Cambridge, Riverside Press. 93p.

Sherry, S.P. (1967) Is high pruning of P. patula economically justifiable? Bosbou in Suid Afrika 8, 87-94.

Smart, J.B. (1966) Seed collection. Kenya For. Dept. Tech. Ord. 36.

South Africa. (1948) Annual report of the South African Department of Forestry, 1948.

South Africa. (1969/1970) Annual report of the South African Department of Forestry, 1969/1970.

South African Department of Forestry. (1973) Annual report, 1972/73.

Stahl, W. (1968) A preliminary report on some aspects of fungus and host relationship of Diplodia pinea. Aust. For. Res. 3, 22-32.

_____ (1969) Personal communication.

Stone, E.C. and Jenkinson, J.L. (1971) Physiological grading of ponderosa pine nursery stock. J. For. 69(1), 31-3.

Stuart, B.E. St. L. (1954) Seed weights for the species commonly grown in East Africa. E.A.A.F.R.O. Tech. Note 2.

Stubbings, J.A. (1958) Raising and use of large close-rooted transplants for commercial afforestation in Southern Rhodesia. J. S. Afr. For. Ass. 32, 36-55.

Styles, B.T. (1973) Personal communication.

Suchtelen, N.J. van. (1962) Mycorrhiza on Pinus spp. Meded. LandbHochsch. Gent. 27, 1104-6.

Sutton, W.R.J. (1974) Personal communication.

Taylor, K.L. (1948) Forest insects in New South Wales. The mottled cup-moth (Doratifera vulnerans). The Pine bark weevils (Aesiotes spp.) N.S.W. For. Record, 1, 42-7.

Theron, J.M. (1972) Nursery research in Malawi, 1964-71. Malawi For. Res. Inst. Res. Rec. 56. 43p.

_____ (1973) Report on initial climatic classification of East Africa. Cyclostyled report, Commonw. For. Inst., Oxford.

Thulin and Firth (1973). Personal communication to G.C. Weston.

Tissot, M. (1968) /The paper making characteristics of some pine introduced into Africa and Madagascar/. Bois For. Trop. 118, 41-55.

Tooke, F.G.C. (1936) Insects injurious to forest and shade trees. Bull. Dept. Agric. For. Un. S. Afr., No. 142. 52p.

_____ (1949) Beetles injurious to timber in South Africa. Sci. Bull. No. 293, Ent. Series No. 28, Dept. Agric., Pretoria. 95p.

Tripconey, D. (1970) Studies on a non-occluded virus of pine tree emporer moth. J. Invert. Path., 15(2), 268-75.

Turnbull, J.M. (1942) A preliminary investigation into the causes of torsion in pine stems. J. S. Afr. For. Ass. 8, 112-7.

_____ and Du Plessis, C.P. (1946) Some sidelights on the rate of growth bogey. J. S. Afr. For. Ass. 14, 29-36.

Turnbull, K.J. and Pienaar, L.V. (1965) A non-linear mathematical model for analysis and prediction of growth in non-normal and thinned forest stands. Paper, International advisory group of forest statisticians, 2nd Conf., Stockholm.

Uprichard, J.M. (1970) Pulps from New Zealand grown P. patula and P. taeda. Appita 29(1), 52-9.

Vail, J.W., Parry, M.S. and Calton, W.E. (1961) Born deficiency die-back in pines. Plant and Soil 14(4), 393-8.

Van Dorsser, J.C. and Rook, D.A. (1972) Conditioning of radiata pine seedlings by undercutting and wrenching: description of methods, equipment and seedling response. N.S. J. For. 17(1), 61-73.

Van Goor, C.P. (1966) /The nutrition of some tropical pines/. Silvicultura en Sao Paulo 1965/66 4/5(4), 313-50.

Veldhoen, B.J. (1968) Interim report on two thinning trials on P. patula. Kenya For. Dept. Tech. Note 111.

de Vergnette, . ., et al. (1968) Fertilisation minérale des plantations de P. patula sur les hauts - plateaux Malgaches. Division sol et forêt C.T.F.T., Republique Malgaches.

Vignal, P. (1956) /Afforestation with Pinus patula in the upper Matsiatra basin in Madagascar/. Bois For. Trop. 45, 15-25.

de Villiers, P.C., et al. (1961) The silviculture and management of exotic conifer plantations in South Africa. Bosbou in Suid Afrika 1, 13-29.

de Villiers, A.M. and Perry, N.G. (1973) The use of South African softwoods. Pretoria South Africa. Dept. of For. p.36.

Walter, H. and Lieth, H. (1967) Klimadiagramm-weltatlas. Jena, Gustav Fischer.

Webb, D.V.V. (1961) Preliminary investigations on the biology, ecology and control of the emperor moths Nudaurelia cytherea capensis Stoll. and Gonimbrasia tyrrhea Cr. attacking trees and shrubs in western and south-western Cape Province. Tech. Comm. Dept. of Agric. Tech. Serv. Un. S. Afr. No. 12, 44-51.

Westhuizen, G.C.A. van der. (1956) Three species of Curvularia from Pinus patula in South Africa. Bothalia 6, 501-5.

_____ (1968) Some aspects of the biology of Diplodia pinea in relation to its control by fungicides. S. Afr. For. J. 65, 6-14.

Weston, G.C. (1973) Personal communication.

Whellan, J.A. (1965) Outbreaks and new records - Rhodesia. F.A.O. Plant Protection Bulletin, 13(3). 67.

Wilkes, W. (1969) Personal communication.

Willan, R.L. (1964a) Trial plots - Southern Highlands. Tanganyika For. Dept. Tech. Note (Silvic.), 64.

_____ (1964b) Trial plots - Sao Hill. Tanganyika For. Dept. Tech. Note (Silvic.), 66.

Wood, P.J. (1964) Trial plots - Northern and Kilimanjaro regions. Tanganyika For. Dept. Tech. Note (Silvic.), 70.

_____ (1965) Germination-major species. Tanzania For. Dept. Tech. Note (Silvic.), 74.

_____ (1971) Note on plantation silviculture in East and Central Africa and Madagascar. Commonw. For. Inst., Oxford. 74p.

_____ (1973) Personal communication.

Wright, H.L. (1974) Personal communication.

Zobel, B.J. (1965) Variation in specific gravity and tracheid length for several species of Mexican pine. Silvae Genet. 14(1), 1-12.

_____ (1972) Fast growing exotic pines as exotics. Econ. Bot. 26(2), 160-8.

Zondag, R. (1965) Insect pests of forest nurseries and young plantations in New Zealand. Proc. XII Int. Congr. Ent., London, 674-5.

Appendix I

Climate

In Figure 2 some climadiagrams from Walter and Lieth (1967) have been reproduced. The data at the top of each chart includes the names of the weather station, its altitude, mean annual temperature and rainfall. The chart is composed of two curves, the mean monthly rainfall, calibrated in 20 mm units and mean monthly temperature in units of 10°C. Where the rainfall curve is above the temperature curve, the intervening area is striped; where below it is stippled.

Charts 1-3 are from stations close to areas where P. patula is found in Mexico. These represent a typical summer rainfall pattern, though the temperature curve for Ixtlan (see Map 1) at the southern end of the range (at latitude 17° 22'N) is flatter than for the other two stations (at approximately latitude 20°N), the annual rainfall is lower and the dry season is longer.

Charts 4 and 5 are from high altitude sites on the equator in south America. There is very little temperature variation (compare with charts 12-14 for equatorial stations in Kenya). The rainfall is good and there is no reason why P. patula should not grow here, though mean annual temperatures are low and growth may be slow.

Charts 6-9 are for stations in P. patula growing areas of southern Africa. There is a marked variation between winter and summer temperatures, but whereas the dry season in Swaziland (6) South African (7) and Rhodesia (8) is short, that in Angola (9) is longer and more severe. The pattern at Cuima in Angola (9) is very similar to that at Sao Hill in Tanzania (10), except that the mean annual temperature at Cuima is higher. P. patula growth at Sao Hill is average to poor, the species has not been fully tested at Cuima and growth may fall off after about age 10.

Chart 11 is for a site near the Cameroun hills; though rainfall is good, temperatures are also high and may affect P. patula growth.

Charts 12-14 are for stations near P. patula growing areas in Kenya. Chart 15 (Addis Ababa) has a very similar pattern to the Kenya sites, and there should be no climatic limitations to P. patula growth there.

Chart 16 gives the pattern for a Queensland site. P. patula is not grown at Brisbane, but is grown at Yarraman some 400 m higher where temperatures will be lower.

Charts 17-19 are for stations where P. patula cannot grow. Jonkershoek (17) has a typical winter rainfall pattern; at Durban (18) temperatures are probably too high. Voi (19) in Kenya is too hot and dry, but it is to be noted that the tree does grow satisfactorily in the Taita hills some 30 km from Voi but 1000-1500 m higher.

Marsh (1972) listed the silvicultural divisions of South Africa in which P. patula grows.

Table 2.222. Silvicultural divisions of South Africa in which P. patula grows (from Marsh, 1972)

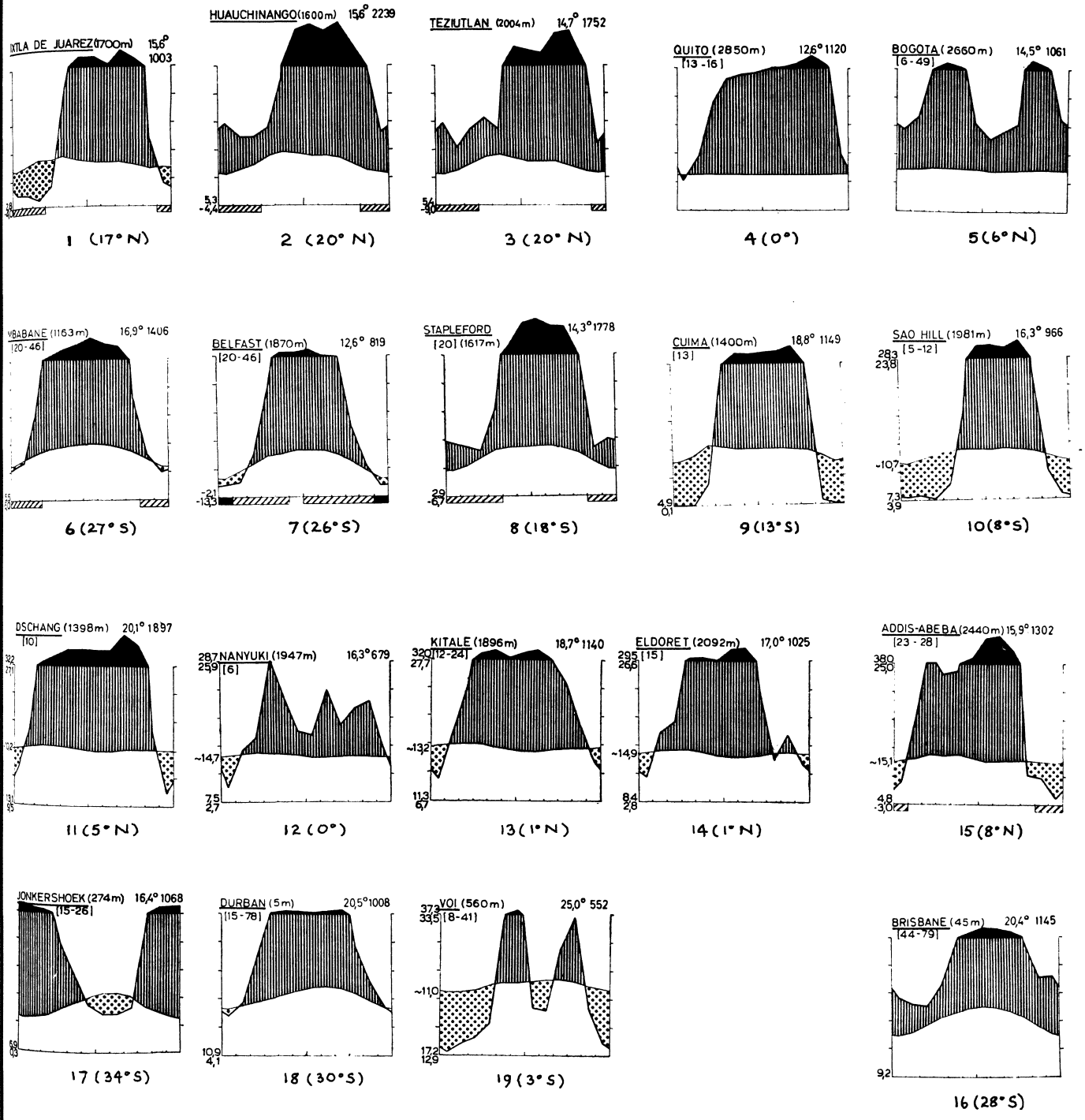
Div.	General description (from Sweet, 1962)	Mean annual temperature °C	Rainfall mm	P. patula growth
	Temperate: colder summer rainfall			
G	Humid		850-1800	Good
H	Subhumid	12.5-16.5	500- 850	Good in wetter parts
I	Semi-arid		250- 500	Too dry - not planted
	Temperate: warmer summer rainfall			
K	Humid		900-1800	Good
L	Subhumid	16.5-19.5	650- 900	Planted on a small scale - not well suited
M	Semi-arid		400- 600	Too dry - not planted
	Sub-tropical summer rainfall			
O	Humid	19.5-23.0	1000-1500	Planted on a small scale - not well suited
N	Sub-humid		750-1000	A failure in hotter areas

P. oocarpa, P. kesiya and P. merkusii are better suited in zone N. P. oocarpa grows moderately well in zone O and P. kesiya in zone L. All three alternative species grow reasonably well in zones G and K.

Poynton (1972) provided a silvicultural map for South Africa based on his earlier work (Poynton, 1971). In this map he made a primary classification by the reason of rainfall - summer, winter or uniform, and a secondary classification on a four point humidity scale which was based on Thornthwaite's moisture index. Overall he superimposed another classification based on mean minimum temperature.

