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African Mahogany Grown in Australia

– Wood quality and potential uses–

A report for the
RIRDC/L&WA/FWPRDC/MDBC
Joint Venture Agroforestry Program

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Foreword

This study evaluated wood quality from older age stands of African mahogany *Khaya senegalensis* grown in Northern Territory, Australia. Potential users of the timber were also surveyed to determine the wood qualities most valued. Based on log qualities, wood properties and potential uses, the report provides early advice on drying and processing needs, and those traits to select for in managing newer plantations. Such information will assist potential investors, producers and processors in growing and producing high value timber, to underpin a sawlog industry in the dry tropics of northern Australia. The opportunity to grow high value sawlogs in Australia's north provides alternatives to landholders and indigenous communities with large tracts of arable land who want to grow trees for commercial timber products.

The study indicated that Australian-grown plantation *K. senegalensis* produces an aesthetically pleasing timber with marketable colour and figure attributes. The wood appears suitable for a number of high value applications including cabinetry, interior joinery, windows, doors, and contempory and reproduction furniture. A number of issues may affect the profitability of converting plantation logs to high-value appearance grade timber, namely: wandering pith, the proportion of stem under heartwood at a young age, and the development of decay and stain. All the identified issues could be addressed through breeding and appropriate silvicultural management.

Based on the findings of this study of processing, use and wood quality properties, Australian plantation grown *K. senegalensis* has proven to be a prime candidate species for the 'dry' northern tropics of Australia.

This project was funded by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D Corporations — Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation (FWPRDC). The Murray-Darling Basin Commission (MDBC) also contributed to this project. The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

This report is an addition to RIRDC's diverse range of over 1600 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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Peter O'Brien
Managing Director
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Abbreviations

ADD	air-dry density
APAD	agar-plate accelerated decay
DBH	diameter at breast height
DBHOB	diameter at breast height over bark
DBIRD	Department of Business Industry Resource Development (now Department of Primary Industry Fisheries and Mining), Northern Territory
DPI&F	Department of Primary Industries and Fisheries, Queensland
EMC	estimated moisture content
GOS	green-off-saw
JD	joint strength group
MC	moisture content
MoE	Modulus of Elasticity
MoR	Modulus of Rupture
r	log radius
SED	small end diameter
SEDUB	Small end diameter under bark

Contents

Executive Summary

What the report is about

This study evaluated wood quality from older age stands of African mahogany *Khaya senegalensis* grown in Northern Territory, Australia. Potential users of the timber were also surveyed to determine the wood qualities most valued. Based on log qualities, wood properties and potential uses, the report provides early advice on drying and processing needs, and those traits to select for in managing newer plantations. It also evaluates the quality of the timber for high value uses. This information will assist potential investors, producers and processors in growing and producing high value timber, to underpin a saw log industry in the dry tropics of northern Australia. The opportunity to grow high value saw logs in Australia's north provides alternatives to landholders and indigenous communities with large tracts of arable land who want to grow trees for commercial timber products.

Who is the report targeted at?

The results gained during this study provide potential investors, producers and processors with concise and accurate information on plantation-grown *K. senegalensis* log qualities and wood properties, and its potential to produce high value timber in northern Australia. The opportunity to grow sawlogs in northern Australia will provide alternatives to landholders and indigenous communities wanting to grow trees for a commercial return. The research will also inform ongoing tree breeding work on this species being undertaken collaboratively in northern Australia.

Background

There is a scarcity of information on the wood properties and utilisation potential of plantation grown African mahogany (*Khaya senegalensis*). As there is renewed interest in *K. senegalensis* as a plantation candidate for the dry tropics of Australia it has become important to learn more about the species' potential to produce high-value products.

During 2003, the Northern Territory's Department of Business Industry Resource Development (DBIRD), in partnership with the Queensland Department of Primary Industries and Fisheries (DPI&F), initiated a wood processing and utilisation study to characterise Australian plantation-grown *K. senegalensis*. These researchers have also established a genetic improvement program, with the aim of producing superior genetic stock to underpin the establishment of new plantations – this breeding program builds from a provenance trial planted by CSIRO near Darwin, Northern Territory in 1972. Thirty-eight of the best trees (32-year-old) from the CSIRO provenance trial, harvested from two sites near Darwin, Gunn Point and Howard Springs, were selected for the wood evaluation and use study. This information is intended to inform wood processors and users, as well as the genetic improvement program. Clonal material was taken from each of these trees in order to preserve the available pool of genetic material.

Aims/Objectives

The broad objectives of this study were to assess processing, seasoning, wood quality and utilisation characteristics of the sampled trees, and use this information to characterise the 'potential' properties of future *K. senegalensis* plantations and to make direct inferences about the individual trees that were selected for the genetic improvement program.

The specific objectives were:

1) Gain a better understanding of post harvest handling and treatment of African mahogany to optimise timber qualities and utilisation potential
2) Obtain fundamental wood properties, sawn recovery rates and arrange industry assessments to determine suitable applications to enhance marketing potential of the timber
3) To provide investors and growers with more information about rotation lengths best suited to the species/environment interaction and the wood qualities at various stages and /or log classes

4) Provide preliminary information on the drying behaviour of plantation grown African mahogany. This preliminary information will form the basis of a recommended drying schedule.

Methods used

Two sites, Gunn Point and Howard Springs, from the CSIRO provenance trial of *K. senegalensis* planted in 1972 near Darwin, Northern Territory, were selected for the study.

Thirty eight trees were selected for assessment and harvesting: 25 from Gunn Point and 13 from Howard Springs. Tree selection was based on diameter at breast height (DBH), clear bole length and form, as well as a general visual assessment of tree vigour (health). Those trees with obvious defect or sweep were excluded.

Log measurements, assessment of processing characteristics and wood properties were undertaken on the 38 trees. An industry assessment to determine the use of African mahogany, quality and perceived benefits of using Australian grown African mahogony was also undertaken.

Results/Key findings

Due to a lack of better-managed older-age stands, the trees were sourced from a stand planted in 1972 with little subsequent silvicultural management. These trees provide useful information on wood qualities, that can be improved upon in new and future plantations. Merchantable log volume harvested from the two sites was 17 m^3, which equated to an average merchantable tree volume of 0.38 m^3. Poor log form, typical from plantations planted with unimproved planting stock and little silvicultural management, typified the logs. The logs exhibited low end-splitting, but did have moderate pith eccentricity. On average, 50% of log volume was under heartwood, a relatively low proportion for plantation grown hardwoods.

A number of the logs were very unstable during sawing causing movement of the flitches and cant. The logs were sawn into a wide variety of dimensioned boards, suitable for furniture type applications. In total, a green-off-saw (GOS) recovery of 39% was achieved. The boards were air-dried over summer (Brisbane, Queensland) for approximately 2½ months from green to 12%. The timber was dried very conservatively to avoid degrade. Seasoning trials on small batches kiln dried timber indicated that the timber was relatively easy to dry over a short time-frame with very little drying degrade. The boards were subsequently dressed and graded according to appearance product standards (AS2796). Grade recoveries (based on total log volume) ranged from 8.1% for the highest grade (Select) in the most demanding product category (Joinery), to 29% for the lowest grade (High Feature) in the least demanding product category (Flooring). The main causes of downgrade were: distortion, knot related defects, wane; and stain. Mean distortion values for spring, bow and twist were 18, 10 and 3 mm, respectively.

Australian grown plantation *K. senegalensis* produces an aesthetically pleasing timber with marketable colour and figure attributes. The wood appears to be suitable for clear-finished or stained high-value applications, such as contemporary and reproduction furniture, cabinetry, windows, doors, and interior joinery. The timber could be described as having a heartwood colour that is pink to red when freshly sawn which generally darkens to pinkish-brown to red-brown after prolonged exposure. The sapwwod is distinctively paler. The texture was medium to course and the grain variable from straight to interlocking. Average basic density was 637 kg/m^3. Unit shrinkage was 0.26% radially and 0.28% tangentially. The timber proved easy to glue with no glue bond failures being recorded. Average Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) was 8.3 Gpa and 81.7 Mpa, respectively. The timber proved to be ‘moderately hard’, in relation to resistance to indentation,with an average Janka hardness rating of 6.4 kN for seasoned timber. For Joint Strength Group the seasoned timber achieved Strength Group JD3 based on nail withdrawal and JD2 based on screw withdrawal. The timber proved naturally resistant to termite attack and highly resistant to decay when trialed in accelerated decay bioassays.

Based on the results of the industry assessment, the plantation trees proved to produce a good quality attractive timber that was judged equal to or better than the native African mahogany currently being imported into Australia (species unspecified). The timber was highly regarded by the various industry assessors who believed that there would be good prospects for the timber on the domestic market in the future, and could conservatively be retailed for between \$3000 and \$5500 per m^3 for dried, dressed Medium feature to Select grade timber.

Implications for relevant stakeholders

Based on the findings of this study, Australian plantation grown *K. senegalensis* has proven to be a prime candidate species for plantation in the 'dry' northern tropics of Australia. The lack of stand management and the flow on effect to log quality was the main negative factor found during the study. However, a *K. senegalensis* plantation planted with improved seed stock and managed according to best practice principles would significantly improve on the results published in this study.

Introduction and Background

There is a scarcity of information on the wood properties and utilisation potential of plantation grown African mahogany (*Khaya senegalensis*). As there is renewed interest in *K. senegalensis* as a plantation candidate for the dry tropics of Australia it has become important to learn more about the species' potential to produce high-value products.

The Governments of the Northern Territory and Queensland are committed to reducing the volume of timber sourced from unsustainable logging both in Australia and overseas. In line with this commitment, the further development of plantations in key areas has become a priority. To date it has been predominately pine and eucalypt species that have been planted. However, there is a need for other plantation species suitable for planting into a broader range of environments, and suitable for a broader range of products. Specifically, the need for suitable plantation species for the dry tropics has been identified, as large areas of both Queensland and the Northern Territory are encompassed within the dry tropics climatic zone.

Khaya senegalensis (African mahogany) has been identified as a potentially valuable plantation species suitable for commercial planting in the dry tropics of Australia. The species was probably first introduced into Australia as a street tree and in parkland plantings. CSIRO established the first plantation trials at sites near Darwin during the late 1950s. It was later included in mine rehabilitation programs established in Cape York during the early 1970s. More recently large-scale plantations have been proposed under the direction of Managed Investment Schemes (MIS). Farm forestry groups and state government organisations have also indicated an interest in *K. senegalensis* for plantations during recent years. However, to date little is known about the potential quality of Australian plantation-grown *K. senegalensis*, primarily due to the shortage of mature trees from which to assess the wood quality and utilisation characteristics.

During 2003 and 2004, the Northern Territory's Department of Business Industry Resource Development (DBIRD), in partnership with the Queensland Department of Primary Industries and Fisheries (DPI&F), initiated a processing and utilisation study to characterise Australian plantation-grown *K. senegalensis*. Building from a provenance trial of *K. senegalensis* planted by CSIRO near Darwin, Northern Territory, in 1972, a genetic improvement program is currently being established, with the aim to produce superior stock to underpin the establishment of plantations. Thirty-eight 32-year-old plantation-grown *K. senegalensis* trees, from the CSIRO trial, were selected for the wood characterisation study.

The broad objectives of this study were to assess processing, seasoning, wood quality and utilisation characteristics of the sampled trees to help characterise the 'potential' properties of future *K. senegalensis* plantations and to make direct inferences on the individual trees that have been selected for the genetic improvement program.

Specifically, the objectives were to:

1) Gain a better understanding of post harvest handling and treatment of African mahogany to optimise timber qualities and utilisation potential;
2) Obtain fundamental wood properties, sawn recovery rates and arrange industry assessments to determine suitable applications to enhance marketing potential of the timber;
3) Provide investors and growers with more information about rotation lengths best suited to the species/environment interaction and the wood qualities at various stages and /or log classes;
4) Provide preliminary information on the drying behaviour of plantation grown African mahogany. This preliminary information will form the basis of a recommended drying schedule.

The results gained during this study will assist in providing potential investors, producers and processors with concise and accurate information on *K. senegalensis* and its potential to produce high value timber. The opportunity to grow sawlogs in the north of Australia will provide alternatives to landholders and indigenous communities wanting to grow trees for a commercial return.

African mahogany the timber

The group of Meliaceous timbers under the trade name mahogany have long been regarded as premium quality woods for use in cabinetry and joinery applications. Mahoganies from South America (*Swietenia* spp) and Africa (*Khaya* spp) are well known in global timber markets and have been traded for centuries.

The trade name 'African mahogany' covers timber from several species of the genus *Khaya*, principally *K. ivorensis, K. anthotheca*, and to a lesser extent *K. nyasica, K. grandifoliola* and *K. senegalensis*. The term 'African mahogany' when used throughout this report refers to this group of species as a whole.

African mahogany came into general use in Europe towards the end of the 19th century to supplement the diminishing supplies of 'true' mahogany from tropical America. Though distinct, the timber is closely related anatomically to the American wood, and is today universally accepted as mahogany. The five 'African mahogany' species are predominately rainforest species and are widely distributed from Portuguese Guinea to Angola and from the Sudan to Mozambique. The nations on the west coast of Africa are the main exporters of mahogany. Europe and Asia are the main importers.

In the past, especially during the 70s, African mahogany was a highly fashionable timber in Europe. It is a wood of medium density and pleasant appearance, with the benefit of being stable and having good working properties. At the height of its popularity it was used extensively in the furniture industry for reproduction furniture, office desks, and cabinetwork. Other applications include:

- interior applications such as rails, shelf-lipping, divisions, cabinet interiors and drawer sides
- boat building, where it is suitable for almost all parts of a boat except steamed bent framing. It is used chiefly for planking, general joinery, keels, hogs, transoms, stems and many other items. For various applications it is commonly laminated, e.g. for stems and frames, and used in veneer form in the cold moulding process. The timber is particularly suitable for use in racing craft where weight is important.
- as a joinery timber for panelling, general interior joinery, mouldings, shells and internal fittings in vans, ambulances and caravans
- veneers
- other purposes where a good quality, medium weight hardwood is required (Farmer, 1972).

Currently, the international trade in mahogany from Africa is very limited. This is due in part to the increasing difficulty in sourcing natural-grown mahogany. Supply is limited due to over harvesting and political instability in several of the countries that have previously supplied large volumes. Trade to Europe has also greatly diminished due to changing trends in timber colour preferences. Lighter coloured timbers are currently in demand as opposed to red and brown timbers.

Given the global demand for good quality joinery and furniture timbers, such as *K. senegalensis*, investigations into its suitability for industrial plantations have, or are, being undertaken across several countries in the dry tropics, both on the African continent and elsewhere around the world, although information is very limited.

Materials and Methods

Location and site details

Two sites, Gunn Point and Howard Springs, from the CSIRO provenance trial of *K. senegalensis* planted in 1972 near Darwin, Northern Territory, were selected for the study. Location details are outlined in Table 1.

Gunn Point

Gunn Point was created as Forestry Reserve in the 1950s and was initially planted with *Calitris intratropica* (northern cypress) and subsequently with *Pinus caribaea* (Caribbean pine). A series of *K. senegalensis* provenance trials were planted in the early 1970s prior to cyclone Tracy, which occurred in December 1974. After planting, the trials received little or no maintenance. A prison farm established in the region was responsible for fire control and site management. Removal of some of the best trees occurred in the mid 80s when the trees were approximately 15–17 years old. The trees were felled by prison inmates for woodworking activities. The Experimental Plots were established over three successive seasons during 1970–71 to 1972–73 and were made up of variable numbers of provenances. Trials comprised plots of 49 trees (7 rows x 7 trees with trees spaced at 3 m x 3 m) in randomised complete block designs with two to four replications. Although provenances are documented by country of origin and an identification number, in most cases there are no records available of precise origins of the seed, nor of numbers of parent trees represented in the collections (Nikles, 2004). Site details are outlined in Table 2.

Howard Springs

Howard springs is approximately 15 km from the Berrimbah DBIRD office and was previously the former Forest Bureau's reserve for trials of a range of hardwood and softwood species. The original clearing of the site took place in the 1960s. The *K. senegalensis* trial site required the removal of natural regeneration and exotic invaders from previous trials. The majority of work undertaken at this site with *K. senegalensis* was to investigate propagation methods, appropriate levels of nutrition, stock type, provenance variation and spacing trials (Cameron, 1985). Most, if not all, the trees planted at the Howard Springs site, were from the Senegal provenance, D417. Site details are outlined in Table 2.

Table 1. Location details of the *K. senegalensis* plantations

	Gunn Point	Howard Springs
Location	33 km NE of Darwin off Gunn Point Rd	20 km SE of Darwin off Gunn Point Rd
Latitude/Longitude	12º41´S / 131º07´	12º28´S / 131º02´
AMG Coordinates	8640600N 721800E	8620500N 721500E

Table 2: Site details

	Gunn Point	Howard Springs
Previous Vegetation	Open mixed eucalypt woodland with predominant species being *Eucalyptus tetrodonta* and *E. miniata*	
Soil	Gravely massive earths, shallow to moderately deep	
Slope	Slight slope of 1:100 from NE to SW	Nil
Elevation	40 m.a.s.l.	10–15 m.a.s.l.
Rainfall	1800–2000 (60 year av.)	1900–2040 mm (60 year av.)

Tree Selection and Log Measurements

Tree Selection

In consultation with colleagues from the Genetics Group, Forest Technologies Program at QDPI&F, 38 trees were selected for assessment and harvesting: 25 from Gunn Point and 13 from Howard Springs. Tree selection was based on diameter at breast height (DBH), clear bole length and form, as well as a general visual assessment of tree vigour (health). Those trees with obvious defect, or sweep were excluded. Appendix A details individual tree data for the selected trees. The aim of the tree selection process was to select trees that were considered typical of the envisaged future resource.

Harvesting, Storage and Transport

Each tree was felled and merchandised into one or two logs (merchandised logs) of variable log length. The maximum and minimum merchantable log length was set at 6 and 3 m, respectively, due to transport and processing constraints. The bark was not removed from the logs.

The logs from Gunn Point retained their respective original tree number[1] and the Howard Springs trees, which did not have an original tree number, were numbered from 1–14 with 'H' as a prefix (signifying Howard Springs). Long logs from both sites were cut into two logs due to transport restrictions. In these instances the two logs were labelled with either an 'A', indicating a butt log, or a 'B', indicating a top log. All assessments throughout the study treated 'A' and 'B' logs as one log. Log numbers were scribed on the end face of each log. Each log was also tagged to ensure accurate tracking of identity during transport.

After numbering, each end face was painted with an emulsion wax sealant to minimise log end-splitting due to rapid moisture loss during transport.

Harvesting was undertaken over two weeks in October 2003. The logs were transported to Darwin where they were stored, exposed to the elements, for six weeks before being transported by truck (covered) to Queensland DPI&F's research mill at Salisbury, Brisbane. The logs were stored for a further week before processing in mid-December.

Log Volume

Log volumes were calculated using Smalian's formula. Smalian's formula uses large and small end diameters (under-bark) and log length for volume calculation. This method commonly results in a 2-3% overestimation of log volume, which disfavours sawn recovery figures, but ensures conservative baseline figures are calculated.

Log volumes were determined for all merchandised logs, and expressed in cubic metres (m^3).

Log End-split

Upon arrival in Brisbane a 40 mm disc was cut from each end of each log, labelled and stored for wood properties analyses. Seventy-two hours after disc removal, log end-splits were scored using a method developed by Knapp et al. (2000). This method assigns a point value to each split based on its radial and tangential development. For non-radial splits, 1 point is assigned per every half radius length. For each radial split, points are assigned for length along a gradient of 0 for no split to 2 for full radius splits (i.e. ½ radius = 1 and ¾ radius = 1.5), plus 1 point for each millimetre of peripheral opening of the split. As an example, a log with two ½ radius splits (0.5 + 0.5), with peripheral openings of 2 and 5 mm (2 + 5) respectively would be scored as 8. Splitting scores do not have to be corrected for log diameter, as it is a relative score.

[1] Original tree numbers were assigned at the time of planting, and allow the retention of provenance and other data for each tree.

Pith Eccentricity

From the discs cut from each end of each log, pith eccentricity (offset) was measured as the distance of the pith from the approximate true centre of the disc, and expressed as a percentage of the disc diameter. Pith eccentricity was averaged across the two discs from each log to give a 'log' value.

Heartwood/Sapwood Proportion

From the discs cut from each end of each log, heartwood/sapwood proportions were measured. The heartwood/sapwood boundary is clearly demarcated in *K. senegalensis* by a change in colour. As such, a visual assessment of the transition point was made without the aid of using a demarcation chemical reagent or examination of anatomical elements.

Heartwood/sapwood proportion was measured on the four axi of the disc and expressed as a percentage of the disc radius. The results from four axi of each disc were averaged and then averaged again across the two discs from each log to give a single 'log' value.

Processing

Sawing

All logs were sawn at Queensland DPI&F's research mill, on a single blade (circular) Kara saw (Plate 1). The logs were sawn into a wide variety of dimensioned boards. However, to ensure that an accurate assessment of natural defects could be made during grading, approximately half of the volume of sawn material was 25 or 12 mm thick, exposing a high proportion of the log volume and the defects contained therein. Movement of the cant and flitches, caused by the release of stresses within the log during sawing, created difficulties for sawing. In an effort to balance the release of stresses during sawing each log was turned several times during breakdown. This method of sawing is based on the principle of 'balanced tangential sawing', which loosely states that when even amounts of wood are removed from opposing sides of the pith, stress release is balanced, and therefore excessive movement and bending of the cant is avoided. This sawing strategy is typically used in the processing of hardwoods that are known to have high levels of stresses. Each board was scribed with its respective log number for tracking.

Plate 1. Queensland DPI&F's Kara saw processing a *K. senegalensis* log

Green-Off-Saw (GOS) Tally

The nominal dimensions (length, width and thickness) of the green boards were recorded to calculate GOS volume, in line with standard industry practice. Excessive wane and other defects significantly affecting the structural integrity of the board were docked out prior to GOS recovery calculations.

GOS recovery was calculated by dividing GOS volume (m^3) by merchandised log volume (m^3), and expressed as a percentage.

Seasoning

Boards were stripped out using 20 x 20 mm seasoned pine stickers spaced at 450 mm centres. Boxed-end stacks were weighted with concrete blocks. The timber was air-dried, under hessian, for 2½ months (January – March 2004) in an air-dry shed before final drying in the Queensland DPI&F solar kiln for two weeks. The average final moisture content of the timber was 10.3%. As DPI&F had not seasoned *K. senegalensis* timber previously, a very conservative approach was taken to drying conditions and speed in order to minimise any potential drying defects occurring.

Seasoning trials

Seasoning trials were conducted to allow the development of suitable drying parameters.

A representative sample of 10 boards from each charge was used to measure the occurrence of checking, distortion and collapse during drying. The report on the drying and seasoning trials is attached as Appendix B.

Dried and Dressed Graded Recovery

All boards were assessed for dried and dressed appearance grade quality in accordance with AS2796:1999 – Timber – Hardwood Sawn and Milled Products. The timber was graded on all faces to a minimum graded length of 300 mm (i.e. the minimum length timber within a board, of a specific grade, that was recorded is 300 mm). Re-sawing was allowed to 50 mm.

From this data, recovery figures were calculated and incidence of downgrade summarised, based on High Feature, Medium Feature and Select grades for Flooring and Joinery product categories.

Dried and dressed recovery was calculated by dividing grade volume (m^3) of sawn boards (in nominal dimensions) by merchandised log volume, and expressed as a percentage. All grades were considered independent of each other.

Wood Properties

Wood properties were determined on samples taken from either sawn boards or discs. Care was taken to ensure that each tree was represented (equally when possible) when sampling for wood property testing.

Those samples cut from boards were selected based on:

- a position approximating breast height (1.3 m), unless otherwise stated
- no sapwood
- away from the heart, based on end-section growth rings.

Colour and Grain Assessment

The colour and grain assessment was written in accordance with Bootle's (1983) 'Wood in Australia – Types, properties and uses', qualitative assessment of texture, grain, figure and colour.

Random samples of seasoned boards were removed from packs of the project timber and inspected on site at the Salisbury Research Centre. Subjective descriptions for colour, texture, grain and figure were recorded. Additionally, a *K. senegalensis* coffee table, commissioned during the project, was evaluated and incorporated in the descriptions.

Density

Density was assessed on segmented wedges cut from discs taken from each end of each log (longitudinal sampling). Wood, and corresponding density, at the base of trees can be abnormal; however, in the case of the project trees average stump height was 38 cm, with a minimum height of 24 cm, thereby avoiding any abnormal wood.

From the sampled discs each wedge was sectioned into four pieces (sap, outer heartwood, mid-heartwood and inner heartwood) to allow the basic density graduation from pith to bark to be assessed.

Basic densities were assessed on the samples used for shrinkage assessment (board samples). Densities were assessed in accordance with AS/NZS 1080.3:1981 Timber – Methods of Testing Timber – Determination of Density.