P. patula plantations grow satisfactorily in the most humid (moisture index greater than about 50) summer rainfall sites that might experience a frost. Sites on which frosts do not occur are not suitable for P. patula. Minimum temperatures are of course correlated with maximum temperatures, but it is almost certainly the latter - and possibly the maximum temperature of the hottest month - that is the limiting factor for successful P. patula growth.

FIGURE 2

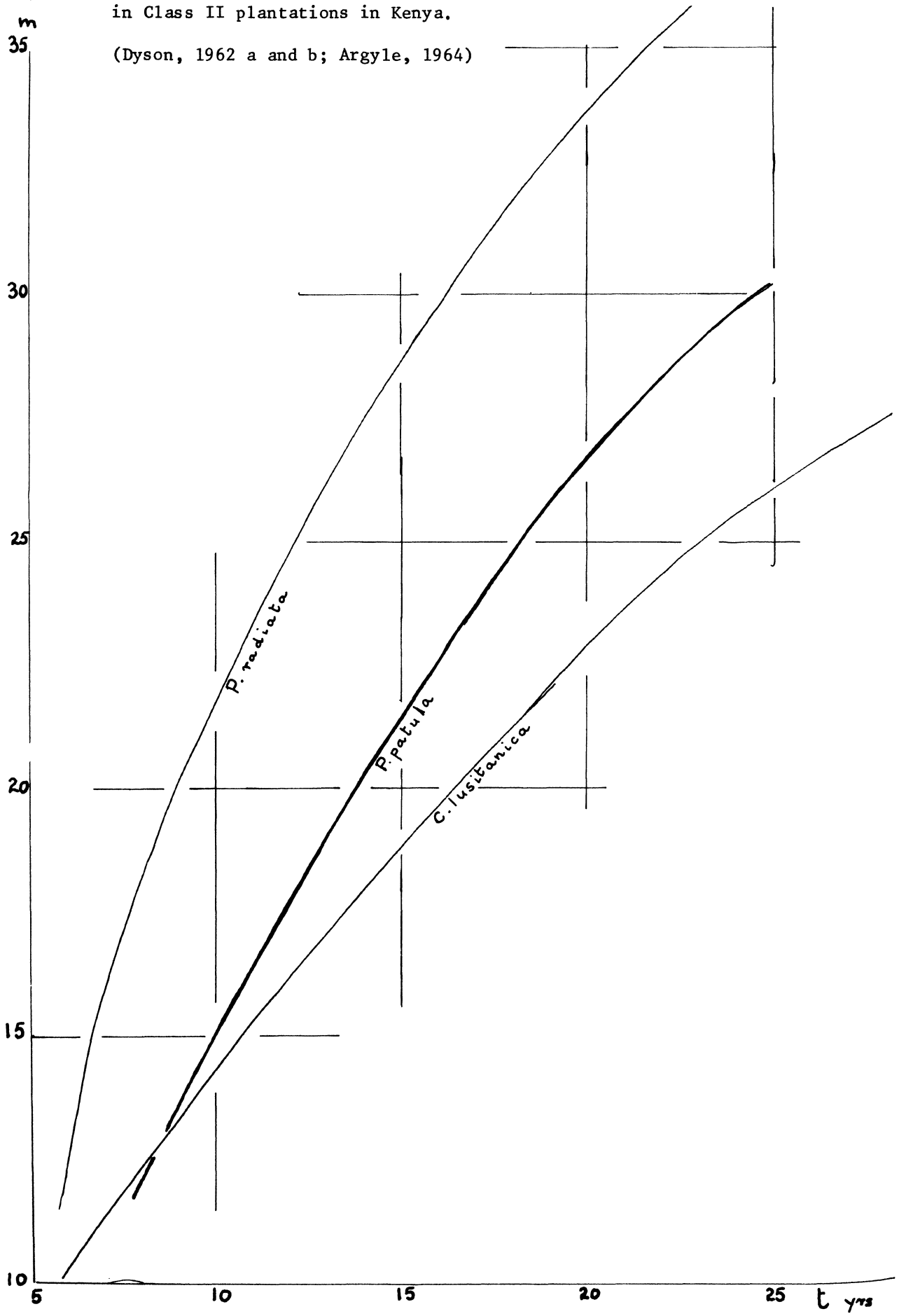


Reproduced with acknowledgement to: Walter and Leith (1967)

Figure 2.31

Height growth curves of P. patula, P. radiata and C. lusitanica in Class II plantations in Kenya.

(Dyson, 1962 a and b; Argyle, 1964)



Appendix I

2.41 Table Weights and macro-nutrient contents of a 19 year old tree from an unthinned stand in the Usutu plantations, Swaziland (Germishuisen pers. comm.)

	Tree statistics H^t m	DBH cm	Moisture %	Ratio Needles/branches Bark/wood	Ratio Overdry/fresh	Mass (kg) Green (Total)	Mass (kg) Dry Wood	Mass (kg) Dry Needles or bark(2)	Chemical constituents (gm) (4) N Wood	N Needles or bark	P W	P N or B	K W	K N or B	Ca W	Ca N or B	Mg W	Mg N or B
Crown upper third			62	1.12	0.38	21.0	3.8	4.2	14.3	60.7	1.4	4.1	9.5	22.8	6.8	14.3	3.2	6.3
mid third			60	0.72	0.40	7.5	1.8	1.3 (3)	5.1	17.3	0.3	1.1	3.5	8.8	3.5	5.8	1.1	2.5
lower third			62	0.91	0.38	8.5	1.7	1.5	5.4	22.5	0.5	1.7	3.6	9.5	3.5	8.3	1.2	3.0
Dead branches			12	-	0.88	11.0	9.7	-	8.7		0.2		0.4		7.7		0.1	
Tip (above 8 cm diam.)			62	0.23	0.38	5.1	1.6	0.4		2.2		-		1.3		2.2		1.1
Stem upper third	25.25	25.90	64	0.09	0.36	65.6	21.4	1.9	14.9	7.7	0.2	0.5	5.1	5.9	12.9	9.5	3.9	4.1
mid third	(Stem volume approx. 0.55 m^3)		62	0.10	0.38	171.1	58.8	5.8	35.3	-	1.2	1.2	17.6	10.4	35.3	33.5	11.8	11.0
lower third			61	0.04	0.39	276.4	104.6	3.9	83.7	9.0	1.0	0.8	26.2	5.3	62.8	20.2	25.1	6.0
Total						566.2	203.4	19.0	167.4	119.4	4.8	9.4	65.9	64.0	132.5	93.8	46.4	34.0

NB 1) These figures represent the value for the mean tree; dominants and subdominants were in fact analysed separately.
2) Bark only represents some 6% of the total dry weight of the stem. (Compare with volume estimates (in 5.14).
3) The very much lower weight of needles in the mid and lower thirds of the crown. The weights on a dominant tree were 4.8 (upper): 8.6 (mid): 4.5 (lower) (Cf. discussion on pruning 3.521).
4) For a very approximate estimate of quantities per hectare these figures can be multiplied by 1000.

Appendix II

Table 3.510.2. Some P. patula thinning schedules

A Saw Log

	1	2	3	4	5	6	7	8
	Age	N after Thinning	$\bar{h}$ dom	$\bar{d}$	Spacing % Before Thinning	Thinning Yield m^3/ha	Cumulative Yield	MAI
South Africa 1948-70	0	1240						
(Burgers, 1972)	6	740	10.3	15.8	30	27	77	12.8
	14	495	19.3	26.4	20	70	278	19.9
	20	320	22.8	32.3	21	86	421	21.5
	25	250	25.5	27.6	24	59	529	21.2
	30	250	27.7	41.1	25		613	20.4
	35	250	29.9	43.7	23		710	20.3
	40	0	31.7	45.7	22	545	787	19.7
South Africa	0	1240						
(Saw log recommended	11	740	16.6	21.6	18	64	192	17.5
by Burgers, 1972	15	370	19.8	26.6	20	112	327	21.8
	20	220	22.8	33.8	25	92	446	22.3
	25	150	25.5	40.6	28	80	545	21.8
	30	150	27.7	46.7	32		642	21.4
	[35	0	29.9	50.8	30	378	726	20.7]
South Africa	0	2200						
(Veneer regime	10	990	16.0	17.5	14	114	243	24.3
recommended by	15	495	19.8	23.9	17	111	388	25.9
Burgers, 1972)	20	310	22.8	30.2	21	76	498	24.9
	25	200	25.5	36.8	24	88	607	24.3
	30	150	27.7	43.4	28	59	691	23.0
	35	150	29.9	48.5	30		787	22.5
	[40	0	31.7	51.8	28	407	855	21.4]
South Africa	0	1330						
(Saw log regime	10	530	16.0	19.0	18	105		
recommended by	15	270	19.8	28.5	24	102		
Grut, 1967)	20	160	22.8	36.0	29	84		
	25	0	25.5	45.5	33	264	556	22.2
Rhodesia	0	1675						
(Banks, 1962)	7	990	10.5	9.7	25	7		
	12	740	18.9	18.8	18	24		
	18	495	24.1	27.7	16	84		
	24	320	27.3	34.8	18	108		
	30	0	28.2	40.6	21	492	695	23.2
Malawi	0	1335						
(Marshall & Foot	8	860	11.4	12.5*	36			
1969 'A Site')	16	610	20.8	21.0*	18			
	23	370	26.5	26.7*	17			
	30	0	30.2	35.1	19			

Continued/

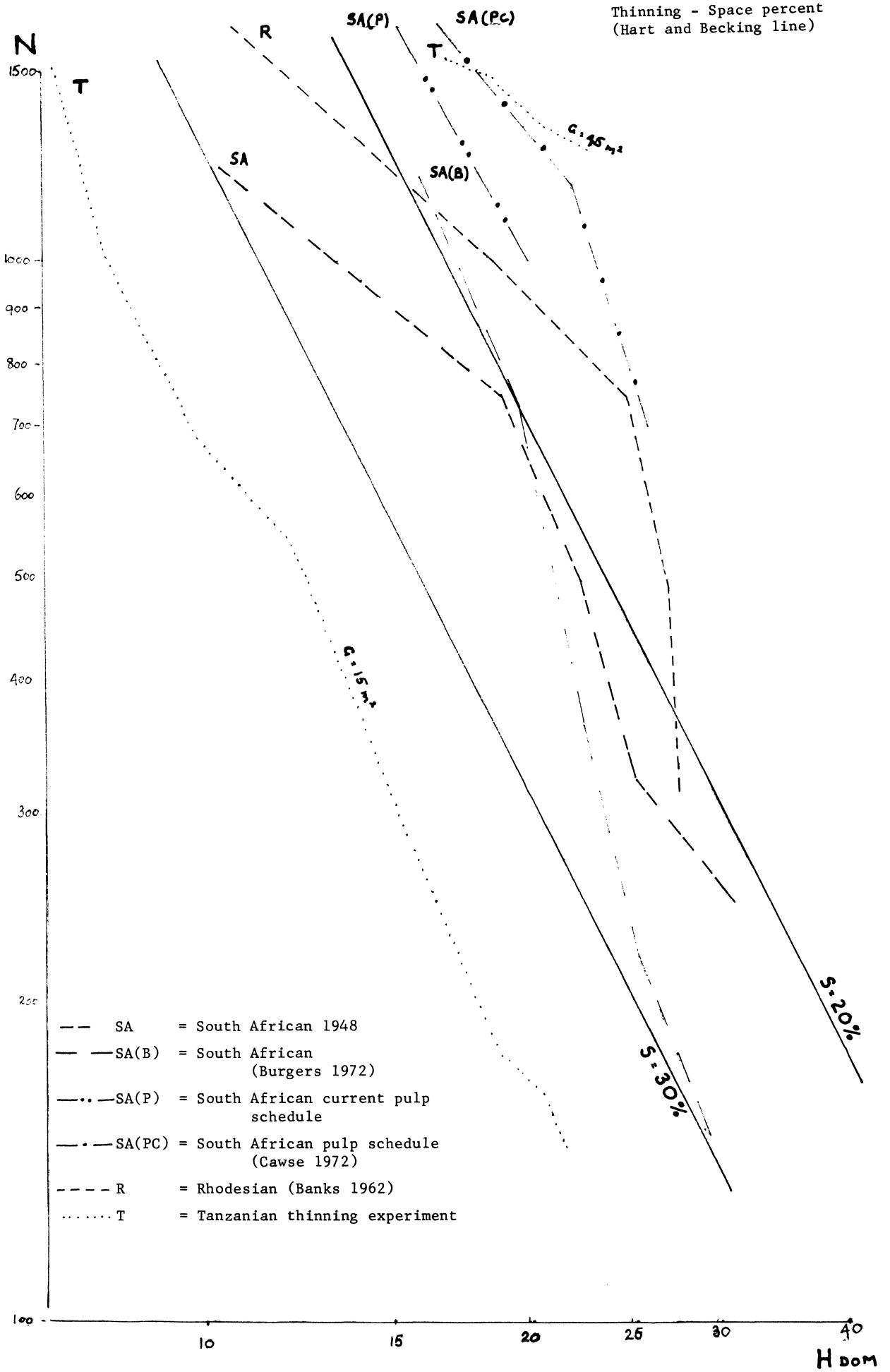
Table 3.510.2. Continued:

	1	2	3	4	5	6	7	8
Kenya	0	1660						
(Saw log Category III	8	711	12.0	17.8*	22			
Logie, 1969)	16	533	22.1	29.2*	18			
	21	356	27.4	36.3*	17			
	30	0	31.8	48.3*	18			
B Pulp								
South Africa	0	1675						
(Pulp, current	10	990	15.2		17			
regime Cawse, 1972)	15	0	20.3		17		345	23.0
South Africa	0	1675						
(Pulp, recommended by	11	1173	16.6	15.2	16	34		
Cawse, 1972)	18	704	23.2	21.8	13	145		
	25	0	26.5	30.5	15	512	691	27.6
South Africa	0	2800						
(Pulp recommended by	10	1480	16.0	15.2	13	84	222	22.2
Burgers, 1972)	15	740	19.8	20.3	14	126	373	24.9
	20	740	22.8	24.9	17		535	26.8
	25	720	25.5	27.9	15		703	28.1
	30	690	27.7	30.5	15		839	28.0
	35	0	29.9	32.3	14	744	954	27.3

* Estimates

FIGURE 3.510.31

Thinning - Space percent
(Hart and Becking line)



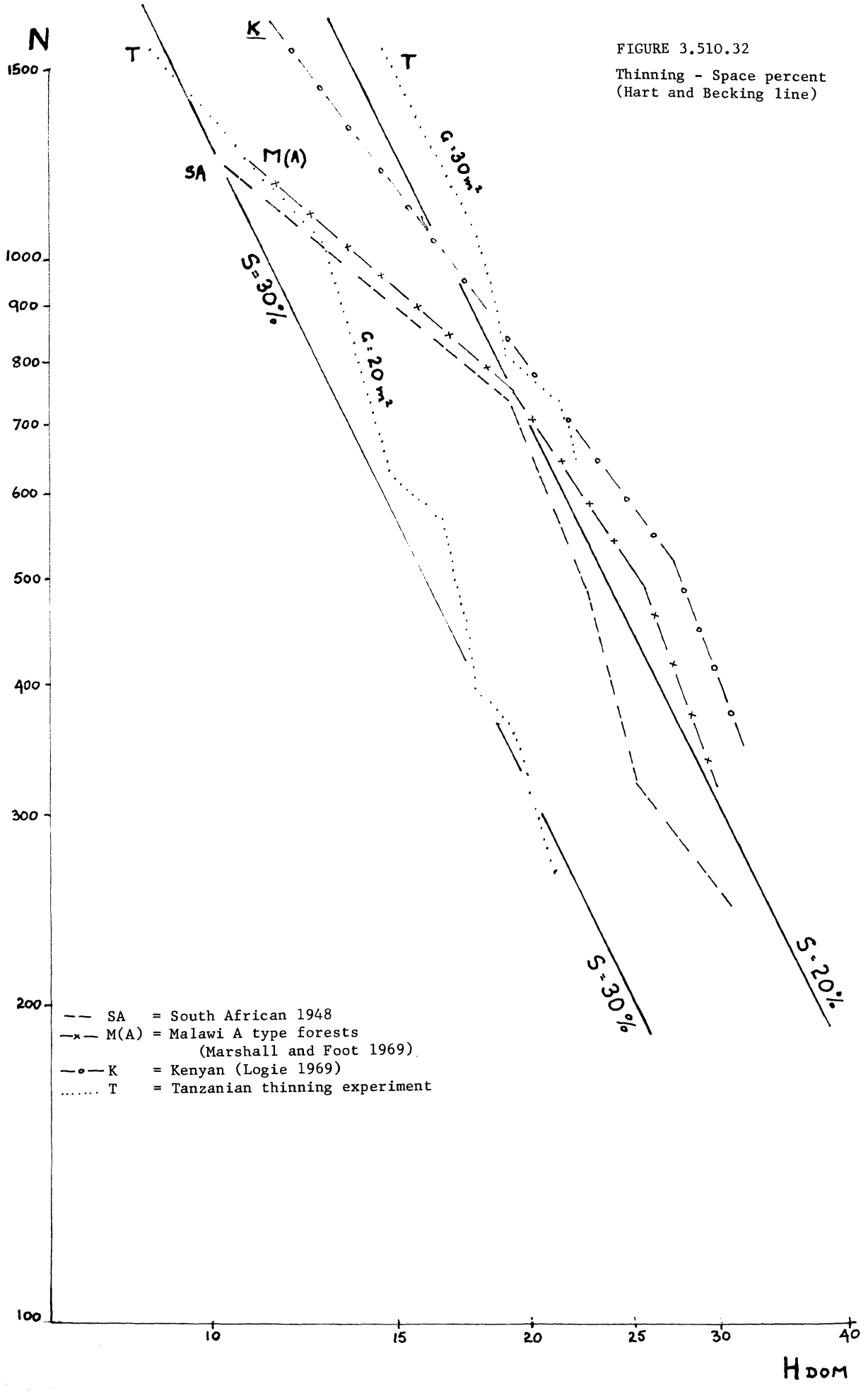
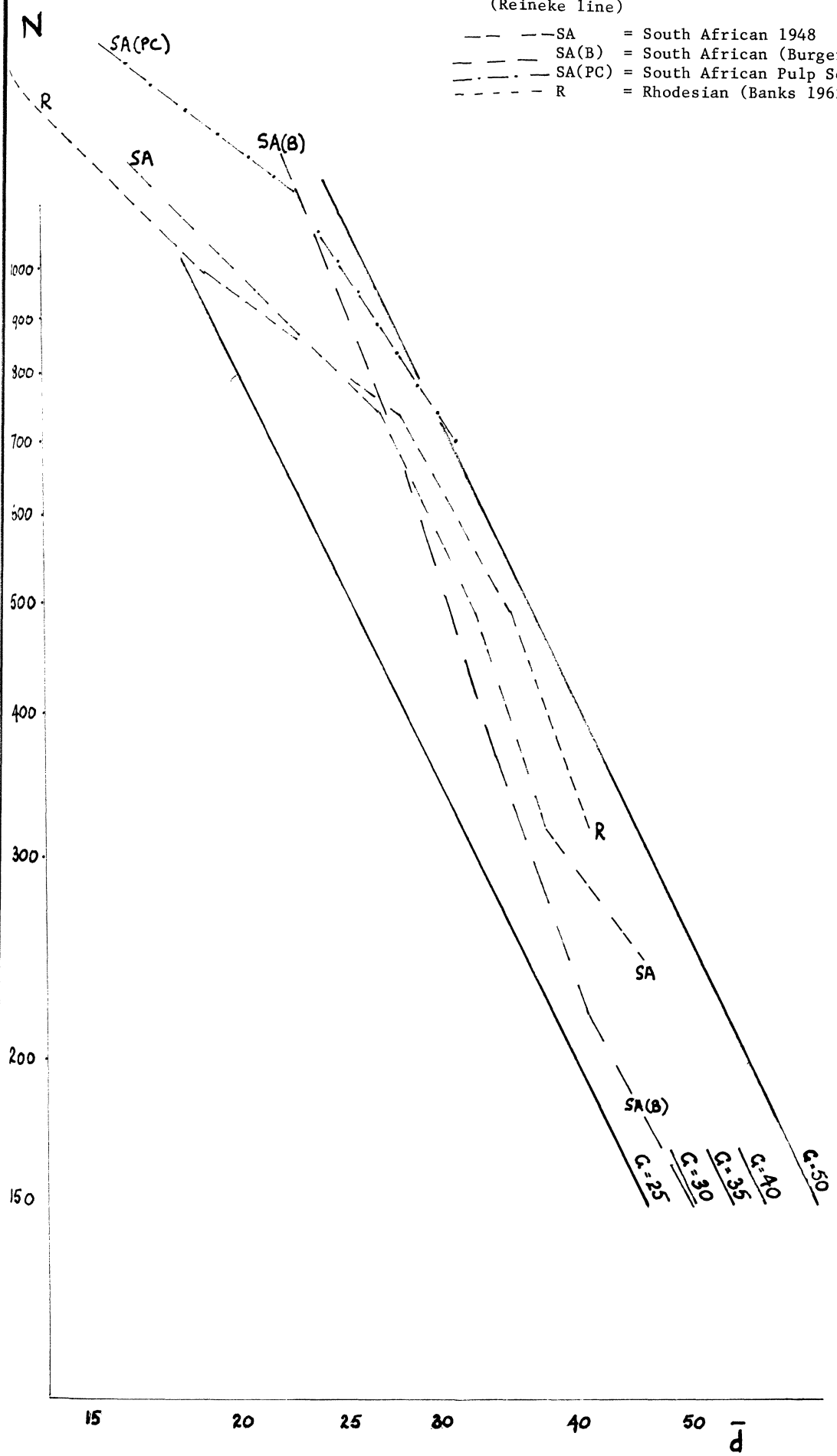


FIGURE 3.510.32

Thinning - Space percent (Hart and Becking line)

FIGURE 3.510.33
Thinning - Basal area line
(Reineke line)

— — — —SA = South African 1948
SA(B) = South African (Burgers 1972)
— . — . — SA(PC) = South African Pulp Schedule (Cawse 1972)
– – – – – R = Rhodesian (Banks 1962)



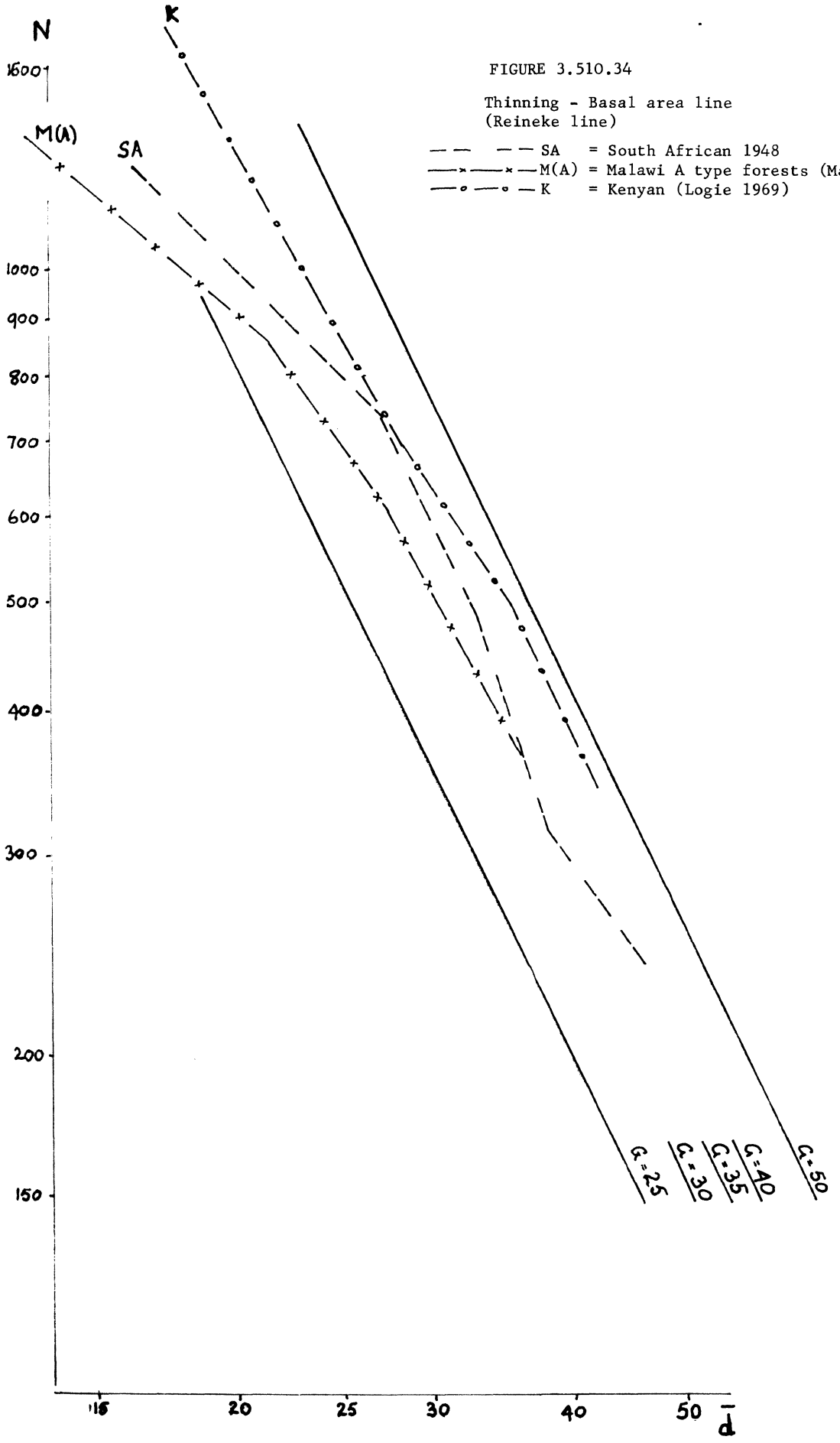


FIGURE 3.510.34

Thinning - Basal area line
(Reineke line)

— — — — SA = South African 1948
—×——×— M(A) = Malawi A type forests (Marshall and Foot 1969)
—o—o— K = Kenyan (Logie 1969)

Appendix III

5.111 Table. Total volume overbark

SØUTH AFRICAN ALIGNMENT CHART (EVANS 1973)

LØGV=-10,30438+1,91667LØGD+1,07175LØGH

	HEIGHT							
DIAMETER	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0
10,00	0,016	0,033	0,050	0,069	0,087	0,106	0,125	0,144
15,00	0,034	0,071	0,110	0,149	0,189	0,230	0,272	0,313
20,00	0,059	0,123	0,190	0,259	0,329	0,400	0,471	0,544
25,00	0,090	0,189	0,292	0,397	0,504	0,613	0,723	0,834
30,00	0,127	0,268	0,414	0,563	0,715	0,869	1,025	1,183
35,00	0,171	0,360	0,556	0,756	0,961	1,168	1,378	1,590
40,00	0,221	0,465	0,718	0,977	1,241	1,509	1,780	2,053
45,00	0,277	0,582	0,900	1,224	1,555	1,891	2,230	2,574
50,00	0,339	0,713	1,101	1,498	1,903	2,314	2,730	3,149
55,00	0,407	0,856	1,321	1,799	2,285	2,778	3,277	3,781
60,00	0,481	1,011	1,561	2,125	2,699	3,282	3,871	4,467

5.112 Total volume overbark

MALAWI (MARSHALL AND FØØT 1969)

LØGV=-10,1194+1,7603LØGD+1,2335LØGH

	HEIGHT							
DIAMETER	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0
10,00	0,017	0,040	0,065	0,093	0,123	0,154	0,186	0,220
15,00	0,034	0,081	0,134	0,191	0,251	0,314	0,380	0,448
20,00	0,057	0,135	0,222	0,316	0,417	0,522	0,631	0,744
25,00	0,085	0,199	0,329	0,469	0,617	0,773	0,935	1,102
30,00	0,117	0,275	0,453	0,646	0,851	1,065	1,288	1,519
35,00	0,153	0,360	0,594	0,847	1,116	1,397	1,690	1,992
40,00	0,194	0,456	0,752	1,072	1,411	1,767	2,138	2,520
45,00	0,239	0,561	0,925	1,319	1,737	2,175	2,630	3,101
50,00	0,287	0,675	1,113	1,588	2,091	2,618	3,166	3,733
55,00	0,340	0,798	1,317	1,878	2,472	3,096	3,744	4,415
60,00	0,396	0,931	1,535	2,188	2,882	3,608	4,364	5,145