Shrinkage and Unit Shrinkage

Shrinkage (green to air dry) and Unit Shrinkage were measured in accordance with DPI&F's internal procedure, which is based on Kingston and Risdon's (1961) technical paper 'Shrinkage and Density of Australian and other South-west Pacific Woods'. Shrinkage and Unit Shrinkage was assessed on 38 samples, one from each of the project trees.

Glue-ability

The glue-ability of the project timber was tested using the block shear test (Plate 2) and the cleavage test (Plate 3) in accordance with AS/NZS 1328: 1998.

Randomly selected seasoned boards were cut to produce one 100 x 19 x 230 mm gluing sample, and two 100 x 19 x 25 mm moisture content (MC) samples. The MC samples were cut adjacent to each end of the glue sample. Final dressing to thickness was left until just before gluing.

The glue samples were split at random into three groups of 10. Each group of 10 boards were allocated, again at random, into five pairs of boards, which were then glued together, giving five glued assemblies.

The chosen glue was AV Syntec type AV201 resin with SN dry powder hardener. This is a Urea Formaldehyde (UF) adhesive. The adhesive was recently purchased, and was well within the recommended shelf life of six months.

All glue preparation, application and pressing was conducted in an environment controlled laboratory at a temperature of 25^{o}C. Care was taken to ensure that the gluing process conformed with the manufacturer's recommendations on mix ratio, pot life, open and closed assembly times, clamp time and cure time.

Glue was mixed in batches of 100 g in a mix ratio of 10 parts resin to 1 part hardener by weight. Glue mix was applied to one member of each glued assembly by weight, in order to achieve a spread of glue close to the value recommended by the manufacturer. After spreading over the surface, the two boards were brought together and placed in an Amsler (universal) testing machine for pressing. Five glued assemblies were stacked into a pile to create a lay-up ready for pressing (Plate 4).

Plate 2: Shear test samples

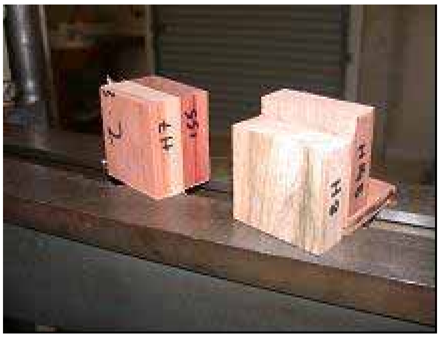


Plate 3: Cleavage samples

Plate 4: Glue press lay-up

Thick steel plates were placed above and below the stack to ensure even transfer of pressure. A pressure of 23 Mpa was applied to the stack, giving the recommended pressure of 1 Mpa to each glue-line. Using the Amsler's automatic load maintainer, load was maintained for five hours, the recommended clamp time for gluing at 25^{o}C.

Three gluing runs were conducted, producing 15 sets of glued assemblies.

Glued assemblies were allowed to condition for a minimum of 24 hours after removal from the press. Test pieces were then cut as shown in Figure 1.

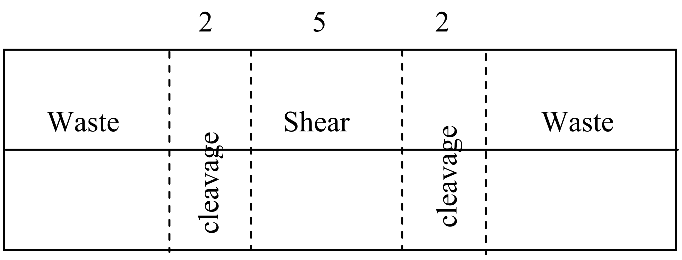


Figure 1. Glue sample allocation

Modulus of Elasticity (MoE) and Modulus of Rupture (MoR)

MoE and MoR from small clears were measured in accordance with the JJ Mack Australian Method[2] which is based on BS 373:1957 – Methods of Testing Small Clear Specimens of Timber.

MoE and MoR were calculated from two samples from each tree (76 samples in total).

Janka Hardness

Janka hardness was measured in accordance with the JJ Mack Australian Method[3] which is based on BS 373:1957 – Methods of Testing Small Clear Specimens of Timber.

Janka hardness was assessed on 38 samples, one from each of the project trees.

Joint Strength Group Testing

The joint strength group (JD) rating of khaya timber was allocated using the nail and screw withdrawal method specified in AS 1649 – 2001.

Seasoned khaya boards were cut to produce two 55 x 25 x 150 mm JD samples, and two 100 x 19 x 25 mm MC samples. The MC samples were cut adjacent to each end of the JD sample.

The two JD samples from each board were split at random into two groups of 10. The identity of each board was maintained throughout the process. Each group of samples was prepared for either a nail or screw withdrawal test. The nail withdrawal tests used Plain shank, flat head nails, 2.8 x 40 mm. The screw withdrawal test used No. 10 x 20 mm wood screws. Two nail or screws withdrawals were undertaken on the radial and tangential faces of each sample.

Joint strength group testing was assessed on 38 samples, one from each of the project trees.

Durability Assessment

Durability was assessed by exposure to termites and from an accelerated decay bioassay trial.

A single 20 x 20 x 100 block of timber from each of the project trees (38 in total) was exposed to the termite *Coptotermes acinaciformis* in aggregation bins for 2½ months, along with pine feeder bloc *K. senegalensis*. Resistance is quantified by weight loss. This type of assessment is only meant as a guide to project timber's resistance to termites.

Accelerated decay bioassay is a rapid laboratory method that may be used to gain an indication of a timber's relative decay resistance. The report on the accelerated decay bioassay is attached as Appendix C.

Industry Assessment

Two types of questionnaires were used – a Survey Questionnaire for potential users of the timber, and an Assessment Questionnaire for those who had already used the timber and were willing to assess timber samples.

A list of products was compiled based on the current use of African mahogany in Europe. From this list it was decided to focus on three main industry sectors in Australia: Furniture/Joinery, Veneer and Instruments. Manufacturers of these products in Queensland, New South Wales and Victoria were identified and asked to complete a Survey questionnaire. The survey questionnaire was limited to the

[2] Mack, J.J. 1979 Australian Methods for Mechanical Testing Small Clear Specimens of Timber. Division of Forest Products Technological Paper No.31, CSIRO, Melbourne

states of New South Wales, Queensland and Victoria, because these States represent a significant proportion of the Australia's manufacturing sector, 70 per cent of sawmills, and are the three largest states in terms of economy and population.

The choice of companies was a function of the first two criteria. Companies that the Queensland DPI&F Innovative Forest Products Program had had successful working relationship within the past were specifically targeted. A total of 23 companies was selected. Merchants and timber importers were also surveyed due to their knowledge of import-export markets and the quality of African mahogany currently being imported. For the purpose of the exercise only the term African mahogany was used, not the scientific names of the various species that are traded under the term.

An introductory letter, setting the context, aim and objectives of the project, was sent with the Survey questionnaire. The questionnaire dealt with the company's history in relation to the use of African mahogany and the company's current manufacturing details. One furniture manufacturer was interviewed in person. The survey included questions on:

- current and past use of imported African mahogany
- current volumes
- products
- quality of the imported timber
- prices, wholesale or retail
- would the company perceive any benefit in using Australian plantation sourced African mahogany

For those companies that were using African mahogany, or had in the past, an Assessment questionnaire was sent as well as a request to assess the project timber. The assessment questionnaire requested further information on the company's experience with the timber, including volumes and prices. A small hand sample of the project timber was also sent.

A parcel of timber was delivered to the companies that agreed to assess the timber.

Examples of the Survey and Assessment questionnaires and a list of the responsive companies are attached as Appendix D.

Results and Discussion

Tree Selection and Log Measurement

Tree Selection

Thirty-eight trees were selected for assessment and harvesting, 26 from Gunn Point and 12 from Howard Springs. The trees, while not all ideal sawlog trees, were selected as being 'typical' of those that would be harvested from a well managed plantation. A lack of silvicultural management had a significant effect on the stands, with a large number of trees being of a small diameter and poor form. In order to select trees with an adequate diameter for processing a number of trees close to the edge of the plots were included in the selection. Edge trees are not ideal for research purposes as they may have non-typical growth, form and wood properties.

Harvesting and Storage

The selected trees were solid through to the pith, reducing the difficulties encountered when felling trees with pipe and associated mud (Plate 5). The average stump height of 0.4 m (Appendix A) was slightly high. In normal practice trees are typically felled with a high stump height on steep slopes or to avoid pipe and other internal defects that are more severe closer to ground level. Given the solidness of the selected trees, commercial cutters would most likely fell such trees closer to ground level, therby increasing log volume.

Best practice for log storage (Nolan et al, 2003) recommends immediate processing (no storage) or minimal storage time. In practice sawmills attempt to store logs for no longer than four weeks. The *K. senegalensis* logs were stored (including being transported) for between six to eight weeks depending on the date of felling (Plate 6). However, the typical defects associated with long storage periods, e.g. severe end-splitting and checked timber, did not occur, indicating that the species is fairly hardy in terms of exposure during storage. The practice of leaving the bark on and coating the exposed log ends with a wax emulsion will certainly have helped preserve the logs by slowing moisture loss (in some environments leaving the bark on logs may increase the risk of insect attack).

Plate 5. Felled tree at Howard Springs displaying a solid heart typical of the project tree.

Plate 6. Logs stored at Darwin, awaiting transport to Brisbane by covered truck.

Log volume

Average log length was 3.8 m with an average large and small end diameter of approximately 400 mm and 300 mm respectively, creating an average log volume of $0.38m^3$. Table 3 details the collated field data for the selected trees.

Although the average merchantable log volume was 0.38 m^3, the relatively high standard deviation of 0.28 m^3 indicates a significant amount of variability in log dimension. This is supported by the divergent minimum and maximum values for the various measurements. Such variability is typical in plantations grown from unimproved seed stock with poor silvicultural management. The logs were merchandised with a relatively large small end diameter (SED), due to heavy crown formation (i.e. the main stem broke into the crown at a relatively low height). The heaviness of the crown may be due to the fact that several trees were 'edge' trees (i.e. situated near the edge of the woodlot). Also, it was noted that tree girth increased at the point of crown development due to the 'whirl' style of branching that the species exhibits, a phenonomen that will have biased the SED average. Hardwood mills typically accept a 25 cm SED.

The column 'Log length to volume ratio' in Table 3 is the averaged volume of timber contained in every metre length of the merchantable bole. This figure expresses the 'fatness' of logs produced, and allows a comparison between trees that discounts log length. On average the project trees produced 0.10 cubic metres of log per metre length.

Many of the logs also had significant buttressing.

Log volume by individual tree and by provenance

By assessing 'Log length to volume' ratio (Fig 2) it can be seen that there is a wide spread of figures, with the majority of trees grouped between 0.06 – 0.15 m^3 of log per metre length.

The trees with 10 largest ratios were (ordered): 16, 122, 11, H1, 14, 70, 80, 15, 4 and H13.

Grouped by site, the trees from Gunn Point and Howard Springs had a similar 'Log length to volume' ratio of 0.10 and 0.09, respectively.

Table 4 details the same collated field data grouped by tree provenance. As the trees were selected on the basis of form, each provenance is not equally represented. For this reason the data can only be used to provide an indication of provenance performance, rather than a clear assessment (as with all provenance assessments in this study). The figures again highlight the high degree of variability in the data.

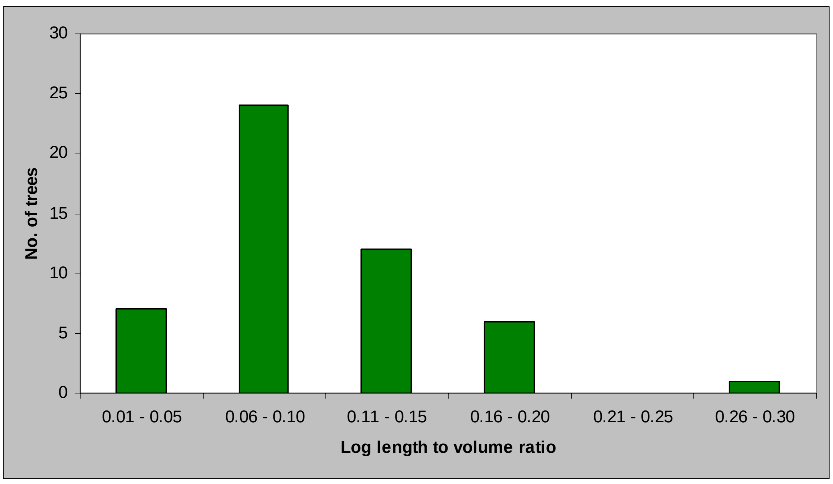


Figure 2. Distribution of trees in 'Log length to volume' ratio classes

Table 3. Log dimensions

	Trees	Tree height (m)	No of logs	DBHOB (cm)	Stump height (cm)	Merch. bole length (m)	SEDUB (cm)	Merch. bole vol. (m^3)	Log length to volume ratio (m^3 per m.)
Total	38	-	42	-	-	-	-	17.38	-
Average	-	18.7	-	36.3	0.4	4.2	30.7	0.38	0.10
Std. Dev.	-	3.5	-	8.2	0.1	1.1	7.4	0.20	0.05
Max.	-	27	-	60	0.7	7.5	49.1	0.91	0.25
Min.	-	13.7	-	25.4	0.2	3.1	19.3	0.09	0.03

Table 4. Collated log dimension data grouped by provenance

	No. of Trees	Tree height (m)	DBHOB (cm)	Merch. bole length (m)	SEDUB (cm)	Merch. bole vol. (m^3)	Log length to volume ratio (m^3 per m.)
Central Af Rep D391	1	14.2	36.4	3.9	29.3	0.35	0.07
Ghana d500	4	21.4	40.2	5.1	35.1	0.59	0.12
New Caledonia D487	3	21.4	39.9	4.4	35.0	0.53	0.11
New Caledonia D488	1	19.4	32.6	3.8	27.7	0.27	0.05
New Caledonia D522	1	20.0	48.4	4.9	44.1	0.85	0.17
Nigeria D486	1	14.5	26.7	4.4	23.0	0.27	0.06
Senegal D417	15	18.8	35.0	4.9	29.5	0.43	0.09
Senegal S10066	2	23.0	39.5	4.3	32.8	0.51	0.10
Senegal S9392	2	14.1	27.1	3.4	22.7	0.18	0.04
Sudan S9687	2	14.6	29.1	4.0	24.8	0.26	0.05
Togo D411	1	17.5	48.9	3.5	40.3	0.52	0.11
Uganda S10053	1	23.0	60.0	6.9	49.1	1.52	0.31
Unknown	2	17.9	34.2	5.2	26.4	0.47	0.10
Upper Volta D415	1	15.3	36.1	4.2	29.8	0.33	0.07
Upper Volta D416	1	15.8	27.2	3.4	22.0	0.18	0.04
Average	38 (count)	**18.7**	**36.3**	**4.4**	**30.7**	**0.48**	**0.10**
Max		**23.0**	**60.0**	**6.9**	**49.1**	**0.18**	**0.31**
Min		**14.1**	**26.7**	**3.4**	**22.0**	**1.52**	**0.04**

Log Properties

Tables 5 and 6 give a summary of average measures of log properties. These properties are then discussed separately below. The individual tree data is presented in Appendix E. End split data in Tables 5 and 6 and Appendix E is based on bottom log data only, to allow a standard comparison between all trees (for some trees top log was also analysed but this data is not shown).

Table 5. Log property data (collated)[a]

	Bark thickness	End-split (score)	Pith offset (%)	Heartwood proportion (%)
Average	8.1	4.4	15.8%	50.3%
Std. Dev.	1.3	1.9	6.8%	11.0%
Max.	11.5	9.0	27.0%	81.1%
Min.	5.5	0.75	0.9%	30.5%
Med.	8.0	4.4	15.1%	49.7%
Count	38	38	38	38

[a]The full data set is contained in Appendix E.

Table 6: Log property data (collated) grouped by provenance[a]

Provenance	**N^o of trees**	**Bark thickness (mm)**	**End-split (score)**	**Pith offset (%)**	**Heartwood proportion (%)**
Central Af Rep D391	1	7.5	3.4	21.5%	42.9%
Ghana d500	4	8.5	5.9	21.4%	46.4%
New Caledonia D487	3	8.2	4.4	14.6%	46.5%
New Caledonia D488	1	8.0	4.9	14.6%	52.0%
New Caledonia D522	1	10.0	3.3	11.0%	56.3%
Nigeria D486	1	10.0	3.9	13.4%	46.2%
Senegal D417	15	7.6	3.8	15.6%	50.8%
Senegal S10066	2	8.9	8.3	11.7%	39.2%
Senegal S9392	2	8.8	5.7	16.7%	48.8%
Sudan S9687	2	7.0	2.1	12.8%	50.0%
Togo D411	1	10.0	1.9	21.2%	63.8%
Uganda S10053	1	9.8	4.9	19.5%	57.5%
Upper Volta D415	1	9.0	4.5	11.3%	55.4%
Upper Volta D416	1	8.5	5.6	2.1%	55.2%
Unknown	2	6.3	4.6	19.9%	59.7%
	Max.	10.0	8.3	21.5%	63.8%
	Min.	7.0	1.9	2.1%	39.2%

[a]The full data set is contained in Appendix E.

Bark Thickness

On average bark thickness was 8 mm (Table 5), with a relatively tight spread between 6 and 12 mm (Fig 3).

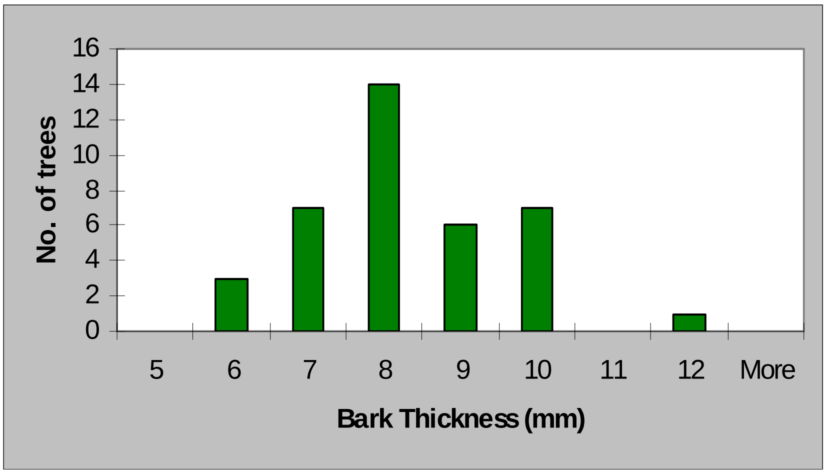


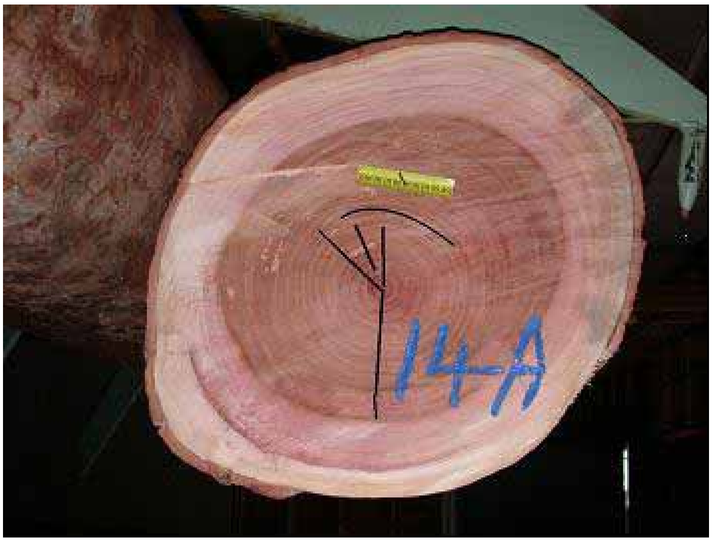
Figure 3. Distribution of trees in 'Bark thickness' classes

End-split

Log end-splitting is often caused by the release of growth stresses within the log (Armstrong 1999). Excessive log-end splitting can reduce recovery and indicate that further stress release related problems might be encountered during processing and utilisation.

The mean log end-split value of 4.2 (Table 5) is relatively low when benchmarked against eucalypts, which are renowned for splitting problems. In eucalypts, average values would commonly range from 10 to 16 in 'normal' populations. The application of the wax emulsion on the log ends after harvesting may have reduced splitting; however, this would be countered by the long log storage period. Overall, end-splitting did not appear to be a significant problem in the study logs.

Plate 7. Log end-splits (splits highlighted)



Log end-splitting by individual tree

By assessing Log end-split by tree (Fig 4) it can be seen that there is a moderate spread in the data, with the majority of trees grouped between scores 4 and 5.

The trees with the 10 lowest end-split scores were (ordered): H12, 25, 80, H7, H6, 18, 122, 154, 151, 84 and H5.

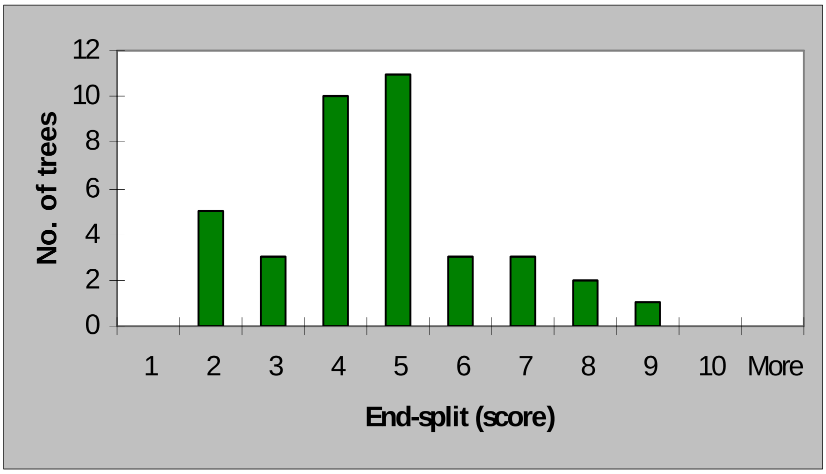


Figure 4. Distribution of trees in 'Log end-split' classes

Grouped by site, the trees from Gunn Point averaged a log end-split score of 4.7, while those from Howard Springs averaged 3.9 (Appendix E). Grouped by provenance (Table 6), log end-split scores ranged from 1.9 to 8.3. Both groupings (site and provenance) indicate a significant variation in growth stress levels within the trees, based on log end-splitting. Nicholson et al. (1975) proposed that the generation of growth stresses within a tree is a result of a combination of genetic and environmental factors, involving each individual tree's difference in growth and response to the environment. Unfortunately, the sample size and sampling method are not suitable for meaningful statistical analyses, however the differences in the log end-split scores grouped by site and provenance support the proposition by Nicholson et al. (1975). Site factors that have been associated with the development of growth stresses in the past include crowded canopy (causing stem re-orientation), wind and drought (Armstrong, 1999).

The trees from provenance 'Senegal D417' made up 10 of the 12 Howard Spring project trees and five of the 26 Gunn Point project trees. This batch of trees had an average overall log end-split score of 3.8, with the Howard Spring trees averaging 3.7 and the Gunn Point trees averaging 4.0. Given the small difference between the averaged 'Senegal D417' from each site, genetic pre-disposition for the development of growth stresses may be a stronger influencing factor than environment in this instance; however, no conclusive statements can be made based on the small sample size.

Pith Eccentricity

Pith eccentricity (or off-set pith) is generally an indicator that the study tree was leaning or contained some stem deviation, and will consequently contain some tension wood. A Pith off-set greater than 10% of disc diameter is considered oblong in shape (Hopewell et al., 1999). An off-set pith usually indicates: the presence of tension wood that will distort upon sawing; distortion in boards; and/or wandering pith that will increase the number of out-of-grade boards due to the presence of pith. Eccentric pith can be caused by a number of factors and in hardwoods includes skewed crown, fast rates of growth, and site factors such as slope, which can be improved with good site selection, silvicultural management and breeding.

As a proportion of log radius (r) the pith of the study trees were, on average, off-set or off-centre by 15.8% (Table 5). That is, when looking at the end of a log the pith was 16% of the radius length off the true centre. Pith off-set of 15.8% is quite high and given that 11 of the 38 study tree had an average pith off-set of approximately 25% or greater, pith off-set may be an issue that requires addressing through genetic selection, site selection or silvicultural management.

As a comparison, a recent study on a species of *Eucalyptus* of very similar age, grown under similar poor silvicultural conditions and situated on the edge of a plot, had an average pith off-set of 8.5%, with a range from 3 to 23%.

Plate 8. Pith off-set

Pith eccentricity by individual tree and by provenance

By assessing Pith Off-set by tree (Fig 5) it can be seen that there is a significant spread in values, with the only six trees being assessed as having an off-set pith of 10% or less.

The trees with 10 lowest Pith Off-set values were (ordered): 157, 158, H8, 154, 156, H10, 14, H5, 11, and 19.

Again there was little difference in average Pith Off-set values between sites (Gunn Point, 15.3% and Howard Springs, 16.8%) or within the 'Senegal D417' provenance trees harvested from the two sites (Gunn Point, 13.8% and Howard Springs, 16.1%), compared to the variation between trees or provenances. This may indicate the pith eccentricity is under strong genetic control.

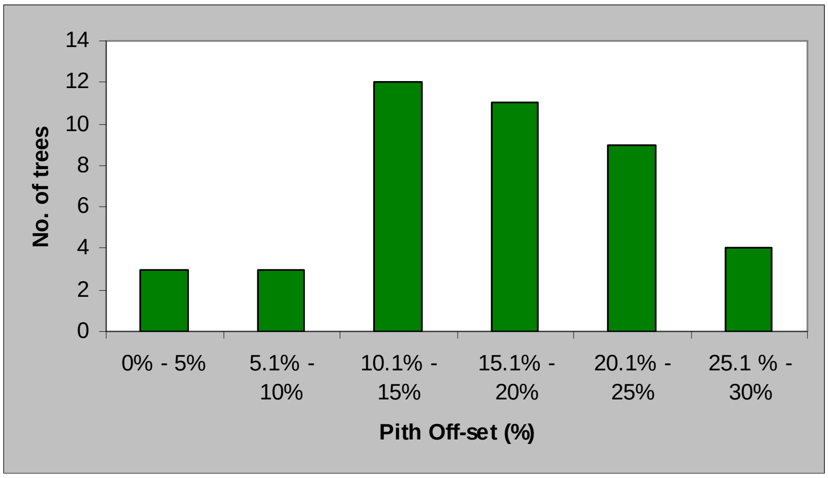


Figure 5. Distribution of trees in Pith Off-set classes

Heartwood/Sapwood Proportion

Heartwood is the non-living central core of the tree or log. Sapwood is the non-durable, living outer wood located between the heartwood and cambium. The relative proportions of heartwood and sapwood have certain implications for use. Heartwood proportion is an important property for a 'mahogany' species that is valued for its distinctly coloured heartwood. The proportion of heartwood wood may significantly affect the value of the timber, as many timber merchants may only pay a premium for 'solid coloured' heartwood boards. Also, as *K. senegalensis* is lyctus susceptible, sapwood volume will influence treatment costs.

Some sawmillers also use sapwood width as an indication of growth stress severity within a log, based on anecdotal evidence that trees with vigorous growth (i.e. a larger sapwood band) develop more stresses. However, this has yet to be scientifically tested.

On average, 70% of the cross-sectional area of the plantation logs was heartwood, i.e. 70% of the log's wood was coloured pink to reddish brown. However, due the volumetric nature of a cylinder, which a log closely resembles, a 70% cross-sectional area on the log end equates to only a 50% volumetric proportion. That is, on average only 50% of volume of each log was heartwood (Table 5) – a figure that is relatively low. For the study trees a 50% sapwood proportion equates to an average sapwood band of approximately 80 mm. As a comparison, Bolza and Keating (1972) noted that mature native forest *K. senegalensis* have a sapwood band of 25-50 mm. Further, commercial hardwood mills in Queensland, processing mature regrowth eucalypts, would typically expect heartwood proportion between 65 and 70% of log volume.

Heartwood/sapwood proportions do not necessarily directly correspond to the volume of boards containing sapwood. During processing approximately 50% of the log volume is converted into board. Of the 50% that is lost during processing, a significant proportion is from around the periphery of the log i.e the sapwood portion. So in practice even though over 25% of a typical log is sapwood, only a small percentage of that volume is converted into boards with a significant level of sapwood. Therefore, for the project logs where 50% of log volume is sapwood, the majority of boards will still only contain heartwood, but a higher percentage of boards (compared to boards produced in a commercial Australian hardwood mill) will have sections of lighter coloured, Lyctus-susceptible sapwood.

Heartwood proportion is a good example of a log or wood property that can directly influence potential financial returns. Therefore, it is important to understand the market's acceptance of such property variations before estimating returns. As previously stated, mahogany is chosen primarily for the traditional 'mahogany' colour. It may well be that certain high-value markets will not accept paler coloured sapwood in boards. Therefore, a certain volume of the sawn timber may not meet market expectations and will therefore not achieve top dollar.

As with the previous log property assessments there was a great deal of variation in heartwood proportion between trees and provenances. Heartwood proportion, if proven to be heritable, would definitely be a trait worth selecting for through genetic selection.

Pith eccentricity by individual tree and by provenance

By assessing heartwood proportion by tree (Fig 6) the significant variation in values is highlighted. There is a consistent spread of trees with heartwood proportions varying from 35% to 75%.

The trees with 10 highest heartwood proportions were (ordered): 157, 158, H8, 154, 156, H10, 14, H5, 11, and 19.

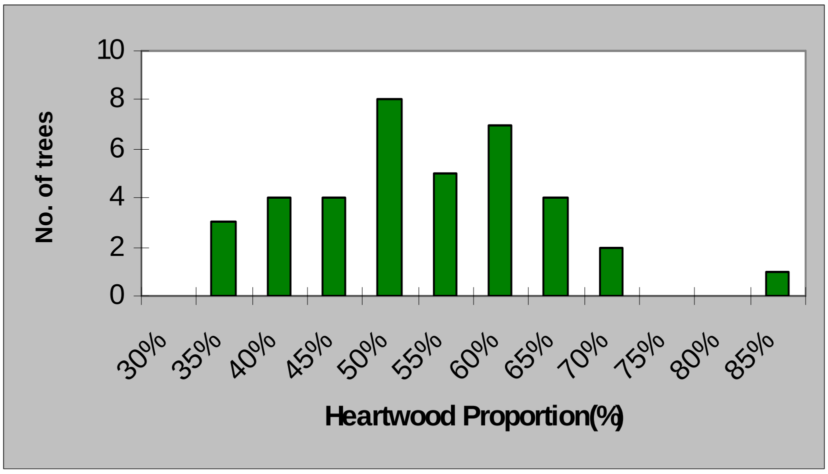


Figure 6. Distribution of trees in 'Heartwood proportion' classes

Again there was little difference in average heartwood proportions between sites (Gunn Point, 49.5% and Howard Springs, 52.0%) or within the 'Senegal D417' provenance trees harvested from the two sites (Gunn Point, 51.4% and Howard Springs, 50.4%), compared to the variation between trees or provenances. This may indicate that heartwood proportion is under strong genetic control.

Processing

Merchandising and log measurement

On average each fully merchandised log was 3.8 m in length with a large and small end diameter of 389 mm and 259 mm respectively, and a volume of 0.38 m^3.

Sawing behaviour

During sawing, movement (bending) of the cant and flitches created difficulties (Plate 9). Movement of the cant and flitches during sawing is caused by the release of stresses within the log and results in inaccurate sizing and often requires the use of 'straightening' cuts[3], which negatively impact on recovery. Movement during sawing is often a good indicator that subsequent boards from that log will have relatively high levels of distortion. Log 14A (Plate 9) displayed noticeably more 'movement'

[3] A straightening cut cuts to waste an uneven sized board from the cant which allows each subsequent board to be sized accurately.

than the majority of other logs. The relatively wide sapwood band in the project trees may have been an early indication that the study logs contained high level of stresses.

Plate 9. Movement within the log during sawing

Green-off Saw (GOS) Tally

A wide variety of dimensioned boards were produced (Table 7), the majority of which were 25 mm in thickness. Of the boards, 77% were full length and 23% were either docked or tailed off due to wane.

GOS recovery

GOS recovery indicates the proportion of saleable sawn timber recovered from a batch of logs or a single log. Leggate (2000) conducted a survey of various hardwood mills in New South Wales and Queensland and reported that, 'the recovery of saleable sawn timber (including flooring, structural, joinery, palings, pallets etc) is typically about 45 to 50%. If pallets, palings and other lower grade products were not included in the calculations then the recovery would be about 35%'. GOS recovery can be influenced by the severity of log taper and the number of natural characteristics docked out prior to tally.

GOS recovery figures are presented in Appendix F. On average, 39.5% of the total log volume was recovered as nominally[4] sized boards. Previous sawing trials of similar dimensioned and aged material commonly produced 40-50% GOS recovery, which are figures similar to industry expectation. Only four of the 42 logs sawn produced a GOS recovery of 50% or higher, a relatively poor result. Commonly the logs were buttressed and often had the largest or smallest girth in the middle of the log (Plate 10 and 11), which would have significantly contributed to the low GOS recovery figure. Due to the nature of the log shape the use of Smalian's formula to calculate log volume (which is based on the large and small end diameters) will have inflated log volume calculations and respectively decreased

[4] Boards when cut from a log are green (wet) and shrink as they lose moisture; therefore boards are cut 'oversize'. That is, they are cut with enough allowance for shrinkage. The nominal dimension of a board is the target dimension after shrinkage. Once the boards are dry they are dressed, which further reduces the dimension of the board, the final dressed dimension is the 'dressed' dimension. It is industry standard to use the nominal dimensions when calculating recoveries, regardless of the actual dimensions.

GOS recovery calculations. In hindsight the use of Huber's formula to calculate log volume (which is based on centre diameter) may have been more appropriate. The issue of log form should be an important factor for consideration in future breeding programs.

Table 7. Tally of GOS boards

Board dimension (mm)	Count	Volume (m^3)	Proportion of GOS volume
25 x 25	1	0.001	0.02%
50 x 12.5	11	0.03	0.3%
50 x 25	31	0.12	1.7%
50 x 50	1	0.01	0.1%
75 x 12.5	23	0.07	1.0%
75 x 25	71	0.47	6.4%
75 x 50	3	0.04	0.5%
100 x 12.5	33	0.12	1.7%
100 x 25	**203**	**2.87**	**38. 8%**
100 x 50	6	0.08	1.1%
100 x 100	8	0.25	3.4%
125 x 12.5	5	0.02	0.3%
125 x 25	40	0.39	5.0 %
125 x 50	0	0	0.0%
150 x 12.5	10	0.05	0.7%
150 x 25	**151**	**1.91**	**25.8%**
150 x 37.5	5	0.10	1.3%
150 x 50	31	0.74	10.0%
370 x 25	3	0.10	1.3%
400 x 25	1	0.04	0.5%
Sum	**637**	**7.40**	**100%**

Plate 10: Log with a large centre girth

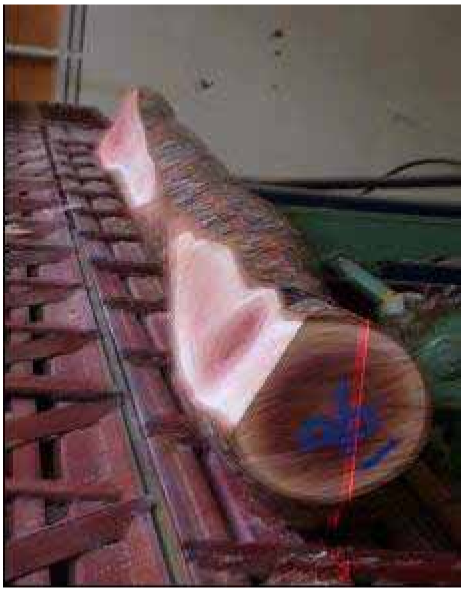
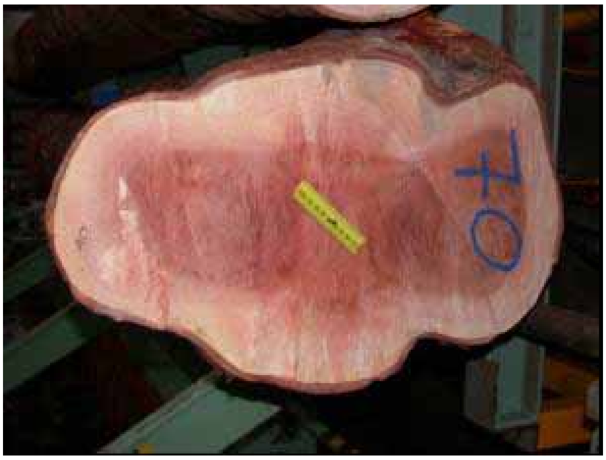


Plate 11: Buttressed log



GOS recovery by individual tree and by provenance

The figures for the individual trees are presented in Appendix F. Figure 7, a frequency histogram, presents the number of trees that fall within each 'GOS recovery' class. Only seven trees had a GOS recovery percentage over 50%.

The trees with 10 highest GOS recoveries were (ordered): H11; 80; 16; 86; 122; 3; H7; 19; 14; and H12.

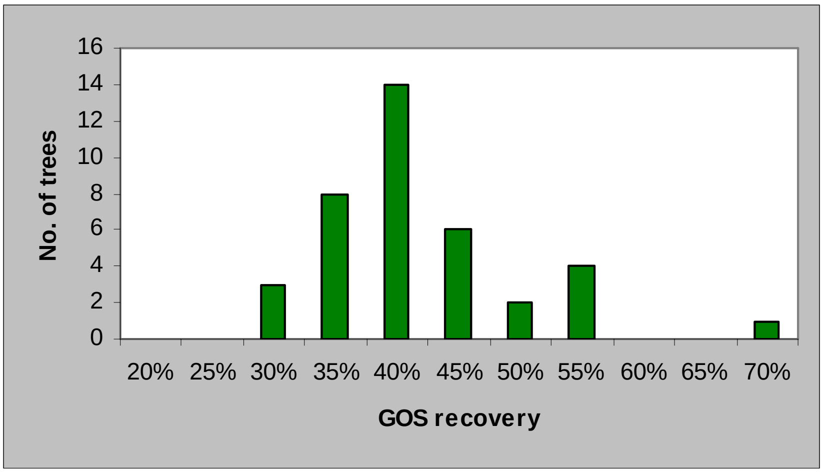


Figure 7. Distribution of trees in 'GOS recovery' classes

Table 8. GOS recovery grouped by provenance

Provenance	**GOS recovery**
Central Af Rep D391	30.5%
Ghana d500	39.5%
New Caledonia D487	40.4%
New Caledonia D488	38.5%
New Caledonia D522	39.2%
Nigeria D486	26.0%
Senegal D417	40.4%
Senegal S10066	37.7%
Senegal S9392	33.5%
Sudan S9687	35.5%
Togo D411	51.8%
Uganda S10053	50.9%
Unknown	36.9%
Upper Volta D415	50.9%
Upper Volta D416	31.7%
Max	51.8%
Min	26.0%

Grouped by site, the sawn boards from Gunn Point tree averaged a GOS recovery percentage of 38.7%, while those from Howard Springs averaged 40.4%. Similarly, the trees from provenance 'Senegal D417'[5] averaged 38.9% at Gunn Point and 41.4% at Howard Springs.

Grouped by provenance (Table 8), GOS recovery ranged from 26% to 51.8%. The variation between provenances indicates a significant variation in log form, the main contributing factor to GOS recovery. However, again little can be said to promote one provenance over another due to the small of number of trees sampled from each provenance.

GOS board features

Interlocked grain was also identified as a common feature of the boards. It becomes most apparent as a 'woolly edge' on the arris of undressed boards (Plate 12), which has previously been noted as a feature of rough sawn *K. senegalensis* (Bolza & Keating, 1972). Interlocked grain can reduce the quality of the final finish of a dressed board.

Other features that became apparent during sawing were the common occurrence of 'wandering pith', which is common in fast grown trees, and decay or discolouration (early decay) from rotten branch stubs.

During tree selection in the field the common occurrence of 'calluses' on the stems was noted as an unusual feature of the species. Upon sawing it became obvious that the calluses were overgrowths over branch stubs (overgrowth of injury). As can be seen in Plates 13 and 14, many of the overgrown branch stubs were rotten and had become an avenue for decay to enter further into the tree. It was not uncommon for the decay, entered via a rotted branch stub, to stretch for up to two metres up and down a tree in the less durable inner heartwood (Plate 15 and 16). This characteristic of the project trees could have a significant impact on the proportion of high quality timber produced, and will need to be an important consideration in the silvicultural management of any future plantings if this trait is shown to be common to the species in general.

Plate 12. 'Woolly edge' to a GOS board, indicating interlocked grain

[5] Senegal D417 is made up 10 of the 12 Howard Spring project trees and 5 of the 26 Gunn Point project trees.

Plate 13. Woody calluses over branch stub

Plate 14. Rotten branch stubs within the woody calluses

Plate 15. Decay in the inner heart, which has entered via a rotten branch stub, across three boards cut consecutively from a cant

Plate 16. Decay in the inner heart which has entered via a rotten branch stub

As *K. senegalensis* is susceptible to lyctus, all the sawn material was boron dipped.

Seasoning

The timber was air-dried undercover for two and a half months (January to March 2004) before final drying in the Queensland DPI&F solar kiln for two weeks, with a final MC of 10.3% achieved.

Seasoning Trials

The report on the seasoning trials is attached as Appendix B.

In summary, the plantation *K. senegalensis* proved to be a relatively easy timber to dry. Given the correct seasoning schedule, the timber dried quickly with little degrade.

Dried and Dressed Graded Recovery

Total recovery

All grading was undertaken in accordance to AS2796 Timber – Hardwood-Sawn and milled products Part 1: Product specification[6]. AS2796 details the specifications for appearance grading of hardwood timber. The standard lists the specifications for:

- product categories, the two most commonly used being Joinery and Flooring, with the level of allowable distortion (spring, bow and twist) differentiating the product categories
- grade categories, High Feature, Medium Feature (Standard) or Select, with the level of allowable natural defect differentiating the grade categories.

For product category 'Joinery', dried and dressed graded recoveries ranged from approximately 8.1% to 9.7%, depending on grade and product category as specified by AS2796. That is, 8.1% of initial log volume could potentially be used for Select grade Joinery, a further 1.4% for Medium Feature grade Joinery and a further 0.2% for High Feature grade Joinery (Table 9).

For product category Flooring, dried and dressed graded recoveries ranged from approximately 24.4% to 29%, depending on grade and product category as specified by AS2796. That is, 24.4% of initial log volume could potentially be used for Select grade Flooring, a further 4.8% for Medium Feature grade Flooring and a further 0.2% for High Feature grade Flooring (Table 9).

Grade is dependant on the combination of defect and distortion. Considering defect alone (in accordance with AS 2796), 16.4% of GOS volume did not meet the criteria for the least demanding grade of High Feature. Of the remaining volume a further 0.6% of GOS volume did not meet the stricter criteria for Medium Feature and a further 11.5% did not meet the criteria for the most demanding grade of Select (totalling 28.5%). The most prevalent defects were: wane; heart-in; tight knots; and knot hole for High Feature grade, tight knot and knot hole for Medium Feature grade, and stain and tight knot for Select grade (Figures 8, 9 and 10).

Due to distortion alone, only 11.3% of GOS volume did not meet the cut-off figures for product category Flooring, while 71.1% of GOS volume did not meet the cut-offs for the more stringent product category Joinery. Mean spring, bow and twist were 17.8, 9.9 and 3.0 mm, respectively.

Importantly, a mean board end-split of 9.1 mm was measured for the study material. End-split in boards can cause considerable losses in commercial operations and can represent a significant problem in some species. There was only one incidence of surface check and none of collapse.

Overall, the recovery of material across the three grades for product category Joinery was relatively low, due predominantly to the significant volume of timber with distortion levels outside of the allowable limits. The recovery for product category Flooring, was relatively normal for plantation grown material based on results from previous sawing trials. A number of issues were highlighted by the incident rate of certain defects:

- heart-in (heartshake) and wane are normal defects and cannot be avoided, however the poor form of the logs and the occurrence of 'wandering pith' may have significantly increased the incident rate of these defects in the project trees

[6] AS2796 sets out the allowable defect parameters and distortion cut-off values. The standard specifies defect parameters for three grades, they are High Feature (most allowable defect), Medium Feature and Select (least allowable defect. Private industries commonly use different trade names for each of the grades. The standard also specifies distortion cut-off values for three product categories, they are Flooring (most allowable distortion), Lining (not commonly used and not used for this study), and Joinery (least allowable distortion). Therefore the highest grade in the most demanding product category, a combination of parameters for Select and Joinery, represents the highest quality timber.

- the high incidence of defects associated with knots, (tight knots, loose knots and knot holes) could have been significantly reduced by pruning throughout the life of the plantation
- of particular interest was the high incidence of stain causing downgrade in Select grade. Select grade timber demands a significant premium in the marketplace; the downgrading to Medium Feature grade represents a considerable economic loss.

Table 9. Graded recovery figures

Product Category	Grade recovery %		
	Select	Medium Feature	High Feature
Joinery	8.1	9.5	9.7
Flooring	24.4	28.8	29

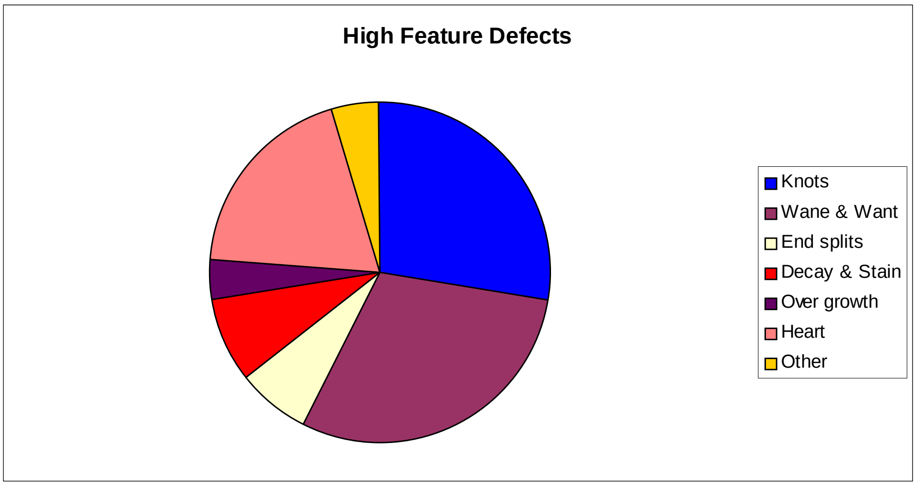


Figure 8. Incidences of defect High Feature grade

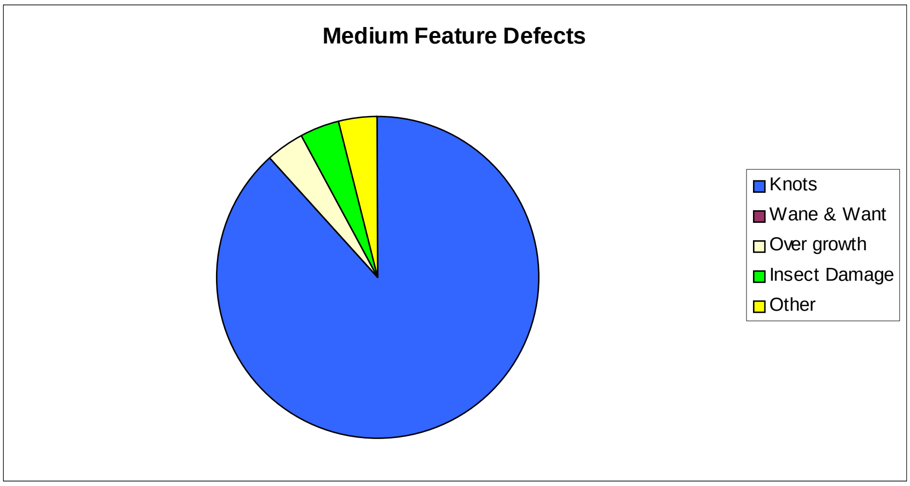


Figure 9. Incidences of defect Medium Feature grade

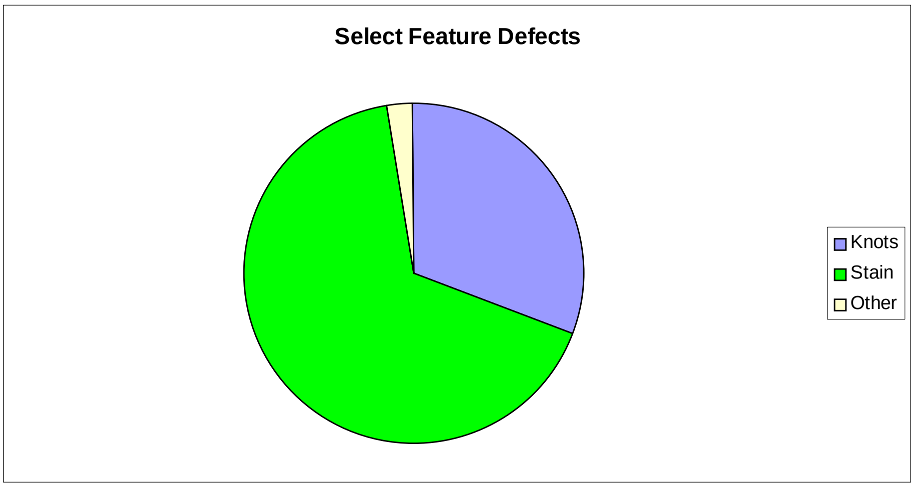


Figure 10. Incidences of defect Select grade

Recovery by individual tree and by provenance

Distortion

Board distortion is often caused by the unbalancing of growth stresses, previously balanced and constrained within the log, during processing (Armstrong 1999).