5.113 Total volume overbark

USUTU(SWAZILAND) 15-19 YEAR ØLD TREES (ØRMERØD IN EVANS, 1973)

LØGV=-10,72212+1,90288LØGD+1,24161LØGH

	HEIGHT				
DIAMETER	5,0	10,0	15,0	20,0	25,0
10,00	0,013	0,031	0,051	0,073	0,096
15,00	0,028	0,067	0,110	0,157	0,208
20,00	0,049	0,115	0,190	0,272	0,359
25,00	0,074	0,176	0,291	0,416	0,549
30,00	0,105	0,249	0,412	0,588	0,776
35,00	0,141	0,334	0,552	0,789	1,041

5.114 Total volume overbark

USUTU(SWAZILAND) 9 AND 10 YEAR OLD TREES (EVANS 1973)

LOGV=-9,763+1,66674LOGD+1,07051LOGH

	HEIGHT				
DIAMETER	5,0	10,0	15,0	20,0	25,0
10,00	0,015	0,031	0,048	0,066	0,084
15,00	0,029	0,062	0,095	0,130	0,165
20,00	0,048	0,100	0,154	0,210	0,266
25,00	0,069	0,145	0,223	0,304	0,386
30,00	0,093	0,196	0,303	0,412	0,523
35,00	0,121	0,254	0,391	0,532	0,676

5.115 Total volume overbark

TANZANIA (ACKHURST AND MICSKI 1971)

LOGV=-9,4655+1,7316LOGD+1,0483LOGH

	HEIGHT							
DIAMETER	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0
10,00	0,023	0,047	0,071	0,097	0,122	0,148	0,174	0,200
15,00	0,046	0,094	0,144	0,195	0,246	0,298	0,350	0,403
20,00	0,075	0,155	0,237	0,321	0,405	0,490	0,576	0,663
25,00	0,110	0,228	0,349	0,472	0,596	0,722	0,848	0,976
30,00	0,151	0,313	0,478	0,647	0,817	0,990	1,163	1,338
35,00	0,198	0,409	0,625	0,845	1,067	1,292	1,519	1,747
40,00	0,249	0,515	0,787	1,065	1,345	1,628	1,914	2,202
45,00	0,305	0,631	0,966	1,305	1,649	1,997	2,347	2,700
50,00	0,366	0,758	1,159	1,567	1,980	2,397	2,817	3,240
55,00	0,432	0,894	1,367	1,848	2,335	2,827	3,322	3,822
60,00	0,502	1,039	1,589	2,148	2,715	3,286	3,863	4,443

5.116 Total volume overbark

UGANDA(WRIGHT 1974)

V=-0,001087+0,000124DD+0,00004375DH+0,0000315DDH

	HEIGHT							
DIAMETER	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0
10,00	0,029	0,047	0,065	0,083	0,101	0,119	0,137	0,155
15,00	0,066	0,104	0,143	0,182	0,220	0,259	0,298	0,337
20,00	0,116	0,183	0,251	0,318	0,385	0,453	0,520	0,588
25,00	0,180	0,284	0,388	0,492	0,596	0,700	0,804	0,908
30,00	0,259	0,407	0,555	0,704	0,852	1,000	1,149	1,297
35,00	0,351	0,552	0,753	0,953	1,154	1,354	1,555	1,756
40,00	0,458	0,719	0,980	1,240	1,501	1,762	2,023	2,283
45,00	0,579	0,908	1,236	1,565	1,894	2,223	2,551	2,880
50,00	0,714	1,118	1,523	1,928	2,332	2,737	3,142	3,546
55,00	0,862	1,351	1,839	2,328	2,816	3,305	3,793	4,282
60,00	1,025	1,606	2,186	2,766	3,346	3,926	4,506	5,086

5.117 Total volume overbark

KENYA(WRIGHT 1974)

V=-0,00041-0,00005711D+0,00013520H+0,00003313DDH

	HEIGHT							
DIAMETER	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0
10,00	0,017	0,041	0,064	0,087	0,111	0,134	0,157	0,180
15,00	0,034	0,082	0,129	0,176	0,224	0,271	0,319	0,366
20,00	0,057	0,136	0,216	0,296	0,376	0,455	0,535	0,615
25,00	0,084	0,205	0,325	0,446	0,566	0,686	0,807	0,927
30,00	0,118	0,287	0,456	0,626	0,795	0,964	1,134	1,303
35,00	0,156	0,383	0,609	0,836	1,063	1,289	1,516	1,742
40,00	0,200	0,492	0,784	1,077	1,369	1,661	1,953	2,245
45,00	0,250	0,616	0,982	1,347	1,713	2,079	2,445	2,811
50,00	0,305	0,753	1,201	1,649	2,096	2,544	2,992	3,440
55,00	0,365	0,903	1,442	1,980	2,518	3,056	3,595	4,133
60,00	0,431	1,068	1,705	2,342	2,978	3,615	4,252	4,889

5.118 Total volume underbark

Rhodesia-Underbark (Prevôst 1971)

V=-.0208 + .0034D + .0024H - .0001628DD - .0001347HH - .00017134DH + .00002972DDH
+ .00001323DHH + .0000000161DDHH

	HEIGHT							
DIAMETER	5	10	15	20	25	30	35	40
10	0.015	0.033	0.052	0.070	0.088	0.106	0.124	0.142
15	0.028	0.065	0.106	0.151	0.198	0.250	0.304	0.362
20	0.040	0.104	0.176	0.254	0.339	0.431	0.529	0.635
25	0.051	0.150	0.260	0.379	0.508	0.649	0.799	0.960
30	0.062	0.202	0.357	0.525	0.708	0.904	1.114	1.338
35	0.071	0.261	0.469	0.694	0.936	1.196	1.473	1.768
40	0.080	0.328	0.596	0.885	1.195	1.526	1.878	2.251
45	0.089	0.400	0.736	1.097	1.482	1.892	2.327	2.786
50	0.097	0.480	0.892	1.331	1.800	2.296	2.821	3.375
55	0.104	0.566	1.061	1.588	2.147	2.737	3.360	4.015
60	0.110	0.660	1.245	1.866	2.523	3.216	3.944	4.709

5.131 Table

MALAWI PATULA STAND VOLUME TABLE - TOTAL VOLUME UNDERBARK PER HA.(CU.M)

V = 4.835+0.3936GH WHERE G IS THE BASAL AREA AND H THE DOMINANT HEIGHT

	DOMINANT HEIGHT(M)						
G/HA(SQ.M)	10,0	15,0	20,0	25,0	30,0	35,0	40,0
10,00	44,2	63,9	83,6	103,2	122,9	142,6	162,3
15,00	63,9	93,4	122,9	152,4	182,0	211,5	241,0
20,00	83,6	122,9	162,3	201,6	241,0	280,4	319,7
25,00	103,2	152,4	201,6	250,8	300,0	349,2	398,4
30,00	122,9	182,0	241,0	300,0	359,1	418,1	477,2
35,00	142,6	211,5	280,4	349,2	418,1	487,0	555,9
40,00	162,3	241,0	319,7	398,4	477,2	555,9	634,6
45,00	182,0	270,5	359,1	447,6	536,2	624,8	713,3
50,00	201,6	300,0	398,4	496,8	595,2	693,6	792,0
55,00	221,3	329,6	437,8	546,0	654,3	762,5	870,8
60,00	241,0	359,1	477,2	595,2	713,3	831,4	949,5

5.132 Table

KENYA PATULA STAND VOLUME TABLE - TOTAL VOLUME UNDERBARK PER HA.(CU.M)

V = 20.764-1.269G-1.3601H+0.2074GH WHERE G IS THE BASAL AREA AND H THE DOMINANT HEIGHT

	DOMINANT HEIGHT(M)							
G/HA(SQ.M)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
10.00	24.4	40.7	57.0	73.3	89.6	106.0	122.3	138.6
15.00	29.6	57.5	85.3	113.2	141.1	169.0	196.8	224.7
20.00	34.8	74.2	113.7	153.1	192.5	231.9	271.4	310.8
25.00	40.0	91.0	142.0	193.0	244.0	294.9	345.9	396.9
30.00	45.2	107.8	170.3	232.9	295.4	357.9	420.5	483.0
35.00	50.4	124.5	198.6	272.7	346.8	420.9	495.0	569.1
40.00	55.7	141.3	227.0	312.6	398.3	483.9	569.6	655.2
45.00	60.9	158.1	255.3	352.5	449.7	546.9	644.1	741.4
50.00	66.1	174.9	283.6	392.4	501.2	609.9	718.7	827.5
55.00	71.3	191.6	311.9	432.3	552.6	672.9	793.3	913.6
60.00	76.5	208.4	340.3	472.2	604.0	735.9	867.8	999.7

Appendix IV

FIGURE 5.31

Mean dominant heights for 4 countries

K = Kenya (Argyle, 1964)

M(A) = Malawi A type forests (Marshall + Foot, 1969)

M(B) = Malawi B type forests Table VII p. 32

*R = Rhodesia (Barrett + Mullin,1968)

*SA = South Africa (in Marshall and Foot, 1969 fig.4)

*Mean heights adjusted to dominant height using conversion tables in appendix IV.

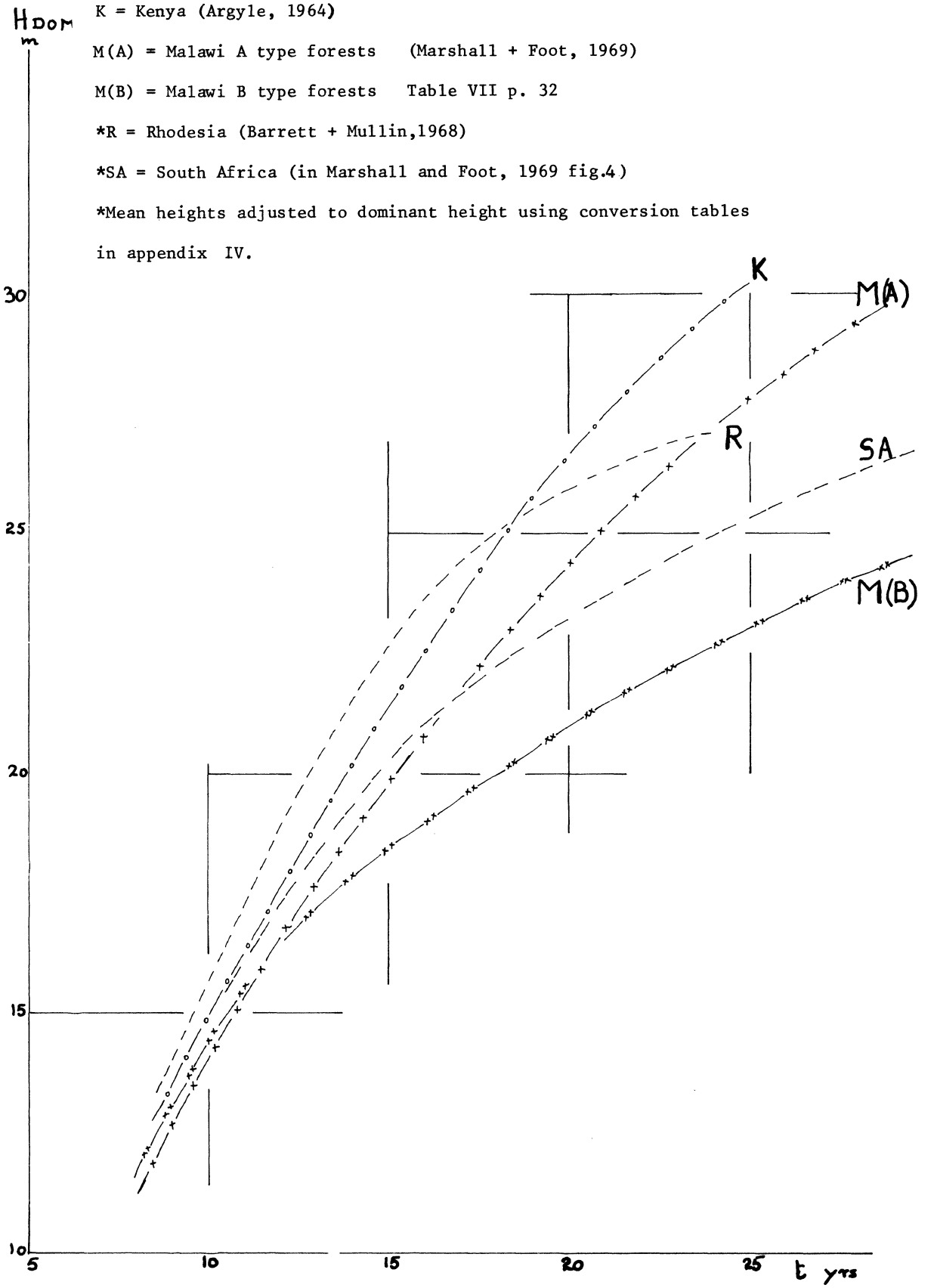


TABLE 5.32. VIPHYA PLATEAU PIN S PATULA YIELD TABLE
BASED ON UNTHINNED STANDS AT AVERAGE STOCKING DENSITY IN 1974
AND OLDER PSP FOR LIMITING BASAL AREA LEVELS