Figure 11 is a frequency histogram which presents the number of trees that fall within each 'Total mean distortion' class. Total mean distortion is the summed value of mean spring, bow and twist measured on the sawn boards from each tree, after drying and dressing. Only 12 trees have total mean distortion of less than 20 mm, a value that could be considered as a cut-off for identifying trees with low distortion.

The top 10 trees were (ordered): H6; 19; H12; 122; 155; 77; 80; 150; 84; and 25.

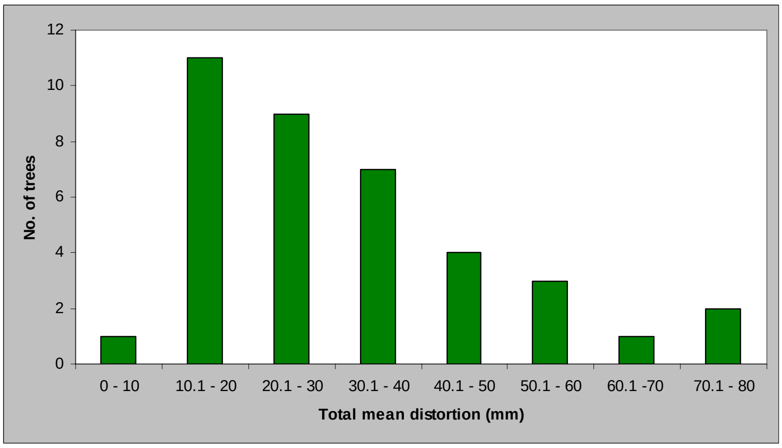


Figure 11. Distribution of trees in 'Total mean distortion' classes

Grouped by site, the sawn boards from Gunn Point tree averaged a 'Total mean distortion' of 28.9 mm, while those from Howard Springs averaged 36.6 mm. Similarly, the trees from provenance 'Senegal D417'[7] averaged 27.2 mm at Gunn Point and 37.1 mm at Howard Springs. These values may

[7] Senegal D417 is made up of 10 of the 12 Howard Spring project trees and five of the 26 Gunn Point project trees.

indicate that an environmental factor could be contributing to the development of stresses within the log, somewhat contradicting the 'Log end-splitting' data that indicated a weak environment pressure on growth stress development.

Grouped by provenance (Table 10), 'Total mean distortion' ranged from 14.8 to 60 mm. Again both groupings (site and provenance) indicate a significant variation in growth stress levels; however, little can be said to promote one provenance over another due to the small of number of trees sampled from each provenance.

Table 10. Average boards distortion values grouped by provenance (mm)

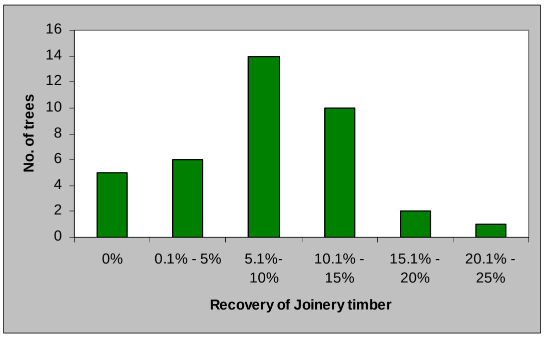
Provenance	No of tree	Spring	Bow	Twist	Total mean distortion
Central Af Rep D391	1	7.7	6.6	2.7	17.0
Ghana d500	4	24.1	13.0	5.5	42.7
New Caledonia D487	3	7.8	7.9	3.1	18.9
New Caledonia D488	1	47.9	8.2	3.9	60.0
New Caledonia D522	1	19.0	9.6	2.2	30.7
Nigeria D486	1	32.7	5.2	2.3	40.2
Senegal D417	15	22.4	8.7	2.7	33.8
Senegal S10066	2	7.0	11.4	1.8	20.2
Senegal S9392	2	10.1	9.9	2.7	22.6
Sudan S9687	2	11.2	5.9	2.1	19.1
Togo D411	1	3.6	8.5	2.7	14.8
Uganda S10053	1	8.1	6.9	4.4	19.4
Unknown	2	12.4	17.7	3.6	33.7
Upper Volta D415	1	44.5	5.2	3.0	52.7
Upper Volta D416	1	13.3	16.0	0.0	29.3
	Max	**47.9**	**17.7**	**5.5**	**60.0**
	Min	**3.6**	**5.2**	**0.0**	**14.8**

Grade recovery

There are six permutations of grade recovery based on the two product categories (Joinery and Flooring) and the three grades (High Feature, Medium Feature and Select). Due to the nuances of the grading system it is possible that the project tree with highest recovery of Select Flooring may not be the same tree that has the highest recovery for Medium Feature Joinery. Therefore in order to compare overall recovery for each of the project trees, each tree was assigned a rank from 1 to 38 for each of the six permutations of grade recovery (1 representing the highest recovery). Therefore each tree was assigned six rankings (High Feature Flooring through to Select Joinery). To provide one simple figure for between tree comparisons, the six rankings for each tree were summed, and the sum of the rankings ranked.

The trees with the top 10 rankings were (ordered): H11; 3; 16; 80; 122; 157; H6; H8; 15; 18; and 19.

While considering overall recovery is important, a premium is paid for Select grade timber, especially within the furniture industry. As can be seen in Figures 12 and 13, the recovery of Select grade Joinery and Flooring timber is quite variable between trees. For the purpose of this analysis, the product categories Joinery and Flooring were not considered independently, i.e. a Select grade piece of timber is either counted in the recovery calculation for Joinery or Flooring, not both (i.e. the sum of Joinery and Flooring recovery equals total Select grade recovery).



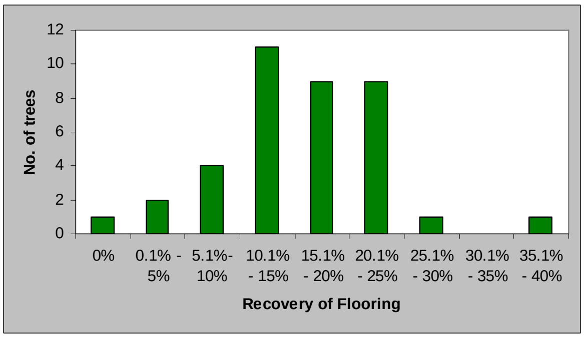


Figure 12. Distribution of trees in 'Recovery of Select Joinery timber' classes

Figure 13. Distribution of trees in 'Recovery of Select Flooring timber' classes

By undertaking a similar ranking exercise, as was used above (i.e. ranking each tree independently for Joinery and for Flooring; summing the ranks; and creating an overall rank for Select grade recovery), the trees with the highest recovery of Select grade timber can be identified.

The trees with the top 10 rankings are (ordered): H11; 3; 80; 16; 18; 122; 157; H7; and 70.

By comparing the individual trees that make up the top 10 rankings for 'Select grade recovery' and 'Grade recovery', the majority of the same trees appear, with a number of rank shifts. Interestingly, four trees dropped out of the top 10 when only Select grade recovery was considered. Most dramatic of the shifts was for tree H6 that had the equal 6^{th} best total recovery but the 20^{th} best Select grade recovery.

As highlighted by Figure 10 'Incidences of defect Select grade', the main contributing factor to downgrade for timber not meeting Select grade was Stain (Plate 17). By assessing the incident rate of stain for each tree, the proportion of boards from each tree that were affected by stain can be calculated. On average 24% of the boards cut from each of the project trees were affected by stain and only six trees had less than 20% of their boards affected by stain (Fig. 14). Although the area of board affected by stain may not be large and can be docked out, the high incident rate of the defect would definitely reduce recovery and increase processing costs.

The top 10 trees for low levels of stain were (ordered): 3; 18; H7; 150; H14; H10; 96; H5; 155; and H8.

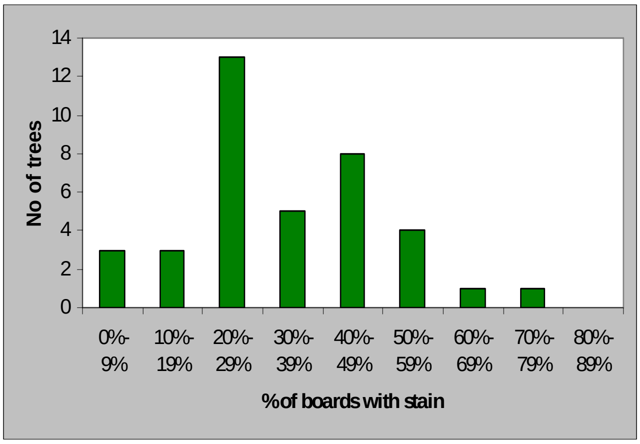


Plate 17. Stained timber

Figure 14. Distribution of trees in 'Percentage of boards with stain' classes

As the effect of stain has such a high potential to degrade boards that would otherwise be graded as Select, and therefore fetch a premium price in the market, investigation of the cause and potential methods of minimising stain would be valuable. While it was not the objective of this study to investigate such issues, the data from this study may provide some early indications.

The project trees came from two sites, Gunn Point (26 trees) and Howard Springs (12 trees). By looking at the average proportion of boards affected by stain grouped by site, it can be seen that on average 28% of boards were affected by stain at Gunn Point, while only 17% were affected at Howard Springs. Unfortunately, the sample size and method are not suitable for meaningful statistical analyses; however, the large difference in the means would indicate that a site effect might be responsible for the higher incident rate at Gunn Point.

Other factors that could influence the stain incident rate include provenance susceptibility or silvicultural management. An examination of Senegal D417, the best replicated provenance (ie 12 of the 14 trees at Howard Springs and five of the 26 trees at Gunn Point), found that on average 34% of the Gunn Point Senegal D417 boards were affected by stain, while only 18% were affected at Howard Springs. This difference in means is similar to the overall site averages, and indicates a site effect more than a provenance effect. As minimal silvicultural management has been undertaken in the past (B. Robertson pers. comm. 2004[8]) the lack of management may have impacted on the health of the plantation.

Wood Properties

The results of the wood property assessments are below discussed as a collated group. The information is intended to provide end users with the necessary information for efficient and 'fit for purpose' usage of plantation grown *K. senegalensis*. The full data set for the relevant wood properties measurements is attached as Appendix G.

Colour and grain – Background

The visual appearance of milled timber is an important determinant of marketability. Milled (dressed or planed) products include flooring, mouldings and joinery and are recognized as high value forest products. Generally, with the exception of exposed solid and laminated timber beams, structural products are not considered decorative and the visual appearance of structural products is less important.

Different markets, cultures and products have different aesthetic requirements. These requirements are generally described under standard terms such as colour, grain, texture and figure. Definitions for these terms are listed below:

Colour

For the majority of appearance products, consumer acceptance is determined by the visual appeal of the wood's natural colour. For example, white and red timbers currently enjoy popularity and are in higher demand than yellowish timbers for flooring and furniture. Consistency of colour can also affect the marketability of a species, for example variation between boards in a floor or furniture item is often unacceptable to consumers, but may suit rustic applications.

Colour in timber is most often determined by the types and amounts of complex organic compounds present (polyphenolics, flavones and quinines). Heartwood (truewood) is the inert core of a tree and sapwood refers to the outer band of living wood tissue at the time of harvest. These zones are often colour demarcated, with the sapwood generally paler. Some species display a transition or intermediary zone between true heartwood and sapwood.

[8] Mr Beau Robertson, Department of Business Industry Resource Development, Northern Territory Governemnt.

Texture
In hardwoods, texture is determined by the diameter of the vessels as seen in longitudinal section, on the dressed face or edge of a board. The vessels usually appear as parallel or wavy lines or fine grooves. Coloured vessel contents can highlight vessel lines and thereby influence the textural appearance. Small diameter elements give rise to fine textured woods, whereas large diameter elements provide a coarse-textured surface. Examples of fine textured hardwoods are the box species (*Buxus* spp.) and examples of coarse textured timbers are spotted gum (*Corymbia* spp.) and meranti (*Shorea* spp.). This feature is considered important by polishers and painters of wood products, who may need to fill coarse-textured wood surfaces and therefore have a preference for fine textured material. An example of this is the popularity of hoop pine *Araucaria cunninghamii*, for mouldings in Queensland domestic dwellings (especially skirting boards, window and door frames) in preference to meranti.

Texture can also be described as even or uneven. 'Even-textured' applies to woods with homogenously sized and arranged anatomical elements (e.g. brush box *Lophostemon confertus*, kauri pine *Agathis* spp.). Uneven-textured surfaces appear in timbers that possess heterogeneously-sized elements, such as small diameter vessels in earlywood zones and large diameter vessels in latewood zones (e.g. ring porous species such as red cedar *Toona ciliata*, and teak *Tectona grandis*).

Grain
Terms describing grain allude to the general direction of woody tissue growth, for example spiral, interlocking, straight or wavy. It denotes the orientation of the vessel lines in relation to the face or arris of a sawn board and is also visible when the wood is split.

Figure
Where the arrangement of anatomical elements gives rise to decorative effects, the wood is said to have figure. In the case where fibres have grown in undulations, the dressed board surface may exhibit 'fiddleback' figure. Where the tissues are interlocked and the wood is carefully dressed, the resulting figure appears as alternating darker and lighter longitudinal stripes and is referred to as 'ribbon', 'stripe' or 'roey'.

Other features
Heritable traits, silvicultural treatment, and exposure to fire, pathogens, and drought prior to harvesting can attribute to the appearance of the finished timber. For example presence and size of knots, kino veins and pockets, spalting and borer holes can be characteristic of a species and are often included in descriptions of the visual appearance of a timber. The presence of tension wood, for example as produced in leaning trees, can also affect the finish and appearance of wood surfaces.

Colour and Grain - Results

Colour
Heartwood
The heartwood of plantation *K. senegalensis*is is pink to red when freshly sawn and generally darkens to pinkish-brown, orange-brown or red-brown after prolonged exposure. A silky sheen can be achieved using conventional polishing methods.

Sapwood
The sapwood is paler; usually light pink and not always distinct from the heartwood. There is an intermediary zone of transition wood from heartwood to sapwood.

Texture
Medium to coarse, uneven texture with distinct vessel lines due to the inclusion of dark-coloured deposits. The vessels are visible to the naked eye on clean-cut transverse sections.

Grain

Straight to interlocking. Interlocking grain is also common in natural-grown *Khaya* timber.

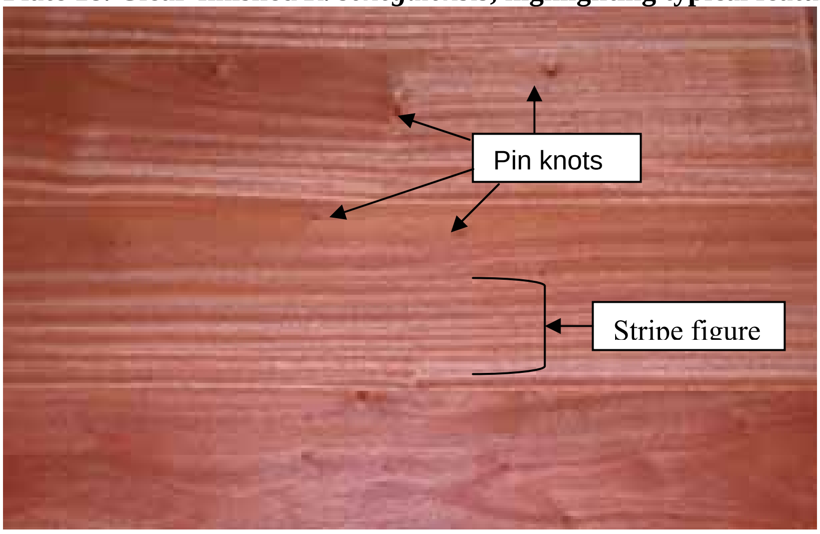
Figure

Interlocking grain gives rise to stripe figure (also called ribbon or roey figure) in quartersawn boards resulting in the appearance of alternating bands of darker and lighter-coloured wood.

Other features

Pin knots appearing as dark circular shapes on the faces and edges of the boards were common in this material. The presence of tension wood and interlocking grain in the source material resulted in a high incidence of woolliness in the sawn boards, requiring careful dressing and sanding to achieve a fine finish (Plate 18).

Plate 18. Clear-finished *K. senegalensis*, highlighting typical features (project timber)



Colour and Grain –Summary Assessment

Plantation-grown *K. senegalensis* provides an aesthetically pleasing timber with marketable colour and figure attributes. The wood appears to be suitable for clear-finished or stained high-value applications such as contemporary and reproduction furniture, cabinetry, windows, doors, and interior joinery. To avoid tearing the grain in material with tension wood, appropriate cutting angles will be required; however, with careful attention to dressing and sanding a fine polish can be achieved.

Density

Wood density is described in three ways: green, basic and air-dry. Basic density is most often used for scientific analysis as it has the advantage of removing variations due to moisture content. For this reason basic density was used in this study. Air-dry density (ADD) is the density at 12% MC (averaged over sample population) and is the measure most often used within industry as it infers the condition of wood in service. ADD was not assessed during this study, however, to provide an indication of the likely ADD of the plantation material it can be approximated by using basic density and a conversion factor of 1.21.

The results, presented in Tables 11–13, indicate that with an overall mean basic density of 637 kg/m^3, the project timber is a medium to moderately heavy timber. The range of average densities across the pith, converted to ADD figures (753 – 803 kg/m^3), compare well to figures cited in the literature. Bolza and Keating (1972) quote ADD values for *K. senegalensis* ranging from 730 to 900 kg/m^3, depending on provenance.

Longitudinal pith to bark density (radial density variation up the tree) shows a trend of increasing density with height. The evident trend of increasing density with distance from the pith was expected, and would most likely be a function of increasing extractive deposition and thicker walled fibres being produced with increasing age. The trend of increasing radial density is found in the majority of timber species.

Analysing the variance between the densities of the various segments (LSD @ 5% = 12.2 (kg/m^3)) there was no significant difference between the densities of the inner and mid heart segments, a fact that may indicate that the species produces a relatively dense juvenile wood and/or has a relatively similar level of extractive deposition at a young age compared to deposition in later years. Evidence of this may also be seen in the relatively few incidences of pipe in the harvested logs.The mean density of the outer heartwood and sapwood segments were significantly different to every other segment. Overall the plantation material had a relatively even density from pith to bark, which would have advantages for seasoning and use.

Based on these results it is unlikely that density would be a trait requiring improvement through genetic selection.

Table 11. Combined density data from all trees (kg/m^3)

	Disc position		Average
	Bottom	Top	
Average	629	649	637
St. Dev	43	45	41
Max	696	726	704
Min	539	546	553

Table 12. Combined 'Pith to Bark' density data from all trees (kg/m^3)

Segment	Average	St. Dev	Max	Min
Sapwood	643	53	797	548
Outer Heartwood	662	58	881	457
Intermediate Heartwood	624	65	868	271
Inner Heartwood	621	67	760	510
Average	**637**	**63**		

Table 13. Density by provenance (kg/m^3)

Provenance	Segment				Average
	Sapwood	Outer Heartwood	Intermediate Heartwood	Inner Heartwood	
Central Af Rep D391	604	614	580	645	611
Ghana d500	640	647	615	586	622
New Caledonia D487	653	704	647	624	657
New Caledonia D488	655	721	712	659	687
New Caledonia D522	656	652	585	592	621
Nigeria D486	625	765	697	729	704
Senegal D417	649	659	622	618	637
Senegal S10066	644	619	595	613	617
Senegal S9392	666	716	640	632	663
Sudan S9687	569	612	594	616	598
Togo D411	585	694	669	598	636
Uganda S10053	656	650	601	607	629
Unknown	677	677	634	649	660
Upper Volta D415	586	599	587	643	604
Upper Volta D416	629	653	633	662	644
Max	**677**	**765**	**712**	**729**	**704**
Min	**569**	**599**	**580**	**586**	**598**

Shrinkage

Shrinkage (green to 12% MC) and Unit shrinkage are both very important characteristics. Sawmillers rely on a good knowledge of shrinkage to determine oversizing of boards when processing to allow for dimensional change associated with moisture loss, while builders, furniture makers and designers rely on unit shrinkage information to build and design shrinkage/swelling allowances (anticipated movement with changing environmental conditions, i.e. seasonal) into their respective products.

The shrinkage results, as presented in Table 14 for the project timber, exhibited low 'green to air-dry' shrinkage, typical of mahoganies. Unit shrinkage was moderate compared to many commercial timbers used for furniture and joinery applications.

Table 14. Shrinkage and Unit Shrinkage of the plantation material and native forest material (bracketed)*

Axis	Shrinkage (%)	
	Shrinkage 'green to 12%'	Unit Shrinkage
Radial	1.8 (1.5)	0.26
Tangential	2.5 (3.0)	0.28
Longitudinal	0.3	0.02

*Bootle (1983)

Glue-ability

A species' potential for use is becoming increasingly reliant on its ability to be successfully glued, due to factors such as smaller end-sections (i.e. recovered from smaller logs) and the acceptance of engineered products for structural and appearance applications. Additionally, there is high growth in composite product development, an area of use where gluing characteristics determine feasibility. Traditionally, timbers with high extractive contents have proven difficult to glue.

Acceptance criterion for the cleavage test, AS/NZS 1328 was 60% (average in any one assembly). All samples passed (Table 15).

The acceptance criterion for shear strength according to AS/NZS 1328 is 6.0 Mpa (all glue lines). All samples passed (Table 15). The fifth percentile shear strength of 14.6 Mpa exceeds the characteristic shear strength for SD1 of 12 Mpa.

In addition, a test was conducted on a solid *K. senegalensis* sample in tangential and radial shear. The average shear strength was 17.3 Mpa. The average of the glued samples, at 16.9 Mpa, was 97% of the solid sample. This is a good non-technical indication of the overall glue-ability of the samples.

Overall, *Khaya* spp. can be glued successfully using urea formaldehyde adhesives. No test pieces failed. The glued assemblies met the test criteria for structural glulam specified in AS/NZS 1328: 1998.

Table 15. Gluing test data

Test	Run 1	Run 2	Run 3	Average
Av. MC	8.9	8.7	9.8	9.1
Delta MC[1]	0.6	0.9	0.2	0.6
Spread (kg/100m^2)	26	28	26	26.7
Cleavage (% wf)	82	91	81	84.7
Shear (Mpa)	16.8	18.0	16.0	16.9
5th Percentile Shear (Mpa)				14.6

[1]Mean difference between pairs in glue assembly.

Modulus of Elasticity (MoE) and Modulus of Rupture (MoR)

Based on the testing of small clears, the plantation material achieved an estimated strength grouping of (SD6)[9], with mean stiffness (MoE) and strength (MoR) values of 8.3 Gpa and 81.7 Mpa, respectively. In comparison to values cited in Bolza and Keating (1972) for native grown material (12.4 – 10.7 Gpa and 93.7 – 79.2 Mpa for MoE and MoR, respectively, depending on provenance) the plantation material was relatively weaker.

These results indicate that the plantation timber has low mechanical properties, a factor that should be taken into consideration when assessing the potential of the species for specific products, specifically load bearing applications.

Janka Hardness

Based on density alone, the assessed samples would be rated as a 'Moderately Hard' timber[10]. Based on Janka hardness, the force required in kilo-Newtons (kN) to press a small metal ball a set distance into test piece of timber, the assessed samples had an average value of 6.4 kN. As a comparison, Bootle[11] listed African mahogany (species unspecified) as 4.1 kN. Hard timbers are advantageous for applications such as flooring and tabletops.

9 Estimated strength groups allocated as per AS 2878 for seasoned timber (12% MC)

10 Queensland Forest Service. (1991) Technical Pamphlet No 1: Building Timber, Properties and Recommendations for their use in Queensland. Department of Primary Industries.

11 Bootle, K. R. 1983. Wood in Australia – Types, properties and uses. McGraw Hill, Sydney

Joint Strength Group (Nail and Screw withdrawal)

The joint group rating of *K. senegalensis* timber was allocated using the nail and screw withdrawal method specified in AS 1649 – 2001. Based on nail withdrawal the assessed samples achieved Strength Grouping JD3. Based on screw withdrawal the assessed samples achieved Strength Grouping JD2.

Durability Assessment - Background

Natural durability rating may be defined as the inherent resistance of a timber species to decay, insect, and marine borer attack. In the context of the Australian durability standard, natural durability ratings refer to the timber's performance both in contact with the ground and above ground when exposed to average environmental conditions, and in southern marine waters. The performance of untreated heartwood above ground will generally be better than its performance in the ground.