	AGE	6	8	10	11	12	13	14	15	16	18
YC	22										
	H	11.5	15.1	17.5	18.6	19.5	20.4	21.2	22.0	22.7	24.0
	G	21.6	32.3	39.5	42.7	45.4	46.8	48.0	49.4	50.2	51.8
	V	93.1	182.4	265.4	309.4	350.5	373.4	393.8	418.7	433.4	464.1
	i_v	15.5	22.8	26.5	28.1	29.2	28.7	28.1	27.9	27.1	25.8
YC	21										
	H	10.0	13.8	16.4	17.4	18.5	19.4	20.2	21.0	21.7	23.0
	G	17.2	28.5	36.2	39.2	42.4	39.0	44.8	45.4	46.2	47.6
	V	65.9	146.6	224.7	261.5	305.1	325.7	341.1	350.5	362.4	386.9
	i_v	11.0	18.3	22.5	24.1	24.5	25.0	24.4	23.4	22.7	21.5
YC	20										
	H	8.9	12.5	15.2	16.3	17.3	18.3	19.2	20.0	20.8	22.2
	G	13.9	24.6	32.6	35.9	38.9	40.5	41.7	42.7	43.6	45.1
	V	48.5	114.6	185.5	221.3	257.6	278.6	295.1	309.4	316.8	345.8
	i_v	8.1	14.3	18.5	20.1	21.5	21.4	21.1	20.6	19.8	19.2
YC	19										
	H	8.0	11.2	14.0	15.2	16.3	17.3	18.3	19.0	19.8	21.3
	G	11.3	20.8	29.0	32.6	35.9	38.0	39.4	40.4	41.4	43.1
	V	36.5	87.8	151.0	185.5	221.3	246.3	264.1	277.3	290.9	315.3
	i_v	6.1	11.0	15.1	16.9	18.4	18.9	18.9	18.5	18.2	17.5
YC	18										
	H	7.0	10.2	12.8	13.9	15.0	16.1	17.1	18.0	18.8	20.3
	G	8.3	17.8	25.5	28.8	32.0	34.9	36.5	37.8	38.9	40.9
	V	24.3	69.3	121.6	149.2	179.4	201.0	228.2	243.8	257.6	284.0
	i_v	4.0	8.7	12.2	13.6	15.0	16.2	16.3	16.2	16.1	15.8
YC	17										
	H	6.0	9.2	11.8	13.0	14.0	15.1	16.1	17.0	17.8	19.2
	G	5.3	14.8	22.5	26.1	29.1	32.3	33.8	35.4	36.6	38.5
	V	13.8	53.0	99.3	126.4	151.9	182.4	198.0	215.6	229.4	252.5
	i_v	2.3	6.6	9.9	11.5	12.6	14.0	14.2	14.4	14.3	14.0
YC	16										
	H	5.2	8.1	10.7	11.9	13.0	14.1	15.1	16.0	16.9	18.4
	G	3.0	11.6	19.3	22.8	26.1	29.4	31.0	32.6	34.2	36.4
	V	7.0	37.8	78.3	101.4	126.4	154.6	169.6	185.5	202.3	227.1
	i_v	1.2	4.7	7.8	9.2	10.5	11.9	12.1	12.4	12.6	12.6
YC	15										
	H	4.6	7.3	9.8	11.0	12.1	13.1	14.1	15.0	15.8	17.3
	G	1.2	9.2	16.6	20.2	23.4	26.4	29.3	31.0	32.0	32.5
	V	2.4	27.7	62.6	83.9	105.7	128.7	153.7	169.5	184.0	(182.5)
	i_v	0.4	3.5	6.3	7.6	8.8	9.9	10.9	11.3	11.5	(10.2)

5.33 Table. Yield table site index II
- Group A forests

(Marshall and Foot, 1969)

Volume in m^3/ha

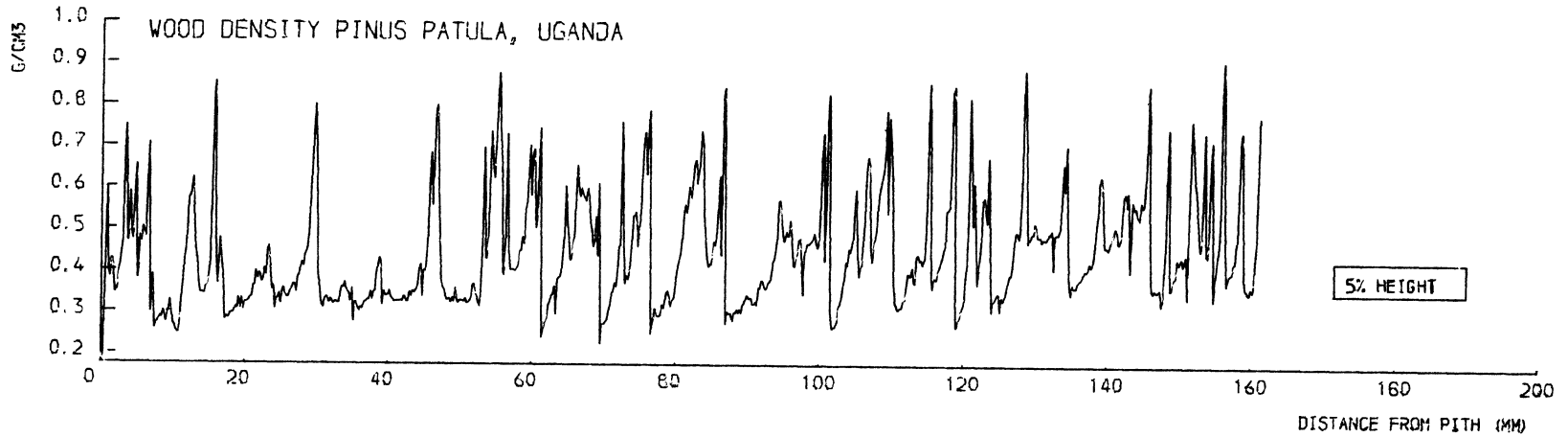
N st/ha \ t years	10	12	14	16	18	20	22	24	26	28	30
988	154	214									
927	147	206									
865	140	198	258	319	379						
803	133	189	247	307	365						
741	127	180	236	295	352	407	464				
680	118	170	224	281	337	391	446				
618	110	160	212	266	321	376	429	480			
556			200	252	305	356	406	455			
494			189	238	288	336	384	430	473	513	556
432					266	312	357	526	441	479	518
371					244	288	331	372	410	445	480
309							301	337	371	402	433
247							271	303	332	360	386

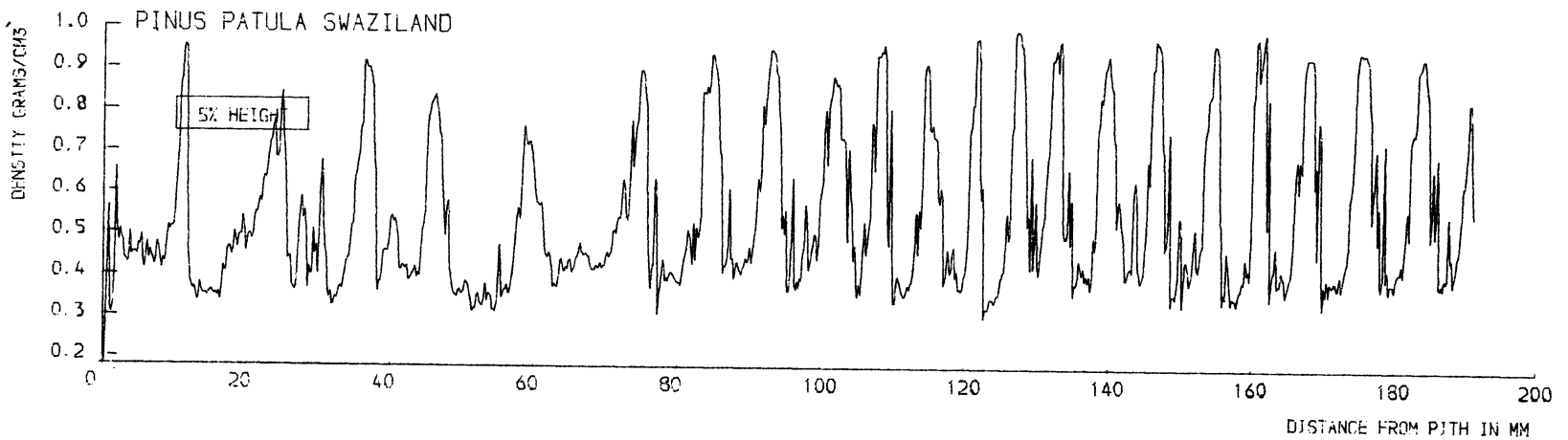
5.34 Table. Relation between dominant and mean height for a series of stocking classes (Marshall and Foot, 1969)

Dom. height (m)	Stocking Classes (Stems per ha)					
	988	865	741	618	494	371
	Mean height (m)					
12.1	11.0	11.0	11.0	11.1	11.1	
13.7	12.3	12.4	12.4	12.4	12.5	
15.2	13.7	13.7	13.8	14.0	14.2	
16.8	15.2	15.3	15.4	15.5	15.6	
18.3	16.6	16.8	16.9	17.0	17.2	17.5
19.8		18.3	18.4	18.5	18.7	19.0
21.3		19.7	19.8	20.0	20.3	20.6
22.9				21.5	21.8	22.2
24.4				23.0	23.5	31.9
25.9					25.1	26.4
27.4						27.1
29.0						28.8

Appendix V

Figure 6.214. Densitometer traces of Pinus patula from East and Southern Africa showing differences in pattern





6.42 Table : Mechanical properties of Pinus patula and similar timbers
(based on clear specimens at 12% moisture content)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Density g/cm^3			Modulus of Rupture (Static bending)			Modulus of Elasticity			Maximum crushing strength in compression parallel to grain			Side-grain hardness (Janka test)		
	Mean	S	SE	Mean	S	SE	Mean	S	SE	Mean	S	SE	Mean	S	SE
South African Pinus patula	0.497	0.061	0.005	73.57	11.89	1.07	11 039	2 517	228	40.96	7.74	0.70	2 758	725	71
Pinus elliottii	0.497	0.080	0.003	70.88	16.22	0.57	9 267	2 593	145	37.37	7.85	0.34	2 936	845	36
Pinus taeda	0.497	0.063	0.002	72.60	13.78	0.43	9 184	2 517	110	35.85	5.98	0.21	2 624	734	27
Pinus radiata	0.545	0.059	0.002	84.67	15.50	0.54	12 914	2 648	165	36.96	8.00	0.57	3 158	680	49
Cupressus species	0.481	0.030	0.005	72.95	10.35	1.65	8 598	1 448	234	41.78	4.90	1.55	2 936	338	62
Pinus sylvestris	0.481			77.22			9 791			43.85			2 447		

Note:

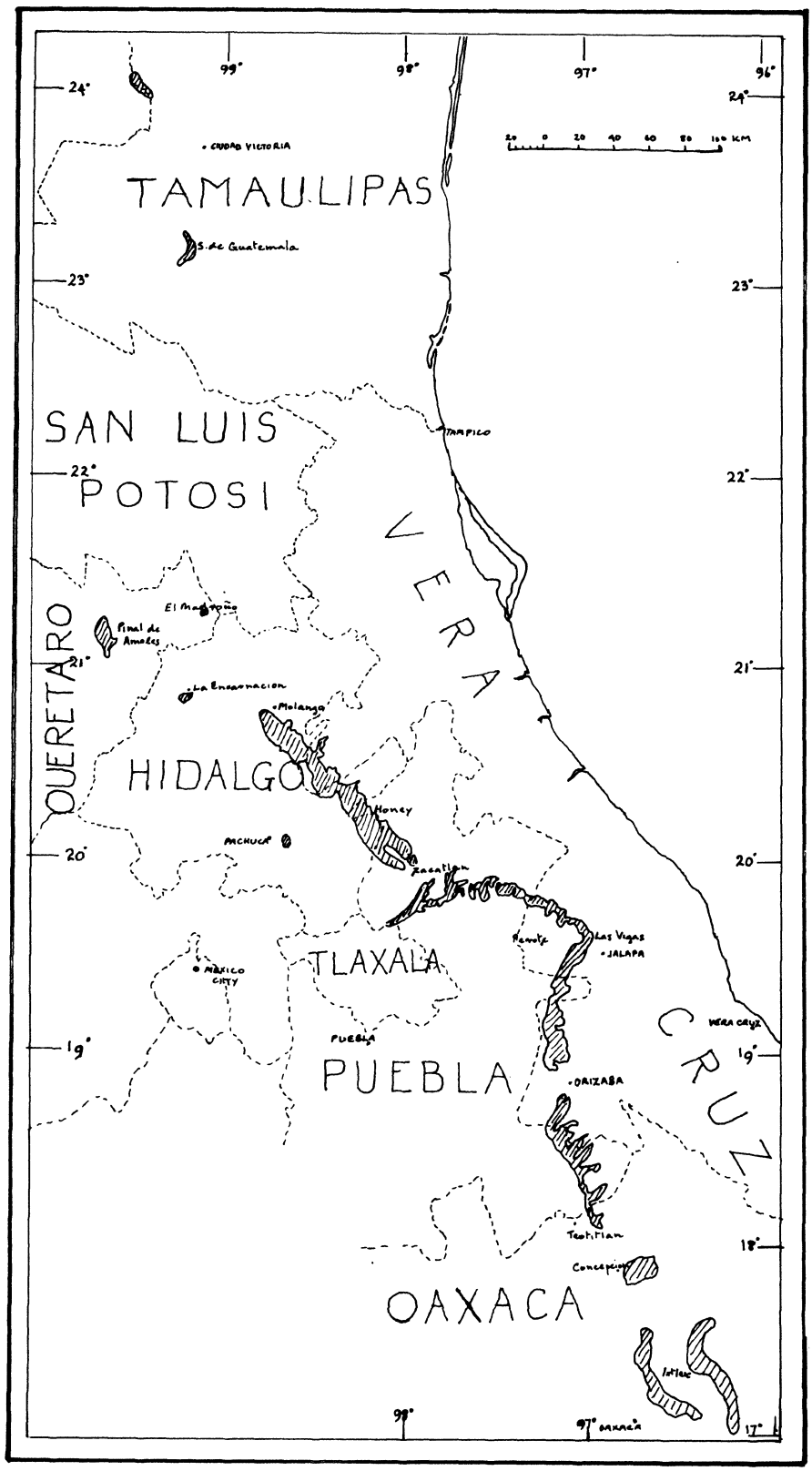
(a) Columns 5-13: Newtons (N) per square millimetre
(b) Columns 14-16: Force required to imbed a 0.44 inch (11.278 mm) steel ball to its mid-diameter in the wood, expressed in Newtons
(c) S - Standard deviation
(d) SE - Standard error of mean
(e) Table based on De Villiers and Perry (1973)

Table 6.211.1 Physical and Mechanical Properties of Pinus patula

Source of Test Information	Age of Trees	Basic density vol @ 12%mc	Modulus of Rupture	Modulus of Elasticity	Total work of fracture	Compression axial plane	Side hardness	Radial cleavage	Tangential cleavage	Radial Shrinkage	Tangential Shrinkage	Volumetric Shrinkage	Fibre length	Fibre widths	Remarks	Reference to source of date
	yrs.	g/cm^3	N/mm^2	N/mm^2	mm^N/mm^3	N/mm^2	N	N/mm width	N/mm width	%	%	%	mm	mm		
Angola (Chiguri)	15	0.488*	98.2			40.6	1 1.49	9.3	12.2	3 4.09	3 7.87	3 12.63	2 J=2.7 I=4.4 A=4.9		1 Chalais Merdou hardness test 2 J = juvenile wood I = intermediate wood A = adult wood 3 Shrinkage green to oven dry	IIAA (1973)
Kenya	17	0.401	58.0	8340		32.6	1750									Paterson (1961)
Madagascar	20	0.486	96.5	9318		37.8				3.2	8.8	13.9	3.6-4.2	0.047 to 0.062	Shrinkage green to oven dry	Tissot(1968) and Gueneau (1970)
South Africa	8 18 30 30	0.380* 0.496*	38.6 41.4 74.8 73.1			 30.3 29.7	 2400 2523									Scott(1953) Turnbull (1942) Turnbull (1942) Scott(1943)
Swaziland (Usutu)													2.5-2.7	0.057 to 0.064		Tissot(1968)
Tanzania	12 17 22 30 33	0.385 0.417 0.449 0.515 0.609	46.9 57.9 67.6 78.6 82.8	5860 6900 8140 9660 12760		27.6 33.1 33.7 44.8 50.3	1110 1470 1870 2580 -	8.0 9.7 10.5 12.1 -	12.9 12.1 13.3 14.1 -							Bryce(1967)
Uganda	12 20	0.369 0.426*	44.4 49.1	5931 6501	 0.068	29.4 34.1	1352 2047	- 5.02	- 6.83	- 1 2.83	- 1 3.92	 1 7.25	-	-	Pilot test on limited sample Sample from 400 positions in 20 trees. 1 Shrinkage green to 12% mc	Plumptre (1968 and 1972)

Note: 1 Unless otherwise stated all hardness tests were carried out by the Janka method
2 Sources of test information are referenced to the bibliography by the number against the source location.
3 Mean values only are given. Where Basic Density values are marked * information regarding variation around the mean is given in the original source.

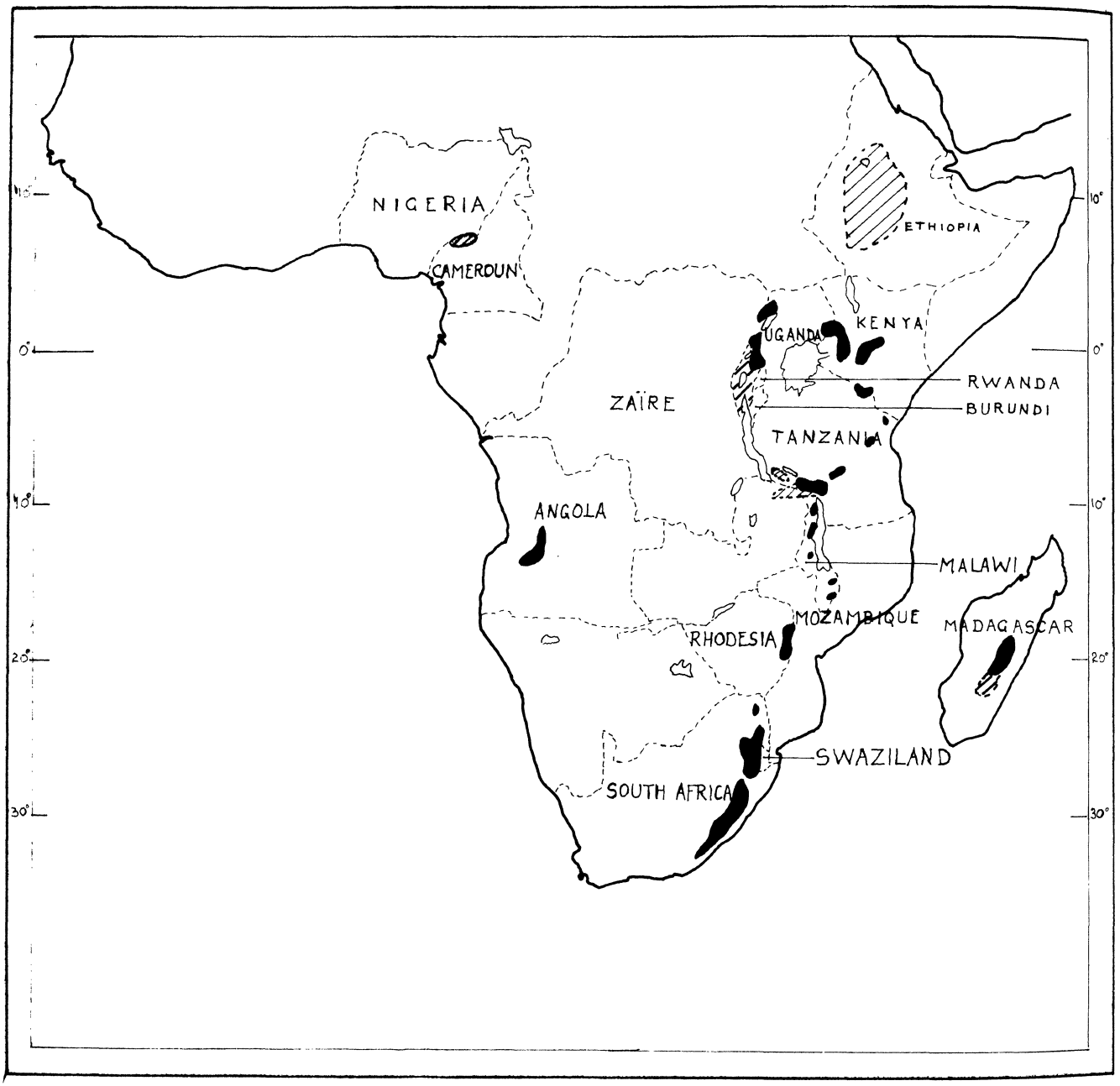
Appendix VI



MAP 1 Distribution of P. patula

in Mexico

(after Barrett, 1972)



MAP 2 Occurrence of P. patula

in Africa

Appendix VII

List of tree species referred to
with their authorities

Abies religiosa (H.B. and K.) Schlect and Cham.

Acacia mearnsii De Wild

Cupressus lusitanica Mill

C. macrocarpa Hartw.

Eucalyptus grandis (Hill) Maiden

E. saligna Sm.

Juniperus procera Hochst

Pinus attenuata Lemm.

P. ayacahuite Ehrenb.

P. brutia Ten.

P. caribaea var. bahamensis Barr. and Golf.

P. caribaea var. caribaea Mor.

P. caribaea var. hondurensis Barr. and Golf.

P. elliottii var. elliottii Engelm.

P. greggii Engelm.

P. kesiya Royle ex Gord.

P. lansonii Roezl.

P. leiophylla Schlect and Cham.

P. merkusii Jungh and de Vriese

P. michoacana Martínez

P. montezumae Lamb.

P. muricata D. Don.

P. pinaster Ait.

P. ponderosa Dougl.

P. pringlei Shaw

P. pseudostrobus Lindl.

P. radiata D. Don.

P. roxburghii Sarg.

P. rudis Endl.

P. strobus var. chiapensis Martínez

P. sylvestris L.

P. taeda L.

P. teocote Schlect and Cham.

P. yunnanensis Franch.

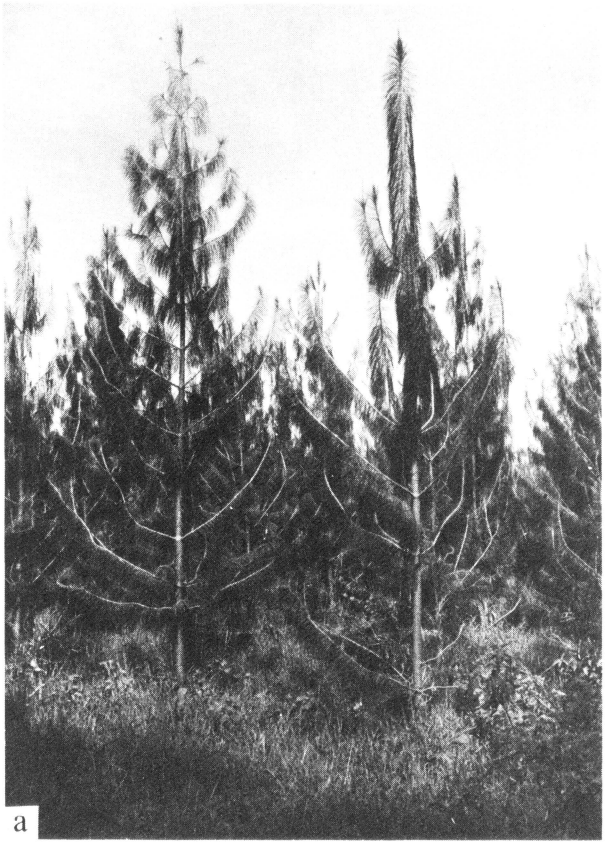
Podocarpus milanjianus Rendle

P. reichei Buchh and Gray

Taxus mexicana Senilis - now T. globosa Schlect.

Appendix VIII

Plates



a

b

c

Plate 1

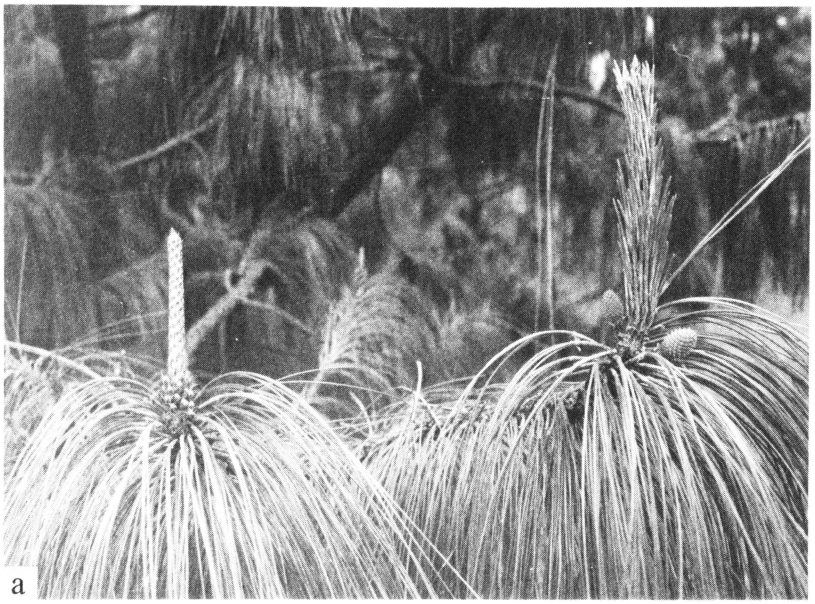
Form in young trees

a) Multinodal and uninodal branching contrasted on two trees at Turbo. The multinodal form on the left is preferable.

b) Turbo office. A thirty month old tree of good appearance, though the branch angle is rather high.

c) A heavy branched, wide crowned tree on the Viphya plateau.

Photos: T.J. Wormald 1974



a

Plate 2

New growth and cones

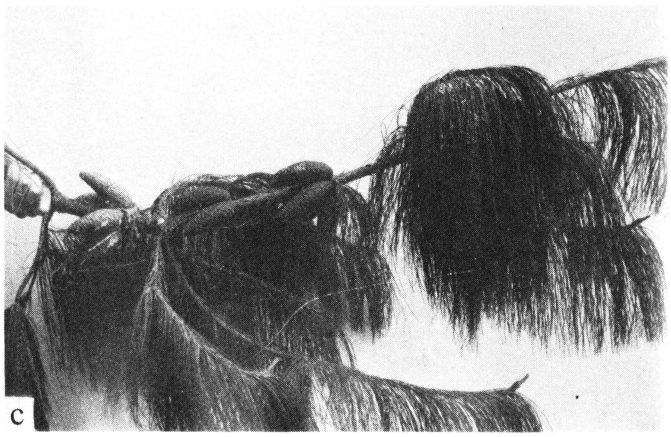
a) Flush of growth on a young tree on the Viphya plateau in May at the end of the rains. The needles have not yet burst their buds on the left hand branchlet. Note the conelets which are still erect, also the typical habit of the needles.

b) An older branchlet. The conelets have turned back to face down the stem.

c) Mature cones.

Photos: T.J. Wormald 1974

b



c

Plate 3

Afforestation with P. patula

A view over plantations near Sabie in the East Transvaal from Long Tom pass. The majority of these plantations are P. patula. Note the natural grass vegetation and the wide fire lines.