Classification of the durability of a species is not something that can be done with great precision because of the variability of wood properties within species, even within the individual tree and the variable nature of the hazard to which the timber will be exposed. An in-ground classification, which is widely accepted as a general guide, is based on one developed many years ago by CSIRO Forestry and Forest Products. It is essentially a rating of the durability of the species' heartwood when in ground contact and exposed to attack by decay and termites. Because of this combined assessment, the classification does not truly reflect the special qualities of some species (e.g. brush box, which is very resistant to termites but much less so to decay). A further consideration is the size of the specimen at risk.

In selection of species for a particular location, local experience should be used as a guide to what is practical in the area. The extent of decay, termite, and marine borer hazard varies greatly in a continent with such a wide range of climates.

All untreated sapwood has poor resistance to biological attack. General species resistance is determined largely by the extractives formed when sapwood changes into heartwood. Termites and marine borers are less easily deterred by these extractives than fungi and will attack most species, though slowly in the case of the very durable species.

For this study durability was assessed by exposure to termites and by accelerated decay bioassay.

Durability Assessment - Results

Termite resistance

After 2½ months there was no apparent feeding damage to any of the sample blocks, except for a slight nibble on block 158 (Plates 19a and b). Based on these results the project timber appears quite resistant, compared to the pine feeder material. It should be noted that pine is a preferred food source for termites, and in environments where only non- preferred food source sources are present (i.e. stronger feeding pressure) a higher level of attack might be expected.

The fact that only one of the project logs had evidence of pipe caused by termite attack also anecdotally supports *K. senegalensis* as being termite resistant.

Plate 19a. ***K. senegalensis*** **and pine feeder block**

Plate 19b. ***K. senegalensis*** **and pine feeder block. Note block 158 with slight damage**

Accelerated decay bioassay
The report on the accelerated decay bioassay is attached as Appendix C. In summary, there was a high amount of variation in the resistance of the *K. senegalensis* samples to fungal decay. Overall decay resistance was high, indicating high durability potential.

Industry Assessment
The suitability of Australian plantation-grown *K. senegalensis* for specific applications and markets will to a large extent govern the potential of the species. To date, very little of this timber has been available for assessment or use by industry. The majority of Australian grown *K. senegalensis* available to industry has been sourced from street trees and has predominantly been used for slab furniture. This project provided suitable material for a relatively comprehensive, independent market survey and industry evaluation.

Table 16 lists the industry sectors targeted to participate in the survey and the results of this consultation.

Table 16. Industry response to survey

Type of business	Number contacted	Responses
Furniture-Joinery manufacturers	10	4
Veneer, plywood manufacturers	3	2
Instrumental makers	6	3
Supplier, merchant, importer-exporter	4	2
Total	**23**	**11**

The 50% reply rate was respectable for an industry survey. The feedback provided by the companies that responded was of a good quality, with precise information and strong interest in further participation.

Based on the responses and further consultation, a sample of timber, specific to each manufacturers needs, was supplied for evaluation. Unfortunately, not all the companies could be supplied due to the volume and dimension of timber available for the study. However, an attempt was made to supply timber to at least one company in each activity and each industry sector and state. The following is a summary, by industry sector, of manufacturers' responses to the questionnaires and industry assessment comments. Specific responses from individual companies have not been included for reasons of confidentiality.

Furniture and Joinery Sector

All of the furniture manufacturers who responded were using or had used African mahogany. The timber was purchased through Australian timber merchants. Due to their experience with native African mahogany the information and responses they provided were particularly useful.

Project timber was supplied to two companies for assessment, Paragon Furniture and F. H. Weisner of Toowoomba.

Overall opinion, based on questionnaires responses and the industry assessment, was that prospects for Australian plantation-grown *K. senegalensis* were good. General comments included:

- the plantation material was of superior quality to that previously supplied from Africa in terms of stability, density, hardness and colour
- the use of Australian plantation timbers were viewed favorably by consumers
- the timber machined well and produced a good finish
- the timber had a good colour, texture and overall aesthetic appeal
- the timber was suitable for domestic and export products.

Paragon Furniture crafted a chess table and matching chairs from the timber provided and entered the piece into the Annual Furnishing Industry Association of Australia's Furniture Awards 2004 (Plate 20). The piece won first prize in the category 'Excellence in furniture using Australian plantation timber' at the state (Queensland) and national level, as well as winning the 'Best of the best award' for Queensland.

Responses on price indicated that the current average wholesale price varies from \$2800 to \$3800 per m^3. However, one company bought a batch of 25 mm thick material for \$2450 per m^3.

Plate 20: Paragon Furniture's award winning Chess table (project timber)[12]

Plate 21:Frank Weisner's timber thread stool (project timber)

[12] © Paragon Furniture

Veneer Sector

Only one of the contacted companies was using (or had used) African mahogany. However, the species is widely recognised as a good quality veneer species in Europe. Supply was noted as the main factor inhibiting the wider use of the species in Australia. The general opinion of the sector was that plantation material could be used for veneer if the trees had very good log form and wood quality and were of a large diameter. The one company currently using African mahogany purchases the veneer sheets directly from a manufacturer in Africa. The company noted that 'as a veneer the timber has good stability, is relatively soft and accepts staining and finishing without problems'.

Overall opinion, based on questionnaires responses and the industry assessment, was that prospects for Australian plantation-grown *K. senegalensis* were good depending on the production of large diameter, pruned logs. General comments included:

- the veneer had a slight fuzz on the surface
- care would have to be taken to ensure correct blade and pressure selection
- the timber had a good colour, texture and overall aesthetic appeal
- the timber is suitable for domestic products.

It would appear that as a potential plantation species, a major strength is its suitability for high quality decorative veneer production. One company, Proveneer, was supplied two large billets for veneer slicing.

Currently rotary peeled African mahogany veneer is imported for approximately \$2 m^2 a sheet.

Instrument Sector

Two companies manufacturing musical instruments (guitars) were currently using African mahogany timber, both of whom purchase their timber directly from foreign suppliers.

The overall opinion based on the questionnaires and industry assessment was that prospects for Australian plantation-grown *K. senegalensis* were good, as the timber is 'excellent for guitar construction' (Plate 22). General comments included:

- colour, aesthetics and texture are good for instrument manufacturing
- the wood has a good strength to weight ratio
- good stability through temperature and humidity fluctuations
- reasonably easy to machine and glue
- the timber is slightly rough across the grain and may require pore filling under finish coats
- the timber is heavier than Brazilian mahogany.

One company Gerard Gilet and Guitarwood was supplied with timber for assessment.

With regard to pricing, one company believed the timber was similar to Queensland maple and could probably demand a similar price. The companies were currently paying over \$5500 per m^3, a price[13] which is reflective of the industries demand for the highest quality timbers.

[13] 'Cost and Freight' figure

Plate 22. African mahogany guitar (not project timber)

Timber Merchants/Importers

Two specialist timber merchants were found to currently stock African mahogany timber. However, both companies could not specify species. Both merchants were supplied directly from Africa. The overall opinion was that prospects for Australian plantation-grown *K. senegalensis* were good. General comments included:

- colour, aesthetics and texture varied from good to average
- hardness is suitable for good quality furniture
- consistent density (although small sample)
- machined well.

Timber was supplied to Trend Timber and Lazarides Timber Agencies for assessment. Both merchants noted that the largest problem with their current stock from Africa was stability and variable density.

The merchants currently pay approximately $1400–$2400 per m^3 for rough sawn timber (often green) and retail it for approximately $3500 per m^3 after seasoning and machining.

Overall Assessment

Based on the results of the industry assessment, Australian plantation-grown *K. senegalensis* has proven to produce a good quality attractive timber that was judged equal to or better than the native timber currently being imported into Australia. The timber was highly regarded by the various industry assessors who believed that there would be good prospects for the timber on the domestic market.

Tree Rankings

Based on the information derived from this study it is possible to select out superior individuals. This information can inform tree selections for breeding and cloning (e.g. see Reilly et al. 2007; Nikles et al. 2007). This section of the report deals with the identification of superior trees in only a very preliminary manner. Throughout the report those trees with the 'best' properties or assessment results have been listed, where relevant. As a crude method of selecting the best performing trees throughout the study, those trees appearing most frequently could be judged as the best performing trees. Table 17 lists the assessments and the trees with the 10 'best' results for each.

Table 17. The trees achieving the top ten results for various project assessments

Log length to volume ratio	Log end-split	Pith Off-set	Heartwood proportion	Distortion	GOS recovery	Overall grade recovery	Select grade recovery	Proportion of boards affected by stain
16	122	157	H13	H6	H11	H11	H11	3
122	11	158	H8	19	80	3	3	18
11	H1	H8	H9	H12	16	16	80	H7
80	14	154	157	122	86	80	16	150
70	70	156	80	155	122	122	18	H14
14	80	H10	155	77	3	157	15	H10
15	15	14	122	80	H7	H6	122	96
4	4	H5	H11	150	19	H8	157	H5
18	H13	11	16	84	14	15	H7	155
H1		19	25	25	H12	18	70	H8
						19		

Table 18 and 19 list the best and worst performing trees respectively, throughout the course of the study. A complete list of tree rankings is contained in Appendix H. Given that clonal material has been collected from all of the project trees, this variability in overall performance may be exploited to produce a superior second generation planting stock.

Table 18: Best performing trees

Tree	No. of times listed
122	7
80	7
16	6
H8	4
H11	4
157	4
19	4
18	4
15	4
14	4
3	4

Table 19: Poorest performing trees

Tree	No. of times listed
H2	0
153	0
152	0
151	0
12	0
H9	1
H14	1
158	1
156	1
154	1
96	1
86	1
84	1
77	1

Conclusion

It is important to remember when assessing the results of this study that the project logs came from trees that were not well managed silviculturally, and came from un-improved seed stock. In light of this fact and the obvious effect it had on 'log quality', the results in general should be viewed very positively. The lack of stand management, and the flow on effect to log quality, was the main negative factor found during the study. A *K. senegalensis* plantation planted with improved seed stock and managed according to best practice principles could significantly improve on the results published in this study.

During processing there was a significant amount of 'movement' with some stems, indicating high levels of growth stresses. GOS recovery figures were moderate at 39.5%, predominately due to poor log form and the movement of the logs during processing. The timber dried well, with little or no degrade; and the subsequent seasoning trials indicated that the timber could be dried relatively quickly with little degrade when using an appropriate schedule. The moderate GOS recovery, board distortion and the high incidence of knot related defects significantly impacted grade recovery. The high incidence of stain also impacted on the recovery of Select grade material. The finding that the incidence of stain was less severe in those trees from Howard Springs may indicate that staining could be managed through improved plantation health practices (i.e. environmental factors). Recovery figures generated during this study should be seen as baseline figures that could be significantly improved upon through the genetic improvement of the planting stock and improved silvicultural management.

Australian grown plantation *K. senegalensis* produces an aesthetically pleasing timber with marketable colour and figure attributes. The wood appears to be suitable for clear-finished or stained high-value applications, such as contemporary and reproduction furniture, cabinetry, windows, doors, and interior joinery. Further, the wood properties of the study timber support the use of this timber for these applications. However, a number of issues may affect the profitability of converting plantation logs to high-value appearance grade timber, namely: wandering pith; the proportion of stem under heartwood at a young age (relative to native grown material); and the development of decay, and therefore stain – all of which are issues that could potentially be addressed through breeding and correct silviculture.

The species has proven that in a plantation setting it can produce a high quality attractive timber that could conservatively be retailed for between $3000 and $5500 per m^3 for dried, dressed Medium feature to Select grade timber.

Based on the findings of this study of processing, utilisation and wood quality properties, Australian plantation grown *K. senegalensis* has proven to be a prime candidate species for the 'dry' northern tropics of Australia.

References

Armstrong, M. 1999. Effect of Growth Stresses on the Stem and Wood Characteristics of *Eucalyptus cloeziana* (F. Muell.). Honours Thesis, Australian National University, Canberra.

Bolza, E. and Keating, W. G. 1972. *African timbers – The properties uses and characteristics of 700 species*. Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia.

Bootle, K. R. 1983. *Wood in Australia – Types, properties and uses*. McGraw Hill, Sydney

Cameron, D. M. 1985. Forest crops, pp 165-178. In: Muchow, R.C. (ed). Agro-research for the semi-arid tropics: north-west Australia. Univ. Qld Press, St Lucia, Qld. 608 pp.

Farmer, R. H., *Handbook of hardwoods*, 2nd Edition, Department of the Environment, London, 1972

Hopewell, G., Leggate, W., Leet, M. and Spring, G. 2000. An evaluation of 10-year-old, Australian-grown paulownia. Queensland Forestry Research Institute, Department of Primary Industries, Queensland.

Knapp, S., Műller, P., Mabaso, L. and Kietzka, E. 2000. Assessment of 14 year old *E. grandis* clones for high value lumber production. IUFRO Working Party 2.08.01 Conference "Forest genetics for the next millennium" Durban, South Africa, 8-13 Oct 2000.

Leggate, W. 2000. 25-year-old Plantation-Grown Spotted Gum: Productivity, Sawn Recovery and Potential Rates of Return. Queensland Forestry Research Institute, Department of Primary Industries, Queensland.

Nicholson J.E., Hillis, W.E. and Ditchburne, N. 1975. Some tree growth and wood property relationships of eucalypts. *Canadian Jounral of Forest Research* **5(3)**: 424-432.

Nikles, D. G. 2004. A proposal for consideration: establish a northern Australia cooperative tree improvement program (NACTIP) with African mahogany (*K. senegalensis*) initially. Working Paper in: Bevege, D. I., Bristow, M., Nikles, D. G. and Skelton, D. (eds). 'Prospects for high-value hardwood timber planatations in the 'dry' tropics of northern Australia', Proc. Of a Workshop held 19-21 October, 2004, Mareeba, Queensland. Published as CD ROM by Private Forestry North Queensland Association Inc., Kairi, Qld.

Nikles, D. G., Bevege, D. I., Dickinson, G. R., Griffiths, M. W., Reilly, D. F. and Lee, D. J. (2007) Developing African mahogany (*Khaya senegalensis*) germplasm and its management for a sustainable forest plantation industry in northern Australia – progress and needs. Paper presented to the 2007 Australian & New Zealand Institutes of Foresters Conference, 3-7 June 2007, Opal Cove Resort, Coffs Harbour, NSW

Nolan et al. 2000.

Reilly, D. F., Robertson, R. M., Nikles, D. G., Robson, K. and Lee, D. J. (2007) Testing and breeding forest trees for plantations in the Northern Territory. RIRDC Publication No. 07/113. Rural Industries Research and Development Corporation, Canberra.

Smith, W., Kynaston, W., Cause, M. and Grimmett, J. 1991. Technical Pamphlet No. 1: Building Timber Properties and Recommendations for their Use in Queensland. Department of Primary Industries, Queensland Government, Australia.

Publication and Presentation List

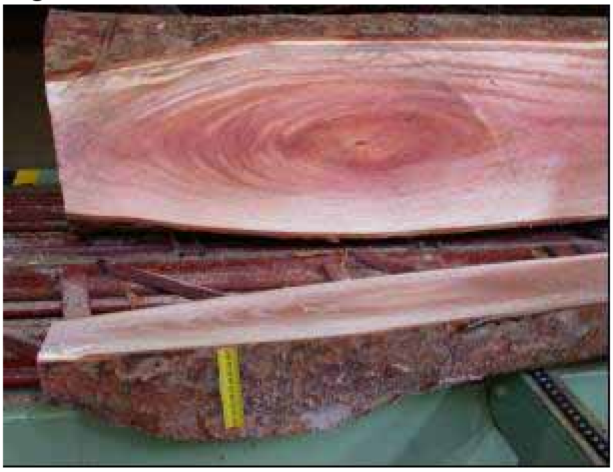
Extracts from this report have used to produce articles published in the following publications:

- Armstrong, M., Lelievre, T., Reilly, D. and Robertson, B. Evaluation of the wood quality and utilisation potential of plantation grown *Khaya senegalensis* (African mahogany). (In Bevege, D.I., Bristow, M., Nikles, D.G. and Skelton, D.J. (eds). 2004. *Prospects for high-value hardwood timber plantations in the 'dry' tropics of northern Australia*. Proc. of a Workshop held 19-21 October, 2004, Mareeba, Queensland. Published as a CD-ROM by Private Forestry North Queensland Association Inc., Kairi, Qld.
- Armstrong, M. 2005. *Khaya senegalensis* (African mahogany): Candidate species for sawlog focused hardwood plantations in the dry tropics. *Australian Forest Grower* **27 (4):** pp28 – 29.
- Armstrong, M. 2005. *Khaya senegalensis* (African mahogany): Candidate species for sawlog focused hardwood plantations in the dry tropics. *Australian Timberman*
- Armstrong, M. 2005. *Khaya senegalensis* (African mahogany): Candidate species for sawlog focused hardwood plantations in the dry tropics. *Australian Joinery Magazine*

Project Photos

Effect of branches on sawlog quality

Figure around knot



Wide sapwood band

Oval log with a graduated sapwood heartwood zone

Wandering pith (pith highlighted)

Boards with excessive spring

Colour variation in timber

The effect that light has on darkening the timber can be seen. The lighter strips have been where timber was laid.

Red heartwood

Sapwood and Heartwood boards

Henry Palaszczuk Queensland's DPI&F Minister and Michael Uljarevic Paragon Furniture's managing Director

Appendix A. Site and Field Data

Tree No.	Provenance	Form (5 – 1)	Dominance	DBHOB (cm)	Total tree Height (m)	Date felled	Stump height (m)	Merch log length (m)
3	Ghana d500	5	D	37.5	23	17/10/2003	0.45	5
4	Ghana d500	4	D	44.5	23.4	17/10/2003	0.47	7.5
11	New Caledonia D522	5	D	48.4	20	17/10/2003	0.5	5
12	Ghana d500	5	D	34.7	18	20/10/2003	0.38	4
14	Senegal S10066	4	D	47	27	20/10/2003	0.57	5.2
15	Ghana d500	3	D	44.1	21	20/10/2003	0.55	4.3
16	Uganda S10053	5	D	60	23	20/10/2003	0.7	7.2
18	New Caledonia D487	2	D	41.3	23.3	21/10/2003	0.4	3.6
19	New Caledonia D487	4	D	42.3	19.8	21/10/2003	0.4	6
25	Sudan S9687	4	CD	31.8	15	22/10/2003	0.4	4.3
77	Senegal S9392	4	D	28.7	13.7	22/10/2003	0.32	3.1
80	Togo D411	4	D	48.9	17.5	22/10/2003	0.48	3.6
84	Central Af Rep D391	4	D	36.4	14.2	22/10/2003	0.35	4
86	Upper Volta D415	4	D	36.1	15.3	22/10/2003	0.38	4.35
96	Senegal S9392	4	D	25.4	14.5	24/10/2003	0.29	4
122	Senegal D417	5	D	51.4	23.3	27/10/2003	0.38	7.2
150	Senegal S10066	3	D	31.9	19	20/10/2003	0.4	3.7
151	New Caledonia D487	4	D	36	21	21/10/2003	0.4	4
152	New Caledonia D488	4	CD	32.6	19.4	21/10/2003	0.4	4
153	Nigeria D486	Edge 5	CD	26.7	14.5	22/10/2003	0.3	4.5
154	Sudan S9687	4	D	26.3	14.2	22/10/2003	0.24	4
155	Senegal D417	4	CD	28.8	14.4	24/10/2003	0.3	3.75
156	Senegal D417	4	D	25.5	13.9	24/10/2003	0.25	4.8
157	Senegal D417	3.5	D	32.9	14.2	24/10/2003	0.27	4.8
158	Upper Volta D416	4.5	CD	27.2	15.8	24/10/2003	0.28	3.5
70	Senegal D417	F4.5	D	45.7	17.4	24/10/2003	0.4	3.7
H1	Senegal D417	edge	D	43	19.8	27/10/2003	0.46	4.85
H2	Senegal D417		D	33.1	19.7	27/10/2003	0.4	5.45
H5	Senegal D417		D	32.4	19.5	28/10/2003	0.36	4.8
H6	Senegal D417		D	28.4	21.2	28/10/2003	0.36	5.6
H7	Senegal D417		D	37.9	24.8	28/10/2003	0.3	4.3
H8	Senegal D417	Good tree	D	34.9	19.8	28/10/2003	0.38	4.5
H9	Senegal D417		CD	31.9	19.6	28/10/2003	0.33	4.25
H10	Senegal D417		D	29.1	19	29/10/2003	0.28	4.63
H11	Senegal D417		CD	35.2	16.1	29/10/2003	0.33	4.84
H12	Senegal D417		CD	34.8	19.7	27/10/2003	0.3	7.4
H13	Unknown	Edge type	D	41.8	18.2	29/10/2003	0.35	4.85
H14	Unknown		D	26.6	17.6	29/10/2003	0.28	5.8

Appendix B. African Mahogany (*Khaya senegalensis*) – Kiln Drying Schedule Development Trials

(Undertaken by Adam Redman)

Scope

The following document is an account of experimental scale drying trials for the development of a drying schedule to dry 25 mm thick (nominal) *Khaya senegalensis* boards.

Equipment

Trials were conducted in the Queensland DPI&F Salisbury Research Centre 0.2 m^3 experimental conventional kiln. The kiln is controlled by an 'in-house' kiln control program. Heat is controlled by a series of electrical elements. Humidity is controlled by an electrical powered boiler and variable venting. Variable speed fans are used to provide airflow. The moisture content of the kiln load is measured using a load cell underneath the stack. In the case of these trials the kiln conditions were controlled automatically based on the moisture content of the timber.

Literature Review of Published Schedules

The following is a review of current available drying schedules for *Khaya senegalensis*. In the case where the schedules obtained specified temperature settings to the nearest 0.1ºC, these settings were rounded to the nearest 0.5ºC.

Reference 1

Boone et al. (1993) suggests the following schedules for 4/4, 5/4, and 6/4 inch dimension stock.

U.S. Schedule (T2-D4)

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 50	37.5	34	15	79
50-40	37.5	32	12	68
40-30	37.5	32	12	68
30-25	43.5	32	8	45
25-20	49	32	6	31
20-15	54.5	32	4.5	21.5
15 to final	65.5	37.5	4	18

British Schedule (A)

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 60	35	30.5	13	72.5
60-40	35	28.5	10.5	61.5
40-30	40	31	9	53
30-20	45	32.5	7	42.5
20-15	50	35	6	37.5
15 to final	60	30	2.5	11.5

The following US schedule is suggested for wider 8/4 inch dimension stock.

US Schedule (T2-D3)

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 50	37.5	35	18.5	84.5
50-40	37.5	34	15	79
40-30	37.5	32	12	68
30-25	43.5	32	8	45
25-20	49	32	6	31
20-15	54.5	32	4.5	21.5
15 to final	65.5	37.5	4	18

Reference 2

The following schedules were developed based on the specific gravity of the timber as suggested by Simpson and Verill (1997). The average specific gravity can be used to produce a drying schedule using the program supplied by Simpson and Verill at the following internet address: http://www1.fpl.fs.fed.us/drying.html. The program itself has a database of species included whereby the specific gravity for each species is fixed from published data.

Alternatively if the exact average specific gravity of the material to be dried is known a schedule can be generated solely dependant on this value. The program generates two schedules based on both regression and classification approaches from published data. Simpson and Verill (1997) suggest that the classification approach schedule is generally considered to be more accurate.

Khaya senegalensis is one of the species included in the computer program database. The recommended schedule in this case is:

Schedule T2-D2 (25-38 mm)

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 50	38	36	18.5	87.5
50-40	38	35.5	17	85
40-35	38	34.5	15	79
35-30	38	32	11.5	66
30-25	43.5	32	7.5	45
25-20	49	32	5.5	31
20-15	54.5	32	4	21.5
15 to final	65.5	38	3.5	19

From recent trials, the average specific gravity of the said material is approximately 0.636. Using this value the program produced the following recommended schedules:

Schedule T5-D3 (25-38mm) – regression approach

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 50	49	46	16	84.5
50-40	49	45	14.5	79.5
40-35	49	43	11.5	70.5
35-30	49	38.5	8.5	52.5
30-25	54.5	35	5	28.5
25-20	60	32	3	15
20-15	65.5	38	3.5	19
15 to final	71	43.5	3.5	22

Schedule T6-D2 (25-38mm) – classification approach

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 50	49	46.5	17	87
50-40	49	46	16	84.5
40-35	49	44.5	13.5	77
35-30	49	41	10	62
30-25	54.5	38	6	36
25-20	60	32	3	15
20-15	65.5	38	3.5	19
15 to final	82	54.5	3.5	27

Reference 3

Farmer (1972) recommends the following schedule:

Schedule F (25-38 mm)

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 60	48.5	44	13.5	77
60-40	48.5	43	12.5	72.5
40-30	51.5	43	9.5	61
30-25	54.5	43	8	51.5
25-20	60	46	7	46.5
20-15	68	51	6	42
15 to final	76.5	58	5.5	42

Reference 4

Rozsa and Mills (1991) recommend a schedule for 25 mm *Khaya spp*. It does not specifically stipulate *Khaya senegalensis* but it does state that this species is an exotic either imported directly into Australia or is an introduced species now growing in plantations. The schedule follows:

Schedule CW (25 mm)

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 60	50	45	13	75
60-40	50	42	10	62.5
40-35	55	45	8.5	57
35-30	55	40	6.5	41
30-25	60	40	5	30.5
25-20	65	45	5	33.5
20-15	70	50	5	35.5
15 to final	70	50	5	35.5

Trial Methodology

The following methodology was used for both trials 1 and 2. Note that end matched samples were used for each trial.