Photo: T.J. Wormald 1973

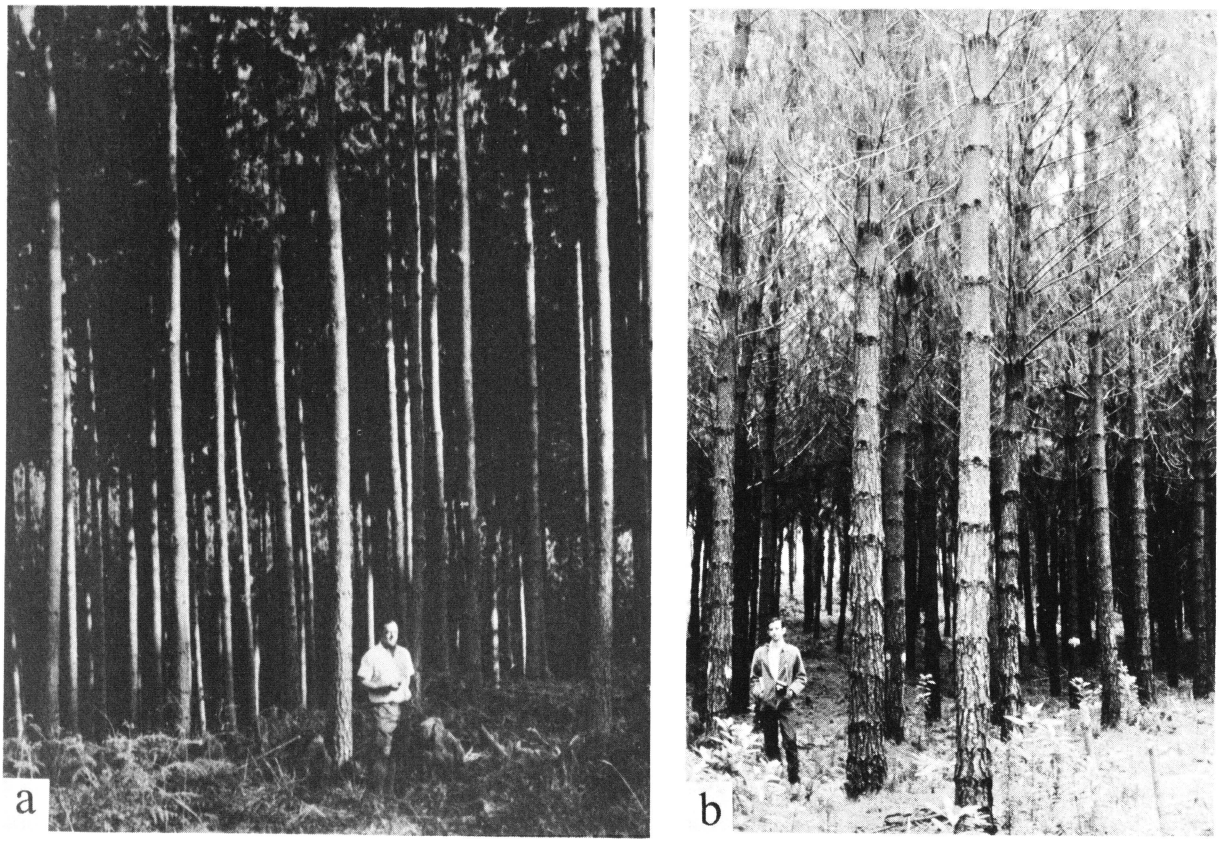


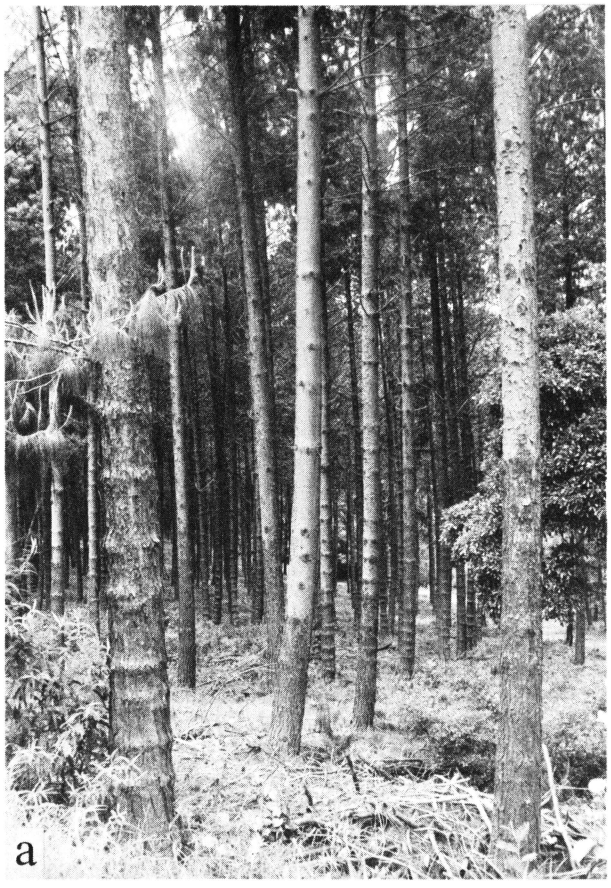
Plate 4

Growth in young plantations

a) A thirteen year old stand on Lionhills forest reserve, Rhodesia. Standing at 988 st/ha, all stems pruned to 6.7 m, a selected 50% pruned to 11 m. An estimate of stand height, judging from the pruned height of the tree on the left, is about 20 m. Photo: R.D. Barnes

b) An eleven year old stand on Fazenda Levantina, Camandicaia, Brazil. Stand height 22 m. Photo: L. Golfari

The growth in the Brazilian plantation appears to be faster but the form of the Rhodesian trees is better.



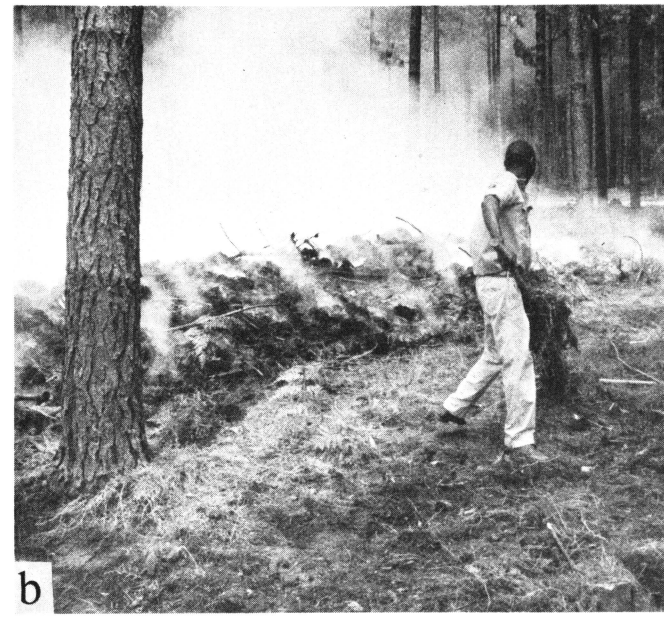


Plate 5

South African plantations

a) A plantation near Sabie, E. Transvaal showing variation in bark types.
b) Burning the needle mat in a plantation.
c) An example of bad nodal swelling. Note the seedlings on the needle mat.

Photos: T.J. Wormald 1973

a

b

Plate 6

Life and death

a) Deaths in a plantation at Turbo, Kenya from drought on a shallow soil over a laterite pan. Photo: P.J. Wood 1973

b) Natural regeneration after a windblow near Sabie. The wind damage is rather atypical here - windsnap at 3 to 6 m height is more usual. Photo: T.J. Wormald 1973

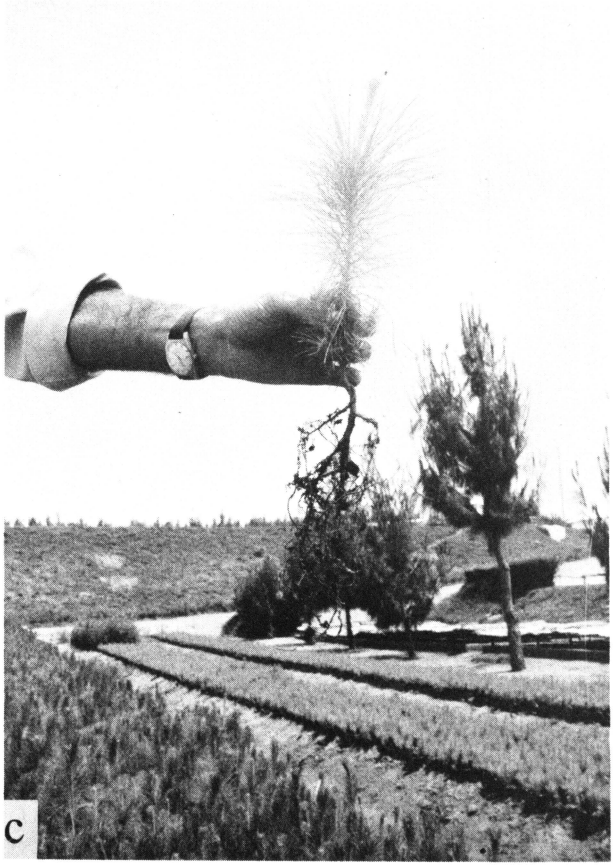


Plate 7

Nurseries 1

a) Recently pricked out seedlings. Department of Forestry nursery Tweefontein, South Africa. Note the wire mesh for hail protection.
b) Seedbed Cuima, Angola. Pricking out is delayed until plants are large. Compare with seedlings in plate 13.
c) A large tube raised plant, Cuima nursery. Note that root deformation has already started.

Photos: T.J. Wormald 1973

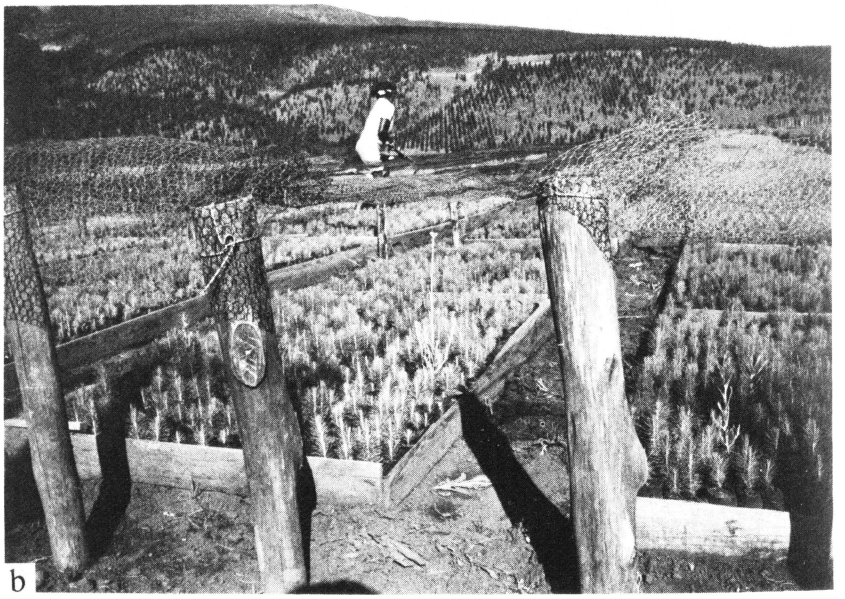
a

Plate 8

Nurseries 2

a) Plants raised in tubes Turbo, Kenya. These plants are 6½ months old and ready for planting. Note boards for keeping the plants in position, for protection from over heating and to facilitate root pruning.

b) Tubed plants Elandshoogte nursery, nearly ready for planting 6 months after pricking out. Each section holds sufficient plants for 1 acre. Note: wire netting hail protection. This is a low altitude nursery, the plantation in the back ground is P. elliottii.



b

c

c) Root pruning tubed plants using a taut wire, Turbo.

Photos: T.J. Wormald 1974

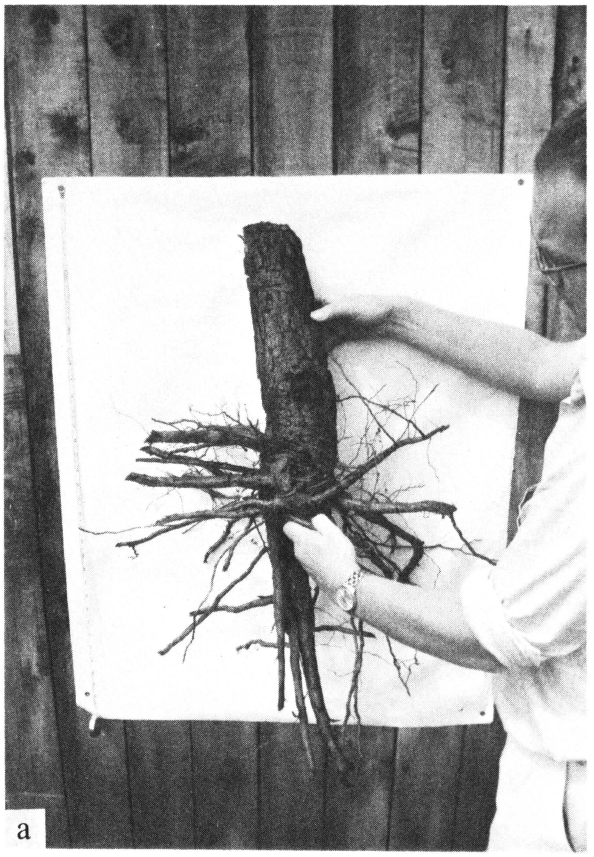


Plate 9

Root deformation

a) A stump showing deformed and spiralling roots. Turbo, Kenya.

b) A strangling root clearly visible on a five year old tree. Turbo.

c) Windblow attributed to deformed roots. Turbo.