Initial Measurements

- Twenty 1000 mm length boards (wrapped) were obtained from the fridge at Queensland DPI&F Indooroopilly and transport to DPI&F Salisbury.
- Each board was previously individually numbered.

- 75 mm was removed from the end of each board and discarded.

- A further 25 mm was removed from the freshly cut end of each board and labelled with the board original number. The pieces were wrapped in impermeable plastic until moisture content/basic density testing.

- The remaining 900 mm sections were end coated.

- In accordance with AS/NZS 4787 – Timber – Assessment of drying quality, collapse, surface checking, end checking and end split was measured on the 900 mm boards. Note: Distortion was not measured because the pieces were too short to be representative and the stack too small to provide representative restraint.

- The weight of the 900 mm sections was recorded. This is required to measure the total kiln load mass and hence moisture content for kiln control.

- The 900 mm sections were wrapped in impermeable plastic until drying was ready to proceed.

- The average moisture content and basic density of the 25 mm samples was measured as soon as practicably possible in accordance with AS/NZS 1080.1 and AS/NZS 1080.3 respectively.

Racking and drying

- Once the average MC of each 900 mm section was calculated drying could commence.

- The material was racked into the kiln and the kiln started using the recommended schedule with an airflow of approximately 1.5 m/s. A four-hour warm-up from ambient temperature to the initial kiln conditions (holding the same initial depression) was employed. The kiln was controlled based on the average MC of the boards via the kiln load cell.

- Following the recommended schedule, the material was dried to an average MC of 9%.

- The material was equalised to 10% MC for 24 hours under the following conditions: Dry Bulb Temp = last dry bulb temperature condition of the schedule and Wet Bulb Temp = wet bulb temperature to provide a 10% equilibrium MC in the kiln.

Final Measurements

- Each board was dressed to a thickness of 19 mm (evenly planed on both wide faces).

- Surface checking on each face, end checking, collapse and end split were measured and classified in accordance with AS/NZS 4787.

- 100 mm was cut from the end of each board and discarded.

- Two 25 mm and one 50 mm length sections were cut from the end of the freshly sawn end of each board and labelled with the same board number appended with ’a’, ‘b’ and ‘c’ respectively.

- The 25 mm ‘a’ sections were used to measure average MC using the oven dry method in accordance with AS/NZS 1080.1. The 25 mm ‘b’ sections were ripped into three equally sized thicknesses to measure the MC gradient using the oven dry method in accordance with AS/NZS 1080.1. In accordance with AS/NZS 4787, the average MC and MC gradient values from the 20 boards were rated to give a quality rating for each property.

- In accordance with AS/NZS 4787 the residual drying stress was measured and rated using the 50 mm ‘c’ sections.

Trial 1 Schedule Development

Initially a schedule was chosen based on the harshest conditions of the above listed schedules. The schedules pertaining to reference 1 have been discounted as they are for 4 inch thick stock and are considered inapplicable. The other schedules presented are specifically designed for 25-38 mm thick material.

Schedule T6-D2 (from reference 2) has the harshest final conditions below the fibre saturation point (25% moisture content) while the schedule CW presented in reference 4 has harsher initial conditions above FSP. Therefore the initial schedule is a combination of the harshest parts of each schedule and is presented below.

Initial Schedule Trial 1

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 60	50	45	13	75
60-40	50	42	10	62.5
40-35	55	45	8.5	57
35-30	55	40	6.5	41
30-25	60	40	5	30.5
25-20	60	32	3	15
20-15	65.5	38	3.5	19
15 to final	82	54.5	3.5	27

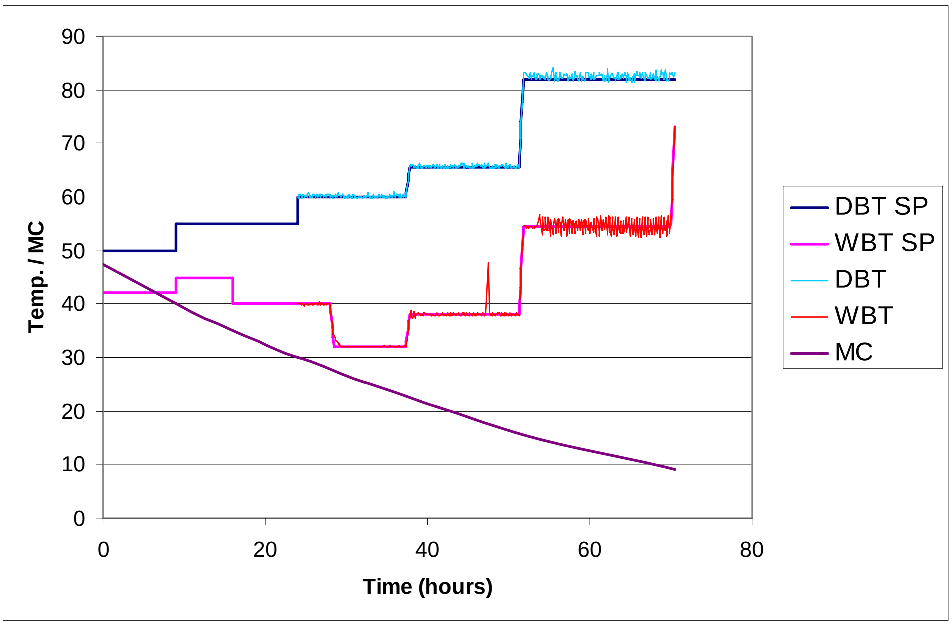
Trial 1 Results

Initial moisture content = 47.4%
Drying Time = 70.5 hrs (excluding 24 hour equalising period)
Final moisture content = 9% before equalising
Final moisture content = 10.5% after equalising
After boards dressed/dried:
  # boards collapsed = 0
  # boards checked = 0 (except 1 board – heart check – not drying degrade)
  # boards end split = 0
Dried quality results (AS 4787) – see following table
  Average MC grade = fail
  MC gradient grade = fail
Drying stress grade = pass

Results from Trial 1

	Average MC %		MC Gradient %				Drying Stress		
Sample #	MC (%)	Grade	MC Sides (%)	MC Centre (%)	MC difference	MC Gradient Grade	Width (mm)	Gap (mm)	Drying Stress Grade
11-2	11.0	A	11.0	11.7	0.7	A	96.35	0.46	A
15?-2	20.3	Fail	15.1	21.9	6.8	Fail	102.1	0	A
15-2	10.8	A	11.4	11.6	0.3	A	101	0.41	A
153-2	11.9	A	12.0	12.7	0.7	A	102.8	1.11	C
154-2	10.3	A	10.9	11.6	0.8	A	101.7	0.43	A
157-2	8.3	B	9.5	9.3	-0.2	A	98.19	0.12	A
25-2	23.7	Fail	16.4	27.1	10.7	Fail	104.2	0	A
7H-2	11.4	A	11.0	11.6	0.6	A	99.56	0.47	A
86-2	19.8	Fail	14.0	19.6	5.6	Fail	102.7	0	A
H10-2	10.8	A	10.7	11.2	0.5	A	100.8	0.83	B
H13-2	9.0	A	10.0	10.1	0.1	A	100.9	0.67	B
H2-2	11.3	A	11.4	12.0	0.5	A	99.69	0.67	B
H8-2	20.7	Fail	16.2	21.7	5.5	Fail	102.3	0	A
T135-2	10.2	A	11.2	11.7	0.6	A	95.15	0.52	B
T138-2	8.2	B	8.9	9.0	0.1	A	100.5	0.61	B
T154-2	8.9	B	9.4	8.8	-0.6	A	102.3	0.47	A
T229-2	10.8	A	11.5	11.8	0.3	A	100.6	0.73	B
T275-2	9.9	A	10.2	10.1	-0.1	A	101.5	0	A
T922-2	11.1	A	11.9	11.9	0.0	A	101.8	0.47	A
T929-2	11.0	A	11.8	12.4	0.6	A	101.7	0.36	A
Total Grade		Fail				Fail			B

Drying Conditions during Trial 1



Trial 1 Discussion

If only the visual appearance grade results are taken into account then this trial would be considered a success; however, due to the failed average final moisture content and moisture content gradient results the overall dried quality is dismal.

Standard AS 4787 gives a quality class from A to E for a range of dried quality criteria. It does this by quantifying quality bandwidths for each class dependent on target values. The standard works such that each board is individually classified and then a total classification or grade is given based on 90% of boards falling into the highest class category. Obviously quality class A is the best or preferred class followed by class B and so on. Generally in industry class B is the cut off for appearance grade products.

From the data above four out of twenty sample boards completely failed to fall into any class for average moisture content and moisture content gradient. Therefore as this represents 20% of the sample size 90% of the boards do not fall into any class and therefore fail completely for these quality criteria. The B rating for residual drying stress is passable.

Obviously the reason that these boards failed was because of their extremely high moisture contents compared with the other sample boards. This shows convincing evidence that these boards have suffered from case hardening. This will generally occur if boards have been dried too quickly after the fibre saturation point (approx. 25% MC). Basically when a board's average MC is around the fibre saturation point (approx. 25% MC) stress reversal occurs whereby the outside of the board goes into compression and the inside of the board into tension (as opposed to early drying). If the drying rate after fibre saturation point is too great the compressive surface stress can cause the surface of the board to permanently 'set' and effectively stop/considerably reduce the water transport through the wood surface. Because wood is an inhomogeneous material not all boards will case harden under the same conditions.

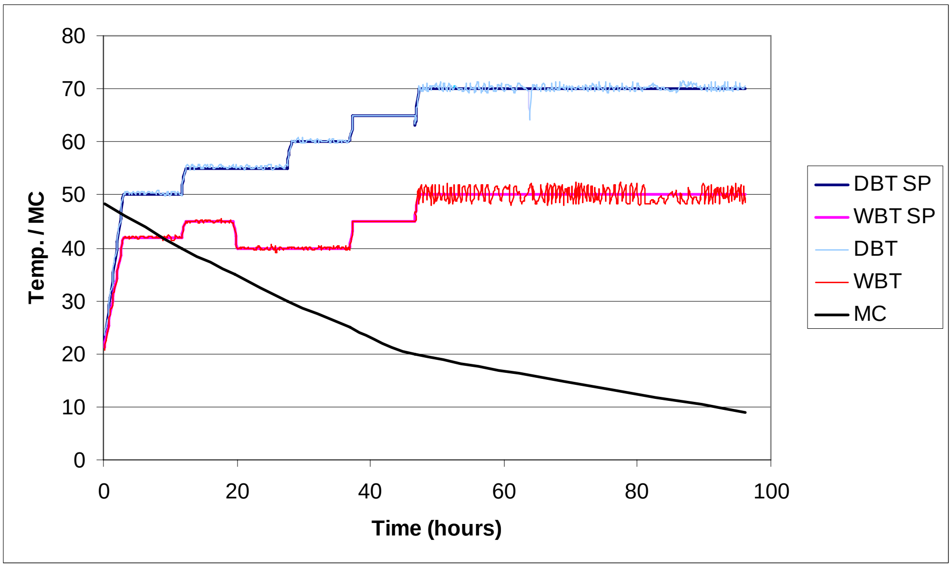
Trial 2 Schedule Development

From the results given from trial 1 the following schedule was proposed. It has the same conditions above the fibre saturation point as the first trial but is considerably less harsh than the first schedule during the later part of drying. It is the same schedule (CW) suggested by Rosza and Mills (1991) for 25 mm thick material.

Initial schedule Trial 2

Moisture Content Change Point %	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	EMC (%)	Relative Humidity %
Above 60	50	45	13	75
60-40	50	42	10	62.5
40-35	55	45	8.5	57
35-30	55	40	6.5	41
30-25	60	40	5	30.5
25-20	65	45	5	33.5
20-15	70	50	5	35.5
15 to final	70	50	5	35.5

Drying condition during Trial 2



Trial 2 Results

Initial moisture content = 48.3%
Drying Time = 96.2 hrs (excluding 24 hour equalising period)
Final moisture content = 9% before equalising
Final moisture content = 10.6% after equalising
After boards dressed/dried:
- # boards collapsed = 0
- # boards checked = 0 (except 2 boards – slight heart check – not drying degrade)
- # boards end split = 0

Dried quality results (AS 4787) – see following table for details
- Average MC grade = B
- MC gradient grade = B

Drying stress grade = C

Results from Trial 2

	Average MC %		MC Gradient %				Drying Stress		
Sample #	MC (%)	Grade	MC Sides (%)	MC Centre (%)	MC difference	MC Gradient Grade	Width (mm)	Gap (mm)	Drying Stress Grade
11-3	9.7	A	9.5	10.0	0.5	A	97.37	0	A
156-3	11.0	A	10.5	10.9	0.4	A	99.88	0.81	B
15-3	11.8	A	11.3	12.0	0.7	A	98.83	1.15	C
153-3	8.6	B	8.5	8.3	-0.2	A	100.5	1.12	C
154-3	11.1	A	11.2	11.5	0.3	A	102.5	0	A
157-3	8.7	B	8.4	8.6	0.1	A	97.92	1.29	C
25-3	10.8	A	10.2	11.2	1.0	A	102.9	0	A
7H-3	12.4	A	11.6	12.7	1.0	A	97.81	0.44	A
86-3	12.7	A	12.4	13.2	0.7	A	104.2	0	A
H10-3	13.0	B	12.6	14.2	1.7	B	99	0	A
H13-3	8.3	B	8.5	8.4	-0.1	A	99.82	0.91	B
H2-3	11.3	A	11.3	11.5	0.3	A	92.6	0.62	B
H8-3	11.1	A	10.7	11.8	1.1	B	102.7	0.63	B
T135-3	9.3	A	8.6	9.6	1.0	A	99.5	0.74	B
T138-3	10.0	A	9.9	10.4	0.4	A	100.9	0.62	B
T229-3	11.6	A	11.8	12.7	0.8	A	102.6	0	A
T275-3	8.3	B	8.1	7.8	-0.3	A	98.96	1.38	C
T922-3	11.3	A	10.9	11.5	0.6	A	99.95	0.7	A
T929-3	10.8	A	10.6	10.8	0.3	A	99.22	0.6	A
Total Grade		B				B			C

Trial 2 Discussion

There was no drying induced collapse, surface checking, or end split measured in this trial. Dried quality in regards to final moisture content and moisture content gradient (both class B) was good. The residual drying stress grade (class C) may be considered a little high but is still satisfactory. Generally the drying stress can be improved by increasing the equalisation period.

Conclusions

Both schedules proved to be adequate at drying the material free of visual degrade. However, the schedule used in trial 1 was too harsh below fibre saturation point resulting in a number of boards exhibiting ‘wet wood’ properties. This is most likely attributed to the phenomena of case hardening.

This was remedied in trial 2 whereby the initial schedule was altered to provide less harsh conditions below the fibre saturation point (25% MC). This did result in an increase in drying time (excluding equalising time) of 36% (96.2 hrs cf. 70.5 hrs).

Due to better results in dried quality the schedule used in trial 2 is recommended for drying this material.

References

Boone, R. S., C. J. Kozlik, et al. (1993). Dry kiln schedules for commercial woods - Temperate and tropical., Forest Products Society.

Farmer, R. H. (1972). Handbook of Hardwoods. London, Ebenezer Baylis & Son Ltd., The Trinity Press.

Rosza, A. and R. G. Mills (1991). Index of Kiln Seasoning Schedules. Melbourne, CSIRO.

Simpson, W. T. and S. P. Verill (1997). "Estimating kiln schedules for tropical and temperate hardwoods using specific gravity." Forest Products Journal **47**(7/8): 64-68.

Appendix C. Accelerated Decay Bioassay

(Undertaken by Lesley Francis)

Background

The following report presents findings from an accelerated decay bioassay of mature plantation grown *Khaya senegalensis* (African mahogany). Accelerated decay bioassay is a rapid laboratory method that may be used to gain an indication of a timber's relative decay resistance.

Natural durability is defined in Australian Standard AS 5604-2003: Timber-Natural Durability Ratings, as the inherent resistance of a timber species to decay and insect attack. Wood properties within a species and even within an individual tree can vary (AWPA 1999; Standards Australia 2003). Consequently, the classification of a species' durability cannot be done with absolute sensitivity, and instead durability ratings reflect a range of expected service life values. A species' performance is also influenced by the hazard to which it will be exposed. Decay hazard influences include the climate and microbial ecology where the timber will used, whether or not it will be used in contact with the ground, as well as its level of exposure to the elements.

In the context of the Standard, natural durability ratings are assigned according to a species performance both in contact with the ground and above ground when exposed to average environmental conditions (Table C–1). AS 5604-2003 classifies natural durability into four groups, with species assigned to durability class 1 being most durable, while species assigned to durability class 4 are the least durable.

Table C–1. Natural durability – probable life expectancy for average environmental conditions (AS 5604-2003)

Durability Class	Probable in-ground life expectancy (years)	Probable above-ground life expectancy (years)
1	Greater than 25	Greater than 40
2	15 to 25	15 to 40
3	5 to 15	7 to 15
4	0 to 5	0 to 7

Notes:

1 As further reliable evidence becomes available, these ratings may require amending.
2 The heartwood of an individual piece of timber may vary from the species' nominated classification.
3 Above-ground conditions equate to outside above-ground subject to periodic moderate wetting when ventilation and drainage are adequate.
4 The ratings in Table C–1 are based on expert opinions and on the performance of the following test specimens: (a) in-ground: 50 × 50 mm test specimens at five sites around Australia; and (b) above-ground: 35 × 35 mm test specimens at eleven sites around Australia (this project continues, and specimens have now been exposed for 16 years) (Standards Australia 2003).

The in-ground classification (Table C–1) is widely accepted as a general guide, and is essentially a rating of the durability of the species heartwood when in ground contact and exposed to attack by decay and termites. Because of this combined assessment, the classification may not truly reflect the special qualities of some species (for example, brush box is very resistant to termites but much less so to decay) (Standards Australia 2003). General species resistance is largely determined by the extractives formed when sapwood changes into heartwood. Termites are less easily deterred by these extractives than fungi and will attack most species, though slowly in the case of the very durable species. It is generally accepted that the performance of untreated heartwood above ground will be better than its performance in the ground, and untreated sapwood is considered to have poor resistance to biological attack (Smith et al. 1991; Standards Australia 2003).

African mahogany heartwood is currently classified as a durability class three timber. Durability class three timbers have a probable in-ground life expectancy of five to 15 years and a probable above-ground life expectancy of seven to 15 years (Standards Australia 2003). The aim of this study was to compare the decay resistance of *K. senegalensis* samples with reference timber species representing each of the four durability classes.

This study was undertaken as part of a comprehensive *K. senegalensis* processing project. As the focus of the project was processing, samples were selected on the basis of suitability for processing studies. After the material was distributed for the processing study a small amount was available for accelerated durability testing. Therefore a relatively small qualitative bioassay was completed.

Method

The agar-plate accelerated decay (APAD) bioassay method used for this study is a qualitative method designed to provide a reproducible means of establishing the relative decay resistance between various species of wood. APAD combines aspects of European Standard EN113, agar jar technique (EN_113 1996) and American Standard D2017-81, soil jar technique (ASTM_D2017-81 1986) and involves the short-term exposure of small timber samples to pure cultures of decay fungi.

Sample selection

K. senegalensis samples, along with samples from various reference species were selected for separate exposure to three decay fungi (Table C–2). All samples consisted of heartwood, except for *Eucalyptus grandis*, spotted gum and *Eucalyptus dunnii* where juvenile wood was used. Spotted gum sapwood was also included for comparison as it is considered to have low durability (Standards Australia 2003). The reference samples represent a range from low to high durability and all reference timber samples were free of knots and excessive amounts of resin or gums, and had no visible evidence of fungal infection. Eighty-eight separate *K. senegalensis* samples were included. These samples were obtained from 42 *K. senegalensis* logs that were harvested from 42 separate trees (Appendix C–2). Discs were cut from the bottom and top of each log, and a small sample from the middle region of heartwood from each disc was retained for accelerated decay testing (i.e. section from mid way along the radius of each heartwood disc). Given the small amount of material available, some *K. senegalensis* samples were irregular in size or appearance; however none had any visible signs of fungal infection.

Sample Preparation

Timber samples were sawn into slices approximately 15 mm (radial) x 25 mm (tangential) x 2-3 mm (longitudinal). These slices were labelled with a waterproof marker promptly after sawing. In most cases *K. senegalensis* timber slices were smaller as there was limited sample material available, samples that were exceedingly small or irregular in appearance were noted (Appendix C–1). Accelerated weathering of slices was then undertaken according to a modified version of European Standard EN 84 (Accelerated Ageing of Treated Wood Prior to Biological Testing – Leaching Procedure) (EN_84 1984). For each timber sample, replicates were transferred to 500 ml flask and immersed in sterile deionised water so that the volume of water was approximately 10 times the volume of the specimens. Samples in flask were then placed on an orbital shaker for five days and the water was changed daily.

Following weathering, samples were oven-dried for approximately 24 hours at 103^{O}C then weighed (constant mass was measured to ensure the samples were completely dry). Samples were then sealed in airtight plastic bags and sent for sterilisation by gamma-irradiation (25 kilograys, i.e.approx. 3.25 hours @ 8 kGy/hr) at the University of Queensland Irradiation Facility.

Table C–2. Timber samples (sample from one timber board unless otherwise indicated)

Reference Samples	Source	Details
Radiata pine *Pinus radiata*	commercially available timber	Durability class 4 - low durability
Dunn's white gum *Eucalyptus dunnii*	young plantation	Juvenile wood (durability class 4 – low durability) Separate samples from four different trees 3,6, 9, 10
Rose gum *Eucalyptus grandis*	young plantation	Juvenile wood
Rose gum *Eucalyptus grandis*	mature native	Durability class 3 – moderate durability
Spotted gum sapwood *Corymbia* spp.	mature native	Low durability
Spotted gum *Corymbia* spp.	young plantation	Juvenile wood
Spotted gum *Corymbia* spp.	mature plantation	Durability class 2 – high durability
Spotted gum *Corymbia* spp.	mature native	Durability class 2 – high durability
Grey ironbark *Eucalyptus* spp.	mature native	Durability class 1 – highest durability
Cypress *Callitris glaucophylla*	commercially available timber	Durability class 1 – highest durability
African mahogany (*Khaya senegalensis*)		
African mahogany *Khaya senegalensis*	mature plantation	88 samples from 42 individual trees

Exposure to Decay Fungi

One set of weathered and sterilised timber samples (consisting of five replicates from each timber sample) were separately exposed to the white rot decay fungus, *Coriolus versicolor*, and the brown rot decay fungus, *Fomitopsis lilacino-gilva*. These species of decay fungi were selected because they are among those recommended for use in conventional soil jar accelerated decay bioassays (AWPC 1997), and they had also best differentiated timbers of different durability in previous accelerated decay bioassays carried out at QDPI&F Horticulture and Forestry Science (H&FS) (Catesby and Powell 1999; Francis and Armstrong 2004; Meldrum and Powell 2002).

To prepare cultures to inoculate test timbers, each of the fungi were aseptically sub-cultured from the QDPI&F H&FS Wood Pathology Culture Collection onto fresh sawdust agar plates consisting of 15 mL of Technical Agar No 2 (Oxoid™) with 1 g of gamma-sterilised *Pinus carribea* sapwood sawdust and 1 g of gamma-sterilised *E. grandis* sawdust, each spread over half of the plate. Revitalised cultures were then transferred onto 1% malt extract agar, then sub-cultured onto 1% malt extract agar plates (15 mL) ready to be used to inoculate timber samples. These inoculum cultures were incubated at 26^{O}C with no light for seven to 10 days, depending on the speed of mycelial growth.

Sterile culture vessels were prepared for each fungus, each consisting of a glass slide support on the surface of a 1% malt extract agar plate (10 mL) (Oxoid™ Technical Agar No 2 and Oxoid™ Malt Extract). Each of the five replicates from each timber specimen was individually added to separate culture vessels. Approximately 1 mL of sterilised de-ionised water was placed on top of each timber sample after it had been aseptically placed on top of a slide in its culture vessel to ensure adequate moisture for the fungi to colonise the sections.