Photos: T.J. Wormald 1974

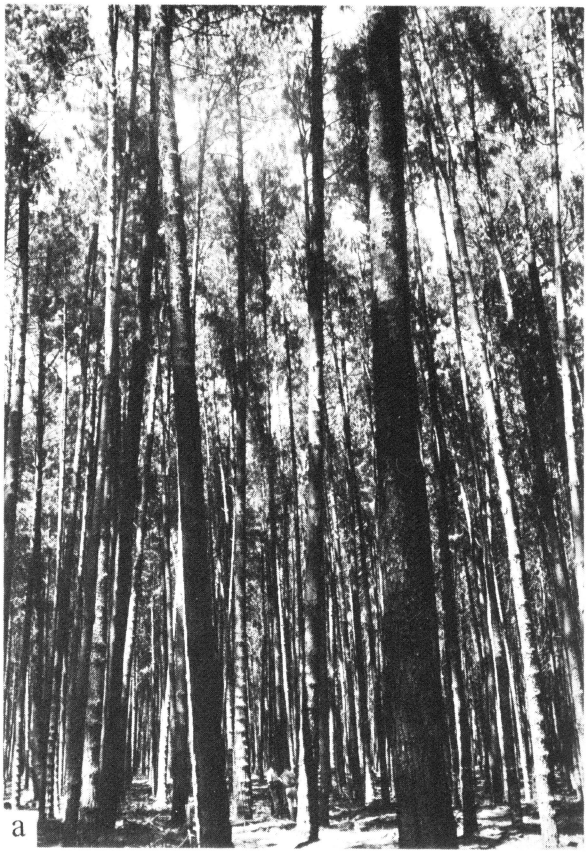


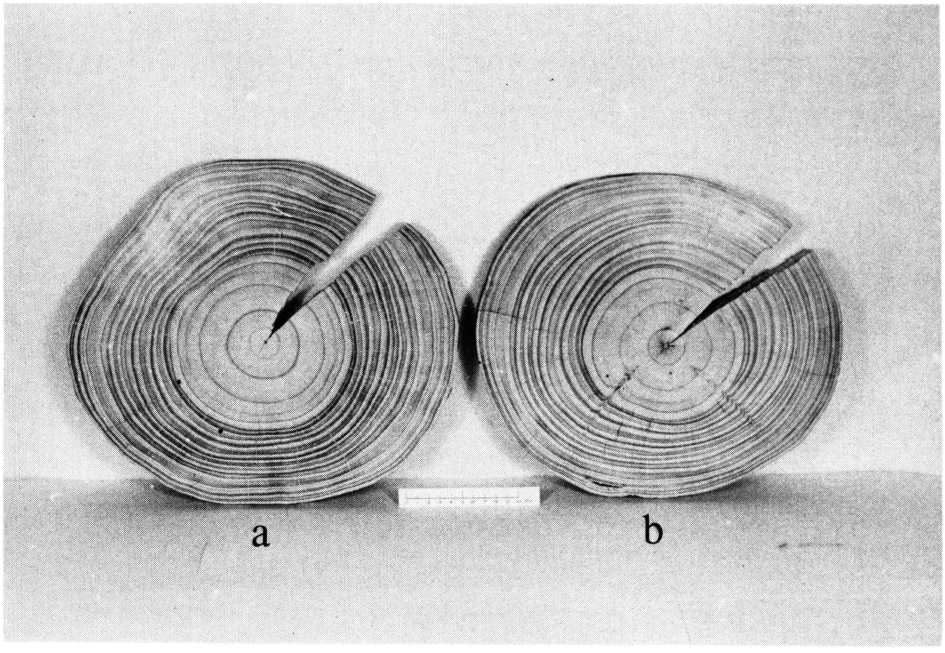
Plate 10

CCT plots - Mac-Mac, age 37 years

a) Standing at 902 st/ha. At age 36 $\bar{H}$ = 25.6 m, $\bar{d}$ = 25.1 cm, gross volume 707 m^3/ha

b) Standing at 111 st/ha. At age 36 $\bar{H}$ = 27.7 m, $\bar{d}$ = 56.1 cm, gross volume 384 m^3/ha.

Photos: T.J. Wormald 1973



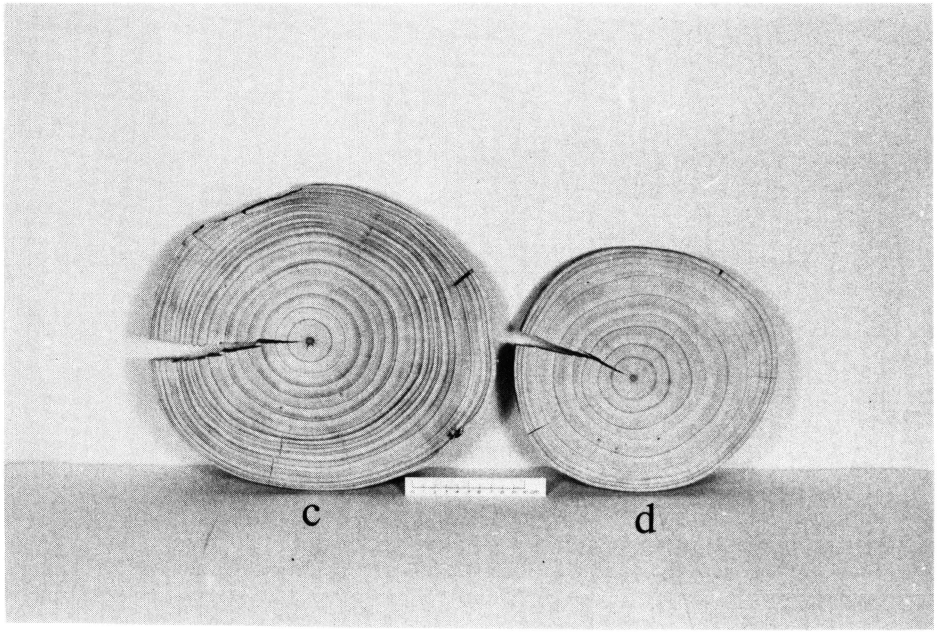


Plate 11

Variation in annual ring growth within a tree

Tree No. 10 from Rwoho, Uganda.

a) Disc taken from 5% height

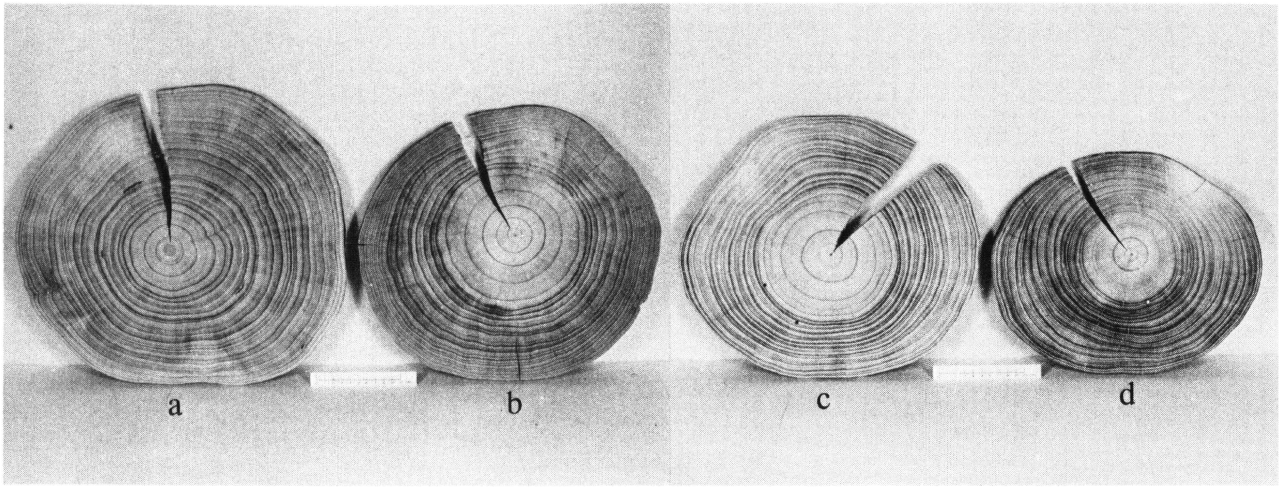
b) Disc taken from 15% height

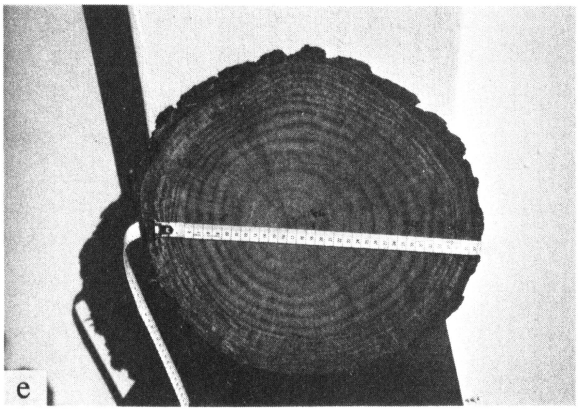
c) Disc taken from 35% height

d) Disc taken from 65% height

Note the more pronounced juvenile core at lower levels.

Photos: H.F. Woodward 1974





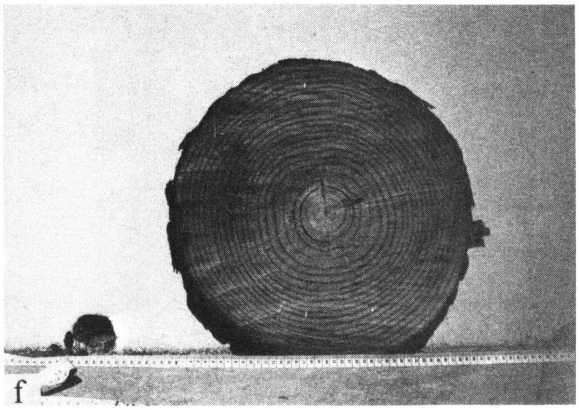


Plate 12

Variation in annual ring growth between sites			Age
a) Tree No. 16	Rwoho	Uganda	22
b) Tree No. 75	Rwoho	Uganda	22
c) Tree No. 10	Rwoho	Uganda	22
d) Tree No. 3	Lendu	Uganda	20

Photos: H.F. Woodward 1974

e) A disc from Cpt. 98 Chikangawa, Viphya plateau, Malawi. Age 17.

f) A disc from a 24 year old tree from Swaziland Plantations. Photos: T.J. Wormald 1974

Note how the latewood becomes progressively more clearly differentiated from the earlywood with an increase in latitude. Densitometer readings for tree L3 and the Swaziland tree are given in figure 3.512.11.

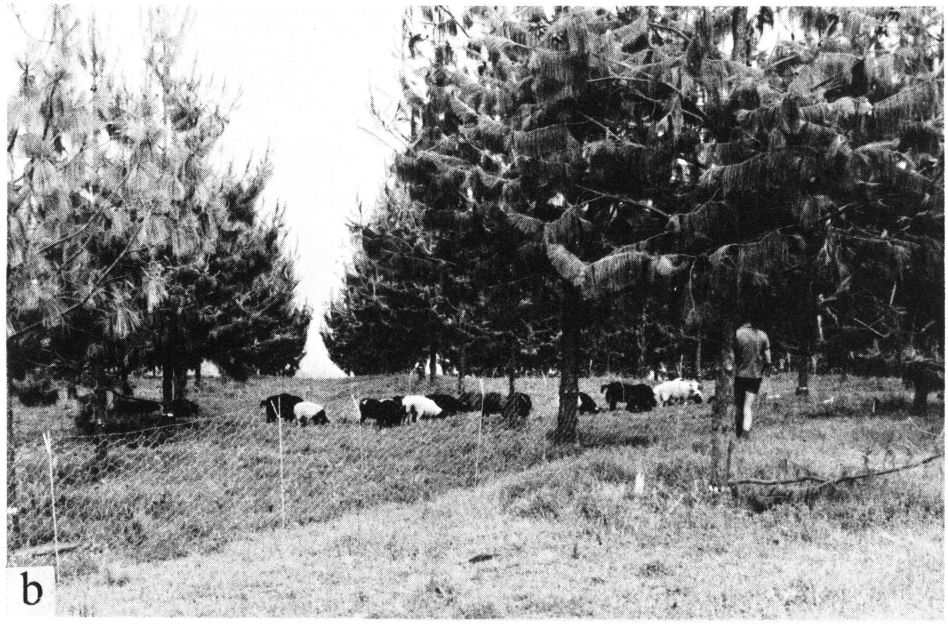


Plate 13

Tree breeding 1

a) Seedlings in the South African Forest Investments nursery, Sabie. Each box contains the progeny from one parent tree. All were sown at the same time. Note how family differences are already clearly visible. Photo: T.J. Wormald 1973

b) Clonal seed orchard, John Meikle Research Station, Rhodesia. Sheep grazing Richmond grass (Digitaria sp.) sward. The orchard is standing at 270 st/ha; productivity at 8 years of age is 8 kg full seed per hectare. Photo: R.D. Barnes

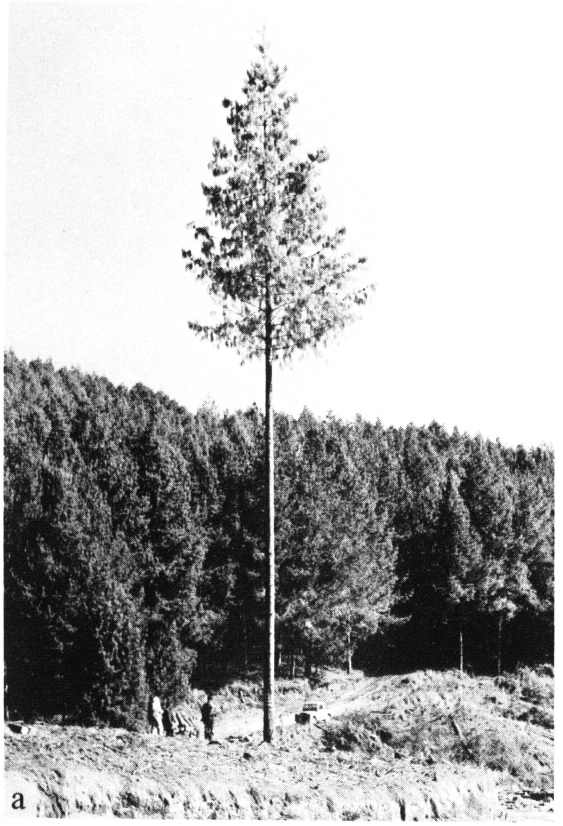


Plate 14

Tree breeding 2

a) Rhodesian plus tree No. 180.

Age: 17 years

Height: 27 m

Dbhob: 36 cm

Photo: L.J. Mullin

b) Progeny test Martin forest reserve, Rhodesia

Age: 6½ years

Spacing: 1.83 m

Left: progeny 24 x 18

Right: unselected commercial check.

Note the greater size and better form of the select progeny, though there is some evidence of Mendelian assortment. A second generation plus tree has since been selected in this progeny test from the cross 17 x 18.

Photo: R.D. Barnes