Culture vessels were then inoculated with plugs of mycelium (3 mm diameter) that were aseptically transferred from the advancing edge inoculum cultures described above. Two mycelial plugs of inoculum were added to each culture vessel, one either side of the timber sample supported by the glass slide. Vessels were enclosed in paraffin tape and incubated at $26^{O}C$ with no light. Ideally, exposure is continued until pine or hardwood sapwood reference samples have undergone at least 20% mass loss, so samples exposed to *Fomitopsis lilacino-gilva* were incubated for 11 weeks while samples exposed to *Coriolus versicolor* were exposed for eight weeks to maximise decay. After the allotted exposure times, all sections were removed from their culture vessels, oven dried overnight (at 103°C) and then weighed. The relative decay resistance of timber samples was then determined by comparing losses in sample weights.

Data analysis was undertaken using GenStat (V6.1). Mean mass lost to decay was calculated for each group of five replicate samples. Box and whisker plots were generated for each set of samples exposed to a particular decay fungus, followed by one tailed analysis of variance (ANOVA) of sample means. Pair-wise multiple comparisons (using Fishers protected least significant difference analysis) were then undertaken if appropriate. In other accelerated decay bioassays such as soil jars and agar jars, timber specimens are often classified according to their mean percent mass loss. This approach however, is of limited statistical significance for APAD bioassay, but it can be used as a general guide (see Appendix C–4).

Results

The relative mass losses of timber samples following exposure to each of the decay fungi are listed in Appendix C–1 and are illustrated in the 'box and whisker' plots below (Figures C–1 and C–2). In the plots, each 'box' spans the inter-quartile range for that species, so that the middle 50% of the data lay within the box, while the line in each box indicates the median. The 'whiskers' extend to the minimum and maximum values.

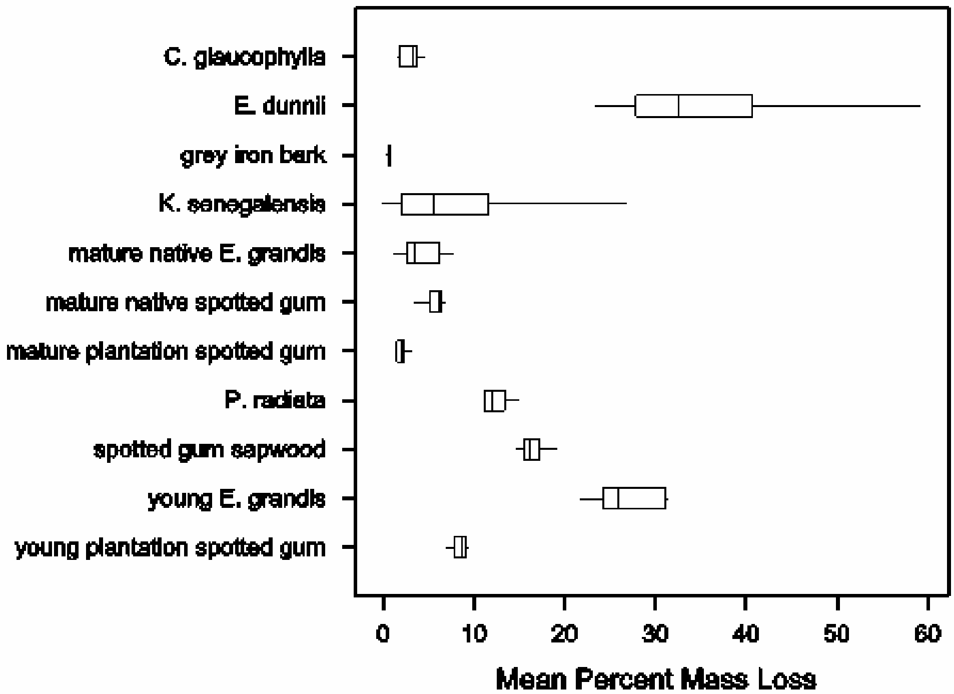


Figure C–1. Relative decay susceptibility of K. senegalensis and reference samples represented as mean percent mass loss following exposure to the white rot fungus *Coriolus versicolor.*

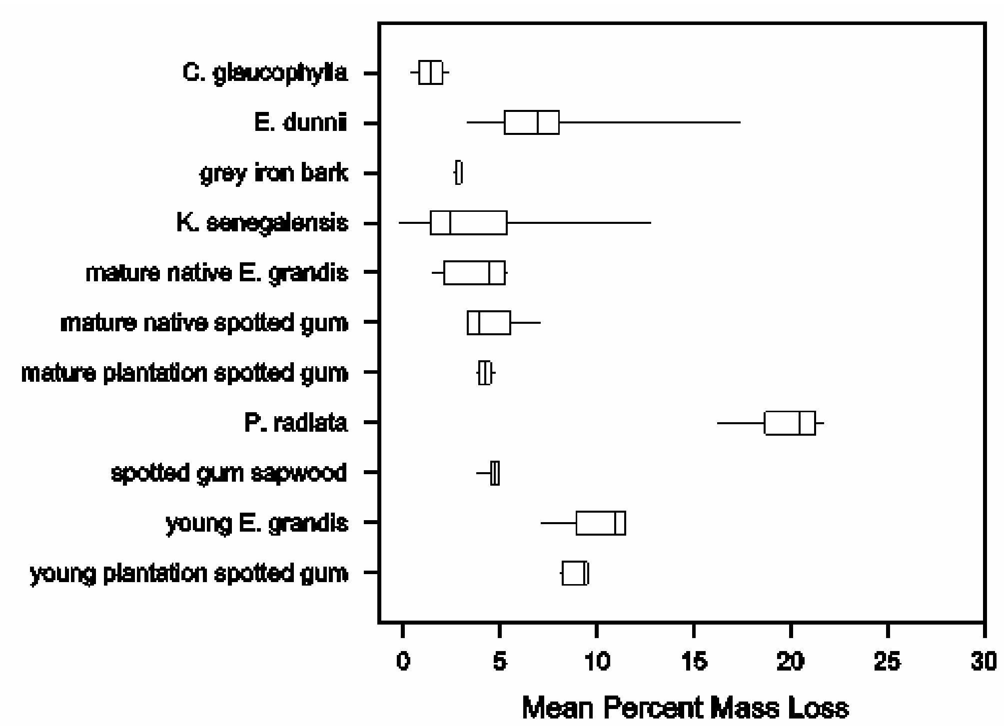


Figure C–2. Relative decay susceptibility of *K. senegalensis* and reference samples represented as mean percent mass loss following exposure to the brown rot fungus *Fomitopsis lilacino-gilva.*

The relative mass losses observed for the reference samples were generally consistent with results from previous accelerated durability bioassays carried out by QDPI&F H&FS (Catesby and Powell 1999; Francis and Armstrong 2004; Meldrum and Powell 2002). In contrast to previous bioassays however, the mature plantation spotted gum had less mass loss than the mature native spotted gum sample, particularly after exposure to the white rot *C. versicolor*. The mature native spotted gum samples were prepared from a large stock and less durable inner heartwood (Clark and Scheffer 1983; Ocloo 1975) may have been used in this bioassay inadvertently. The mature native *E. grandis* sample however, had not been previously tested. Results suggest that this particular mature native grown sample is more resistant to decay by basidiomycete decay fungi than is common for that species (mass loss has been higher for other samples of mature *E. grandis* used in previous bioassays). Reference samples are included as a general guide, and it should be noted that reference samples were each obtained from one timber sample only.

The ranked order of mean mass loss for the replicate samples exposed to the brown rot fungus was somewhat different to that for the white rot (see Appendices C–1 and C–3). For example, juvenile *E. dunnii* and *E. grandis* were most susceptible to decay by the white rot fungus *C. versicolor*. Alternatively, *P. radiata* was most susceptible to decay by the brown rot fungus, *F. lilacino-gilva*.

While the mean decay resistance of the *K. senegalensis* samples was moderately high, considerable variability was observed (see Figures C–1 and C–2, Appendices). To identify which samples had mean mass loss results that were significantly different statistically, pair-wise multiple comparisons were performed. As shown in Appendix C–3, the results provide a continuum of significant differences.

After exposure to *C. versicolor*, *K. senegalensis* samples from 86% (36/42) of trees showed bottom-sample mass losses to be greater than the top-sample mass loss. Of the six trees whose top-sample mass losses were greater than the bottom-sample mass loss, three were ‘b’ samples (8 m in length). For samples exposed to *C. versicolor*, the bottom-samples’ mass losses ranged from 1.23 to 22.23% while the top-samples’ mass losses ranged from 0 to 14.27%. The mean mass loss from bottom-samples was 9.4% while the mean mass loss for the top-samples was 3.9%.

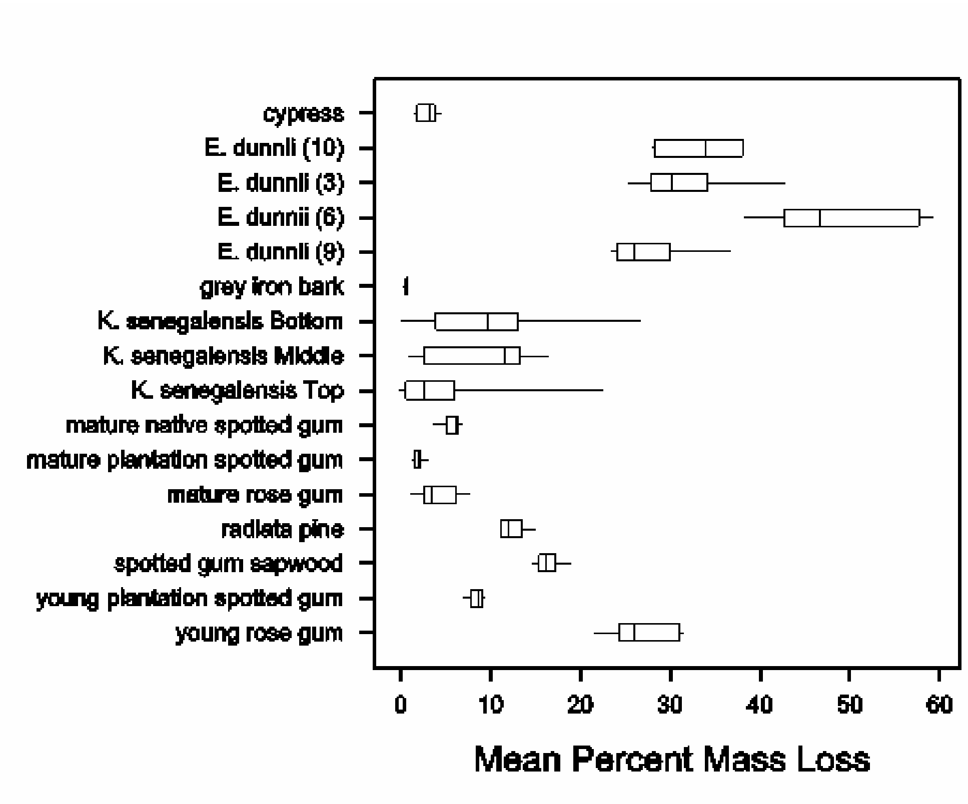


Figure C–3. Relative decay susceptibility of *K. senegalensis* samples from different sample locations. With reference samples, represented as mean percent mass loss following exposure to the white rot fungus *Coriolus versicolor.*

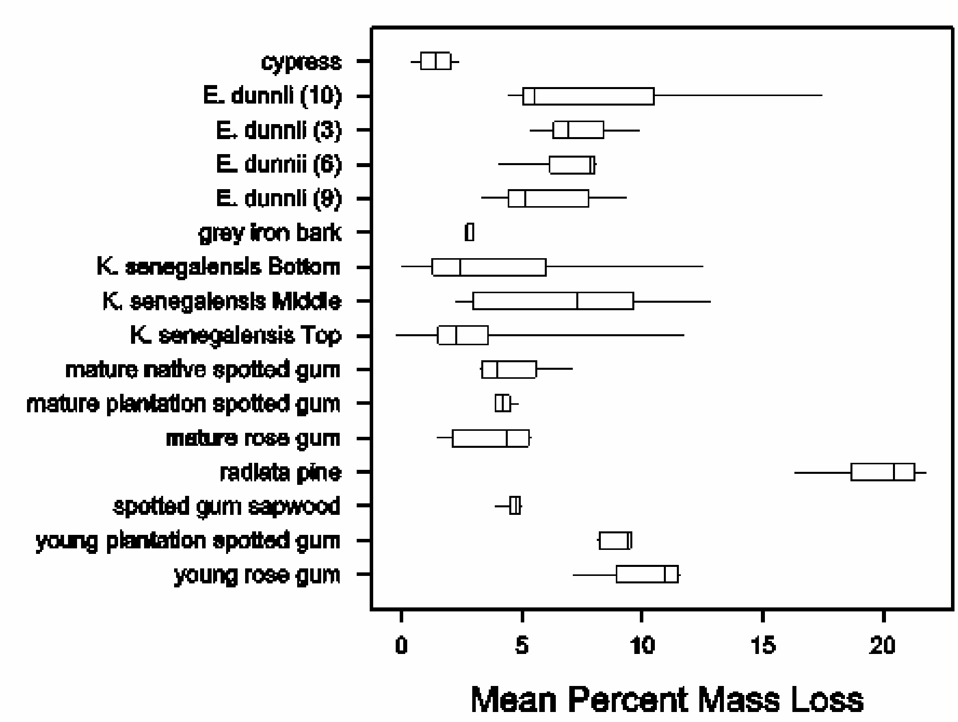


Figure C–4. Relative decay susceptibility of *K. senegalensis* samples from different sample locations. With reference samples, represented as mean percent mass loss following exposure to the white rot fungus *Fomitopsis lilacino-gilva.*

After exposure to *F. lilacino-gilva*, *K. senegalensis* samples from 76% (32/42) of trees showed bottom-sample mass losses to be greater than the top-sample mass loss. Of the 10 trees whose top-sample mass losses were greater than the bottom-sample mass loss, three were ‘b’ samples (8 m in length). For samples exposed to *F. lilacino-gilva,* the bottom-samples’ mass losses ranged from 0.41 to 10.48% while the top-samples’ mass losses ranged from 0 to 10.33%. The mean mass loss from bottom-samples was 3.8% while the mean mass loss for the top-samples was 3.2%.

Discussion and Conclusions

Many variables affect a timber’s performance in service. These include the climate and microbial ecology of the local area, along with the purpose, design and maintenance of the timber product. These factors are in addition to the relatively mild variations that occur naturally between timbers from different trees of the same species. Field exposure trials that are designed to simulate field conditions similar to those for the perceived end use of the timber in question are an ideal method for determining the natural durability of a timber species. However, these field trials can take decades to complete, and the expense involved in setting up field trials with sufficient replication is often prohibitive.

Agar plate accelerated decay bioassay was used to determine the ability of *K. senegalensis* (African mahogany) to resist attack by pure cultures of *Coriolus versicolor* and *Fomitopsis lilacino-gilva*. Conventionally, soil jar or agar jar techniques have been used for accelerated decay testing. The jar techniques require larger samples (which were not available for this study), more support substrate (soil or agar) and their preparation and incubation are more time consuming and therefore costly. The jar techniques however, still provide qualitative data regarding the relative decay susceptibility of timbers that are tested.

Considering results for both decay fungi, the samples can be more or less divided into two groups according to their relative mass losses. *Callitris glaucophylla* and grey ironbark were found to be most resistant to decay by pure cultures of decay fungi, followed closely by mature native spotted gum, mature plantation spotted gum and mature native *Eucalyptus grandis*. Conversely, *Pinus radiata* had poor decay resistance, as did *E. dunnii* and *E. grandis* juvenile woods.

While the results for *K. senegalensis* varied considerably, it is important to note that mean *K. senegalensis* result represents 88 separate samples (from 42 separate trees of different ages). Given that the logs were obtained from trees from a range of genetic material, and that samples were taken from the each end of a log, a degree of variation was expected. In addition, some of the observed variability could have been influenced by differences in sample size (some samples were quite small due to limited sample material being available). In contrast, the mean for each of the reference species represents only one timber sample (apart for *E. dunnii*, where four separate samples were used).

Approximately half of the *K. senegalensis* samples were taken from the bottom of the harvested logs and the other half from the tops. Interestingly, in most cases, the *K. senegalensis* sample from the bottom end of any particular log was less durable than sample from the top end. This result is in contrast to durability studies of several other timber species which have revealed that the outer heartwood of the butt log is commonly more durable than the outer heartwood from further up the tree (Clark and Scheffer 1983). After exposure to *C. versicolor*, paired (top and bottom) *K. senegalensis* samples from 86% of trees (36/42) had bottom-sample mass losses that were greater than the top-sample mass loss. Of the six trees that were exceptions, three were ‘b’ samples (8 m in length) and one had grater mass loss for the bottom sample than the top after exposure to the other fungus. After exposure to *F. lilacino-gilva*, paired *K. senegalensis*samples from 76% (32/42) of trees showed bottom-sample mass losses to be greater than the top-sample mass loss. Of the ten trees that were exceptions, three were ‘b’ samples (8 m in length) and five had grater mass loss for the bottom sample than the top after exposure to the other fungus.

Four of the logs selected for testing were very much longer than the others (Appendix C–2, shaded grey with ‘b’ following tree number), and their diameter at the top end was considerably less than at their bottom end. Consequently, heartwood from the top of these logs may still have been quite young;

results are consistent with this possibility. For three out of the four logs, the sample from the bottom of the log was more durable than the sample from the top. When the bottom sections of the taller ‘b’ logs are compared with the results for the bottom sections of all logs, the bottom of the taller ones (‘b’ samples) were among the most durable (those with least mass loss). Furthermore, comparison of the results for the top sections of all trees, the top of the taller ones were among the least durable (those with most mass loss).

Even though many of the variables that impact a timber species performance in service are absent during accelerated decay bioassay, this method still provides valuable information regarding a timber’s resistance to attack by basidiomycete decay fungi. Given the length of field trials, accelerated decay data information can be used in the interim, for instance during selection of trees for breeding. For example, *K. senegalensis s*ample 595 was amongst the most resistant to decay by each of the three decay fungi. If this sample also had good results for other characteristics such as timber strength or growth habit, it may be useful for breeding.

The results of this study support anecdotal evidence suggesting that *K. senegalensis* may be more durable than is commonly thought (Armstrong, pers. comm. 2005) particularly for above-ground applications. Placement of *K. senegalensis* samples at standard research field exposure sites is recommended. Furthermore, it would be desirable for replicate samples.

Acknowledgements

The assistance of Dr Lyel Carrington with the use of the University of Queensland’s irradiation facility is gratefully acknowledged.

Appendix C–1. Mean mass loss for each timber sample

Table C–3. Ranked mean mass loss data for *Coriolus versicolor*: Numbered *K. senegalensis* samples with reference species

Timber	Mean percent mass loss
595	0.00
627	0.00
227	0.00
315	0.06
411	0.10
427	0.15
179	0.19
283	0.21
379	0.23
459	0.50
643	0.59
grey iron bark	0.68
347	0.89
271	1.09
499	1.23
43*^	1.56
195	1.72
59	1.80
11	1.86
mature plantation spotted gum	2.01
419^	2.07
163	2.11
683	2.18
147	2.22
211	2.30
363	2.57
19	2.71
659	2.77
67	2.77
403	2.84
475	2.85
83*	2.88
691	2.91
C. glaucophylla	2.96
491	2.99
299^	3.06
443	3.30
235	3.62
635	3.84
435	4.00
mature native *E. grandis*	4.22
571*^	4.27
291	4.56
507	4.58

Timber	Mean percent mass loss
467	4.73
563	5.02
123	5.15
323	5.24
187*+	5.34
339	5.48
75*	5.50
331	5.51
603	5.59
mature native spotted gum	5.66
667	6.20
355	6.74
611^	7.05
579	8.29
young plantation spotted gum	8.46
3^	8.63
395	8.73
619	9.21
651	9.33
699	9.41
307	9.92
114	10.06
451*	10.17
107	10.53
531*^	11.31
219*	11.57
251	11.58
243	11.61
387*^	11.65
515	11.77
131+	12.18
P. radiata	12.45
275*^	12.49
99	12.87
483	12.92
371+	13.02
155	13.30
259	13.43
539	13.50
523	13.60
587	13.65
203+	13.85
675	14.03
91	14.13

Timber	Mean percent mass loss
547*^	14.27
555+	14.45
171	14.81
27+	15.12
35^	16.30
spotted gum sapwood	16.45
139*^	18.69
51+	22.23
young *E. grandis*	27.01
E. dunnii (9)	27.65
E. dunnii (3)	31.69
E. dunnii (10)	33.30
E. dunnii (6)	49.11

Notes

*	Very small or irregularly–shaped samples
+	Light-coloured samples
^	Patchy colour or density

Table C–4. Ranked mean mass loss data for *Fomitopsis lilacino-gilva*: Numbered *K. senegalensis* samples with reference species

Timber	Mean percent mass loss
611^	0.41
435	0.42
419^	0.58
459	0.81
219*	0.81
3^	0.92
683	1.01
315	1.04
667	1.10
363	1.25
19	1.28
427	1.32
467	1.34
627	1.41
C. glaucophylla	1.41
163	1.53
691	1.53
403	1.59
187*+	1.60
339	1.64
595	1.66
347	1.77
603	1.81
211	1.90
227	1.94
411	1.95
355	1.95
283	1.97
659	1.98
475	1.99
147	2.00
123	2.02
67	2.04
171	2.04
443	2.18
114	2.19
699	2.26
107	2.47
59	2.49
271	2.51
235	2.58
643	2.71
635	2.77

Timber	Mean percent mass loss
grey iron bark	2.83
299^	3.14
331	3.22
195	3.29
83*	3.31
11	3.33
mature native *E. grandis*	3.78
395	3.82
451*	4.09
mature plantation spotted gum	4.25
563	4.31
mature native spotted gum	4.55
307	4.57
spotted gum sapwood	4.66
243	4.86
651	5.06
675	5.43
571*^	5.67
E. dunnii (9)	5.96
371+	6.09
387*^	6.11
579	6.45
587	6.57
507	6.78
E. dunnii (6)	6.97
91	7.01
515	7.10
E. dunnii (3)	7.36
523	7.52
259	8.13
E. dunnii (10)	8.18
155	8.71
483	8.96
young plantation spotted gum	8.97
619	9.30
young *E. grandis*	10.12
531*^	10.18
99	10.33
51+	10.48
27+	10.48
P. radiata	19.84

Notes

*	Very small or irregularly–shaped samples
+	Light-coloured samples
^	Patchy colour or density

Appendix C–2. Results with sample information

Key to abbreviations below.

LC	light coloured sample
RC	cracking radial
GC	cracking along growth rings
IS	irregularly sized sample
ss	small sample
Black text	bottom mass loss > top mass loss
Blue text	top mass loss > bottom mass loss
Red Text	top mass loss >>> bottom mass loss
Shaded	Long logs (~8m) top samples from very top of tree

Table C–5. All data in order of source

Source	Tree Number	Disc position	Segment Number	Mass Loss *C. versicolor*	Mass Loss *F. lilacino-gilva*
Central Af Rep D391	84	Bottom	155	13.30	8.71
Central Af Rep D391	84	Top	147	2.22	2.00
Ghana d500	3	Bottom	107	10.53	2.47
Ghana d500	3	Top	114	10.06	2.19
Ghana d500	4	Bottom	699	9.41	2.26
Ghana d500	4	Top	691	2.91	1.53
Ghana d500	12	Bottom	75	5.50	
Ghana d500	12	Top	83	2.88	3.31
Ghana d500	15	Bottom	483	12.92	8.96
Ghana d500	15	Top	475	2.85	1.99
Ghana d500	4b	Bottom	611	7.05	0.41
Ghana d500	4b	Top	619	9.21	9.30
New Caledonia D487	18	Bottom	635	3.84	2.77
New Caledonia D487	18	Top	627	0.00	1.41
New Caledonia D487	19	Bottom	243	11.61	4.86
New Caledonia D487	19	Mid	235	3.62	2.58
New Caledonia D487	19	Top	227	0.00	1.94
New Caledonia D487	151	Bottom	435	4.00	0.42
New Caledonia D487	151	Top	427	0.15	1.32
New Caledonia D488	152	Bottom	67	2.77	2.04
New Caledonia D488	152	Top	59	1.80	2.49
New Caledonia D522	11	Bottom	403	2.84	1.59
New Caledonia D522	11	Top	395	8.73	3.82
Nigeria D486	153	Bottom	355	6.74	1.95
Nigeria D486	153	Top	347	0.89	1.77
Senegal D417	70	Bottom	603	5.59	1.81
Senegal D417	70	Top	595	0.00	1.66
Senegal D417	155	Bottom	187	5.34	1.60

Table C– 5. All data in order of source (continued from previous page)

Source	Tree Number	Disc position	Segment Number	Mass Loss *C. versicolor*	Mass Loss *F. lilacino-gilva*
Senegal D417	155	Top	179	0.19	
Senegal D417	156	Bottom	387	11.65	6.11
Senegal D417	156	Top	379	0.23	
Senegal D417	157	Bottom	219	11.57	0.81
Senegal D417	157	Top	211	2.30	1.90
Senegal D417	a122	Bottom	451	10.17	4.09
Senegal D417	a122	Top	443	3.30	2.18
Senegal D417	b122	Bottom	259	13.43	8.13
Senegal D417	b122	Top	251	11.58	
Senegal D417	h1	Bottom	555	14.45	
Senegal D417	h1	Top	547	14.27	
Senegal D417	h10	Bottom	203	13.85	
Senegal D417	h10	Top	195	1.72	3.29
Senegal D417	h11	Bottom	307	9.92	4.57
Senegal D417	h11	Top	299	3.06	3.14
Senegal D417	h12	Bottom	419	2.07	0.58
Senegal D417	h12	Top	411	0.10	1.95
Senegal D417	h12b	Bottom	499	1.23	
Senegal D417	h12b	Top	491	2.99	
Senegal D417	h2	Bottom	371	13.02	6.09
Senegal D417	h2	Top	363	2.57	1.25
Senegal D417	h5	Bottom	91	14.13	7.01
Senegal D417	h5	Top	99	12.87	10.33
Senegal D417	h6	Bottom	35	16.30	
Senegal D417	h6	Mid	27	15.12	10.48
Senegal D417	h6	Top	19	2.71	1.28
Senegal D417	h7	Bottom	171	14.81	2.04
Senegal D417	h7	Top	163	2.11	1.53
Senegal D417	h8	Bottom	3	8.63	0.92
Senegal D417	h8	Top	11	1.86	3.33
Senegal D417	h9	Bottom	275	12.49	
Senegal D417	h9	Top	271	1.09	2.51
Senegal S10066	14	Bottom	523	13.60	7.52
Senegal S10066	14	Mid	515	11.77	7.10
Senegal S10066	14	Top	507	4.58	6.78
Senegal S10066	150	Bottom	539	13.50	
Senegal S10066	150	Top	531	11.31	10.18
Senegal S9392	77	Bottom	467	4.73	1.34
Senegal S9392	77	Top	459	0.50	0.81
Senegal S9392	96	Bottom	291	4.56	
Senegal S9392	96	Top	283	0.21	1.97
Sudan S9687	25	Bottom	323	5.24	
Sudan S9687	25	Top	315	0.06	1.04
Sudan S9687	154	Bottom	571	4.27	5.67
Sudan S9687	154	Top	563	5.02	4.31
Togo D411	80	Bottom	667	6.20	1.10
Togo D411	80	Top	659	2.77	1.98
Uganda S10053	16	Bottom	339	5.48	1.64
Uganda S10053	16	Top	331	5.51	3.22

Table C–5. All data in order of source (continued from previous page)

Source	Tree Number	Disc position	Segment Number	Mass Loss *C. versicolor*	Mass Loss *F. lilacino-gilva*
Uganda S10053	16b	Bottom	683	2.18	1.01
Uganda S10053	16b	Top	675	14.03	5.43
Unknown	h13	Bottom	587	13.65	6.57
Unknown	h13	Top	579	8.29	6.45
Unknown	h14	Bottom	139	18.69	
Unknown	h14	Mid	131	12.18	
Unknown	h14	Top	123	5.15	2.02
Upper Volta D415	86	Bottom	651	9.33	5.06
Upper Volta D415	86	Top	643	0.59	2.71
Upper Volta D416	158	Bottom	51	22.23	10.48
Upper Volta D416	158	Top	43	1.56	

Appendix C–3. Results of pair-wise multiple comparisons

Testing was undertaken using Fischer's Least Significant Difference Analysis after analysis of variances revealed that at least one of the means was significantly different to the others.

Table C–6. Results of pair-wise multiple comparisons for *Coriolus versicolor*

Timber	Mean % Mass Lost to Decay by *C. versicolor*	Result for Fischers PLSD (Genstat v6.1)	Timber	Mean % Mass Lost to Decay by *C. versicolor*	Result for Fischers PLSD (Genstat v6.1)	Timber	Mean % Mass Lost to Decay by *C. versicolor*	Result for Fischers PLSD (Genstat v6.1)
K 595	0.00	a	K 443	3.30	cdefghijklmn	K 387	11.65	vwxyzABCD
K 627	0.00	ab	K 235	3.62	defghijklmn	K 515	11.77	wxyzABCD
K 227	0.00	ab	K 635	3.84	efghijklmno	K 131	12.18	xyzABCDE
K 315	0.06	abc	K 435	4.00	fghijklmno	*P. radiata*	12.45	yzABCDE
K 411	0.10	ab	mature native *E. grandis*	4.22	fghijklmno	K 275	12.49	yzABCDE
K 427	0.15	abc	K 571	4.27	fghijklmno	K 99	12.87	yzABCDE
K 179	0.19	abc	K 291	4.56	ghijklmno	K 483	12.92	yzABCDE
K 283	0.21	ab	K 507	4.58	ghijklmno	K 371	13.02	zABCDE
K 379	0.23	ab	K 467	4.73	ghijklmno	K 155	13.30	ABCDEF
K 459	0.50	abc	K 563	5.02	hijklmno	K 259	13.43	BCDEF
K 643	0.59	abcd	K 123	5.15	ijklmno	K 539	13.50	BCDEFG
grey iron bark	0.68	abcd	K 323	5.24	ijklmno	K 523	13.60	BCDEFG
K 347	0.89	abcde	K 187	5.34	klmonp	K 587	13.65	CDEFG
K 271	1.09	abcdef	K 339	5.48	lmonpq	K 203	13.85	CDEFG
K 499	1.23	abcdef	K 75	5.50	lmonpq	K 675	14.03	CDEFG
K 43	1.56	abcdefg	K 331	5.51	lmonpq	K 91	14.13	CDEFG
K 195	1.72	abcdefg	K 603	5.59	jmonpqr	K 547	14.27	CDEFG
K 59	1.80	abcdefg	mature native spotted gum	5.66	mnopq	K 555	14.45	CDEFG
K 11	1.86	abcdefg	K 667	6.20	nopqr	K 171	14.81	DEFG
mature plantation spotted gum	2.01	abcdefgh	K 355	6.74	nopqr	K 27	15.12	EFG
K 419	2.07	abcdefghij	K 611	7.05	opqrs	K 35	16.30	FGH
K 163	2.11	abcdefghj	K 579	8.29	pqrst	spotted gum sapwood	16.45	GH
K 683	2.18	abcdefghijk	young plantation spotted gum	8.46	qrstu	K 139	18.69	H
K 147	2.22	abcdefghij	K 3	8.63	qrstuvw	K 51	22.23	I

Timber	Mean % Mass Lost to Decay by *C. versicolor*	Result for Fischers PLSD (Genstat v6.1)	Timber	Mean % Mass Lost to Decay by *C. versicolor*	Result for Fischers PLSD (Genstat v6.1)	Timber	Mean % Mass Lost to Decay by *C. versicolor*	Result for Fischers PLSD (Genstat v6.1)
K 211	2.30	abcdefghij	K 395	8.73	rstuv	young *E. grandis*	27.01	J
K 363	2.57	abcdefghijkl	K 619	9.21	rstuvwx	*E. dunnii* (9)	27.65	J
K 19	2.71	abcdefghijklm	K 651	9.33	stuvwx	*E. dunnii* (3)	31.69	K
K 659	2.77	abcdefghijklm	K 699	9.41	stuvwx	*E. dunnii* (10)	33.30	K
K 67	2.77	abcdefghijklm	K 307	9.92	stuvwxy	*E. dunnii* (6)	49.11	L
K 403	2.84	abcdefghijklm	K 114	10.06	stuvwxyz			
K 475	2.85	abcdefghijklm	K 451	10.17	stuvwxyzA			
K 83	2.88	abcdefghijklm	K 107	10.53	tuvwxyzAB			
K 691	2.91	abcdefghijklm	K 531	11.31	tuvwxyzABC			
C. glaucophylla	2.96	abcdefghijklm	K 219	11.57	uvwxyzABCD			
K 491	2.99	abcdefghijklm	K 251	11.58	vwxyzABC			
K 299	3.06	bcdefghijklm	K 243	11.61	uvwxyzABCD			

Table C–7. Results of pair-wise multiple comparisons for *Fomitopsis lilacino-gilva*

Testing was undertaken using Fischer's Least Significant Difference Analysis after analysis of variances revealed that at least one of the means was significantly different to the others.

Timber	Mean % Mass Lost to Decay by *F. lilacino-gilva*	Result for Fischers PLSD (Genstat v6.1))	Timber	Mean % Mass Lost to Decay by *F. lilacino-gilva*	Result for Fischers PLSD (Genstat v6.1))
K 611	0.41	a	K 299	3.14	ghijklmnopq r
K 435	0.42	a	K 331	3.22	hijklmnopqr
K 419	0.58	ab	K 195	3.29	ijklmnopqrs
K 459	0.81	abc	K 83	3.31	ijklmnopqrs
K 219	0.81	abcd	K 11	3.33	ijklmnopqrs
K 3	0.92	abcd	mature native *E. grandis*	3.78	klmnopqrst
K 683	1.01	abcde	K 395	3.82	lmnopqrst
K 315	1.04	abcdef	K 451	4.09	lmnopqrst
K 667	1.10	abcdef	mature plantation spotted gum	4.25	nopqrstu
K 363	1.25	abcdef	K 563	4.31	opqrstuv
K 19	1.28	abcdef	mature native spotted gum	4.55	Pqrstuv
K 427	1.32	abcdef	K 307	4.57	Qrstuv
K 467	1.34	abcdefgh	spotted gum sapwood	4.66	Rstuv
K 627	1.41	abcdefghi	K 243	4.86	Rstuvw
C. glaucophyll a	1.41	abcdefg	K 651	5.06	Stuvw
K 163	1.53	abcdefghi	K 675	5.43	Tuvwx
K 691	1.53	abcdefghi	K 571	5.67	Tuvwxy
K 403	1.59	abcdefghij	*E. dunnii* (9)	5.96	Uvwxy
K 187	1.60	abcdefghij	K 371	6.09	Vwxy
K 339	1.64	abcdefghij	K 387	6.11	Uvwxy
K 595	1.66	abcdefghij	K 579	6.45	Wxyz
K 347	1.77	abcdefghij	K 587	6.57	Wxyz
K 603	1.81	abcdefghijkl	K 507	6.78	Wxyz
K 211	1.90	abcdefghij	*E. dunnii* (6)	6.97	wxyzA
K 227	1.94	abcdefghijkl	K 91	7.01	xyzAB
K 411	1.95	abcdefghij	K 515	7.10	yzABC
K 355	1.95	abcdefghijkl	*E. dunnii* (3)	7.36	yzABCD
K 283	1.97	abcdefghij	K 523	7.52	yzABCD
K 659	1.98	abcdefghij	K 259	8.13	zABCD
K 475	1.99	abcdefghijk	*E. dunnii* (10)	8.18	zABCD
K 147	2.00	abcdefghijk	K 155	8.71	ABCDE
K 123	2.02	abcdefghijkl	K 483	8.96	BCDE
K 67	2.04	abcdefghijkl	young	8.97	CDE

Timber	Mean % Mass Lost to Decay by *F. lilacino-gilva*	Result for Fischers PLSD (Genstat v6.1))	Timber	Mean % Mass Lost to Decay by *F. lilacino-gilva*	Result for Fischers PLSD (Genstat v6.1))
			plantation spotted gum		
K 171	2.04	abcdefghijkl	K 619	9.30	DE
K 443	2.18	abcdefghijkl	young *E. grandis*	10.12	E
K 114	2.19	abcdefghijkl	K 531	10.18	E
K 699	2.26	abcdefghijkl m	K 99	10.33	E
K 107	2.47	bcdefghijklm n	K 51	10.48	E
K 59	2.49	cdefghijklmn	K 27	10.48	E
K 271	2.51	cdefghijklmn	*P. radiata*	19.84	F
K 235	2.58	cdefghijklmn o			
K 643	2.71	defghijklmno			
K 635	2.77	efghijklmnop			
grey ironbark	2.83	fghijklmnopq			

Appendix C–4. Approximate classification

Although it is not statistically sound to impose discrete cut-offs to categorise the performance of a timber after APAD bioassay, to aid interpretation and provide a general indication of performance, timbers can be categorised into resistance groups based on the mass loss criteria used in the American standard method of accelerated laboratory testing of the natural decay resistance of woods used to interpret soil jar data (ASTM_D2017-81 1986) (Table 9).

To account for greater mass loss when using soil rather than agar (Van Acker et al. 1998) and because the incubation time for agar plate bioassay is less than that for soil jars, the mean mass loss cut off criteria were reduced (in proportion to the soil jar criteria) for interpretation of agar plate data.

Table C–8. General classification of results based on mean % mass loss

Soil Jar data interpretation (ASTM_D2017-81 1986)	
Indicated class of resistance to a specified fungus	Mean mass loss (%)
[1] Highly resistant	0 to 10
[2] Resistant	11 to 24
[3] Moderately resistant	25 to 44
[4] Slightly / non-resistant	45 or more

Agar Plate Accelerated Decay Bioassay data interpretation	
Indicated class of resistance to a specified fungus	Mean mass loss (%)
[1] Highly resistant	0 to 3
[2] Resistant	3.1 to 7.4
[3] Moderately resistant	7.5 to 13.4
[4] Slightly / non-resistant	13.5 or more

(ASTM_D2017-81 1986) states that considerable background data indicate that there is relatively good agreement between weight losses for soil jars and service experience with the tested woods. Examples discussed include:

- Highly resistant / Resistant – redwood, black locust and white oak, western red cedar
- Moderately resistant – Douglas fir, western larch
- Slightly resistant or non-resistant – true firs, spruce, beech, birch and hemlock
- Loose association, for the sake of comprehension, can be made with durability classes

Using the cut-offs above, *K. senegalensis* samples can be separated into four groups according to mass loss criteria, with samples belonging to group one having good potential for above average decay resistance.

Table C–9. Example of approximate classification for *Coriolus versicolor* (white rot, eight week *K. senegalensis* incubation)

Timber	Mean % Mass Lost to Decay
grey iron bark	0.68
***K. senegalensis* group 1** (0 – 3% mass loss)	1.56
mature plantation spotted gum	2.01
C. glaucophylla	2.96
mature native *E. grandis*	4.22
***K. senegalensis* group 2** (3.1 – 7.4% mass loss)	5.04
mature native spotted gum	5.66
young plantation spotted gum	8.46
***K. senegalensis* group 3** (7.5 – 13.4% mass loss)	11.0
P. radiata	12.45
***K. senegalensis* group 4** (> 13.5% mass loss)	15.28
spotted gum sapwood	16.45
Young plantation *E. grandis*	27.01
E. dunnii	35.44

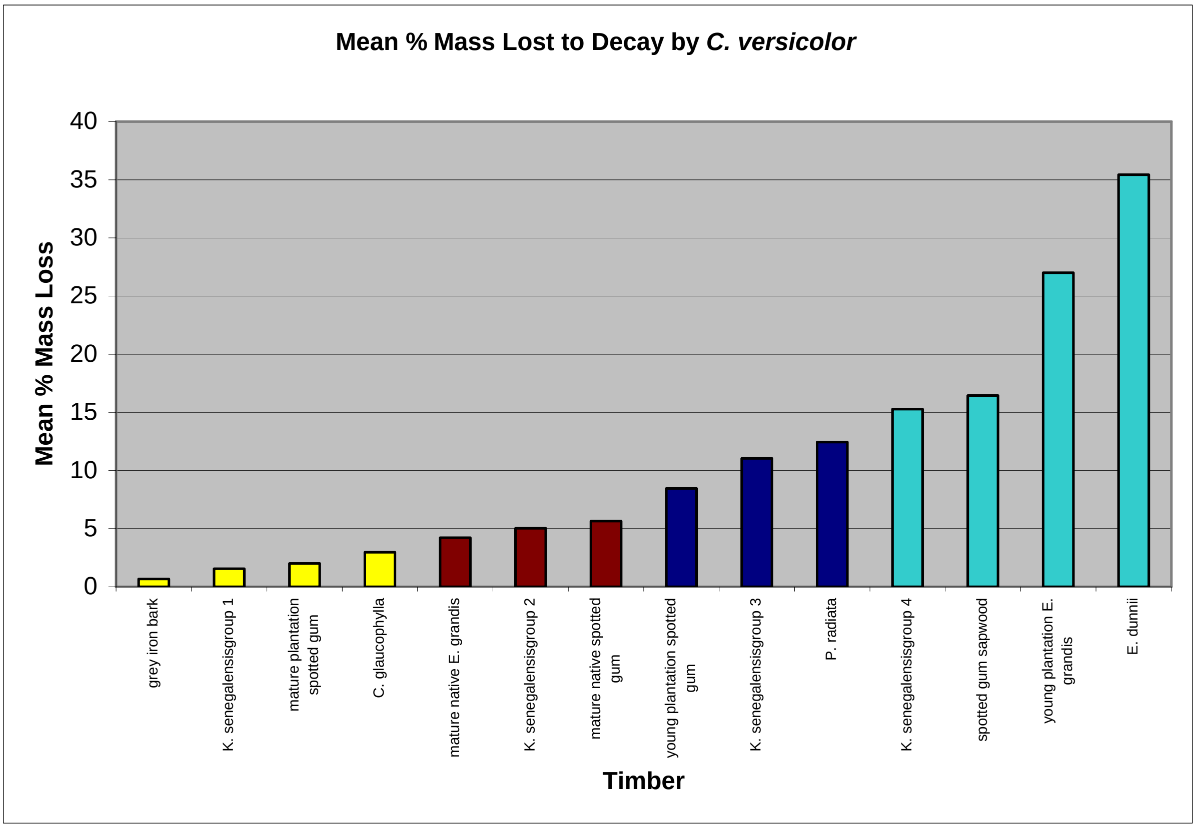


Figure C–5. Approximate classifications similar to conventional interpretation systems, *C. versicolor* example

Table C–10. Example of approximate classification for *Fomitopsis lilacino-gilva* (brown rot, 11 weeks incubation)

Timber	Mean % Mass Lost to Decay
C. glaucophylla	1.41
***K. senegalensis* group 1** (0 – 3% mass loss)	1.68
grey iron bark	2.83
mature native *E. grandis*	3.78
mature plantation spotted gum	4.25
mature native spotted gum	4.55
spotted gum sapwood	4.66
***K. senegalensis* group 2** (3.1 – 7.4% mass loss)	5.01
E. dunnii	7.12
young plantation spotted gum	8.97
***K. senegalensis* group 3** (7.5 – 13.4% mass loss)	9.34
young plantation *E. grandis*	10.12
P. radiata	19.84

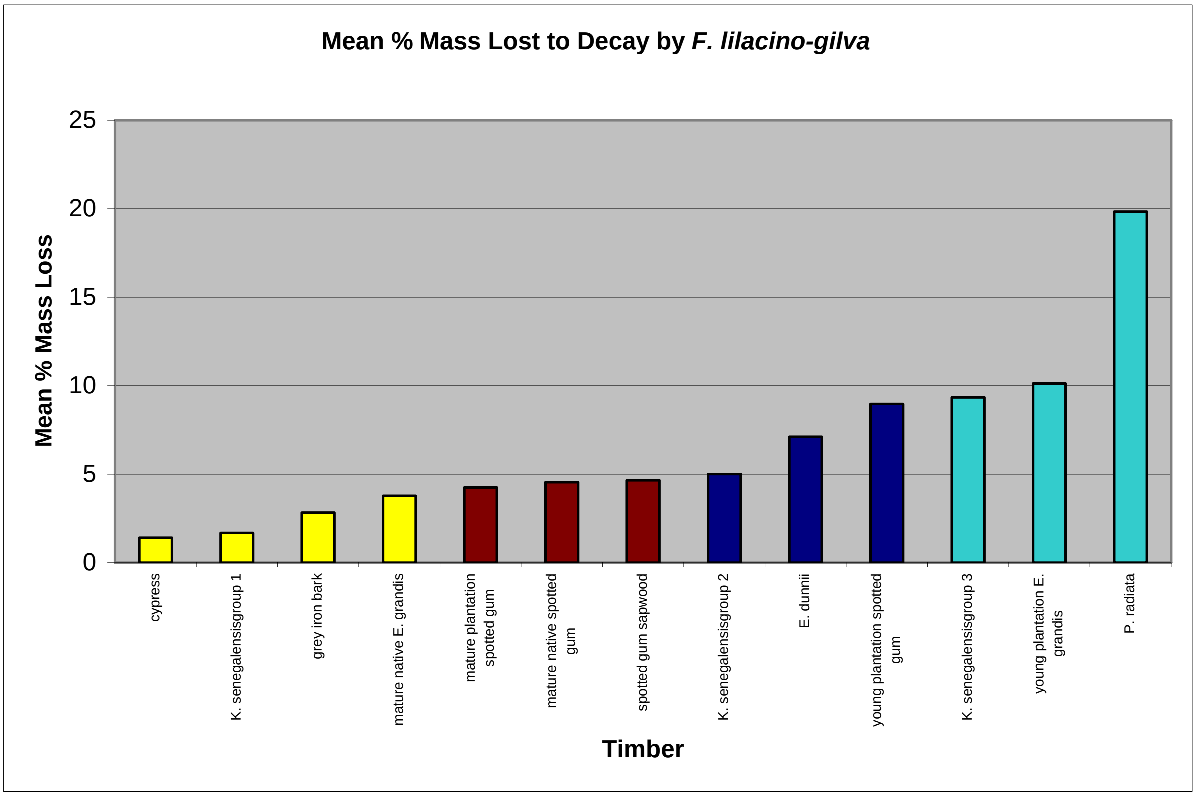


Figure C–6. Approximate classifications similar to conventional interpretation systems, *F. lilacino-gilva* example

References

ASTM_D2017-81 1986. American Society for Testing and Materials ASTM D 2017-81. Standard Method of Accelerated Laboratory Testing of Natural Decay Resistance of Woods. ASTM International (American Society for Testing and Materials), Philadelphia.

AWPA 1999. American Wood Preservers' Association Book of Standards, 1999, Texas, USA. 466 p.

AWPC 1997. Protocols for assessment of wood preservatives. Australasian Wood Preservation Committee. Australasian Wood Preservation Committee. 24 p.

Catesby, A. and M.A. Powell 1999. Laboratory Testing of Timber Natural Durability using Accelerated Weathering and Soil Jar Decay Testing, Internal Report. Queensland Forestry Research Institute.

Clark, J.W. and T.C. Scheffer 1983. Natural decay resistance of the heartwood of coast redwood Sequoia sempervirens (D. Don) Endl. Forest Products Journal. 33:15-20.

EN_84 1984. European Standard EN 84. Wood preservatives. Accelerated ageing of treated wood prior to biological testing. Leaching procedure. European Committee for Standardization. European Committee for Standardization, Brussels, p. 4.

EN_113 1996. European Standard EN 113 Wood preservatives - Test method for determining the protective effectiveness against wood destroying basidiomycetes - Determination of the toxic values. European Committee for Standardization. European Committee for Standardization, Brussels, p. 36.

Francis, L.P. and M.D. Armstrong 2004. Determination of the relative decay resistance of Eucalyptus argophloia (western white gum) (Internal Report). Innovative Forest Products, Horticulture and Forestry Science, Brisbane.

Meldrum, S.I. and M.A. Powell 2002. Pine Panels Decay Plate Bioassay (Internal Report). Horticulture and Forestry Science (formerly, Queensland Forestry Reasearch Institute), Brisbane.

Ocloo, J.K. 1975. The natural resistance of the wood of Ghanian timbers against attack by subterranean termites. *In* Utilisation of wood resources in Ghana Ed. J.G.K. Owusu, University of Sience and Technology, Kumasi.

Smith, W.J., W.T. Kynaston, M.L. Cause and G.J. G 1991. Building Timbers. Properties and Recommendations for their Use in Queensland. V. R. Ward, Government Printer, Queensland-1991, Brisbane.

Standards_Australia 2003. AS 5604-2003. Australian Standard. Timber-Natural durability ratings. Standards Australia International, Sydney, p. 26.

Van Acker, J., M. Stevens, J. Carey, R. Sierra-Alvarez, H. Militz, I. Le Bayon, G. Kleist and R.-D. Peek 1998. Criteria for basidiomycete testing and ways of defining natural durability classes. Proceedings of the 29th Annual Meeting of the International Research Group on Wood Preservation. Maastricht, The Netherlands, June 1998.

Appendix D. Industry Assessment

Companies that responded:

- Queensport Furniture, 71 Gosport St, HEMMANT QLD 4174
- Furniture Concepts Queensland, 64 Randolph St, Rocklea QLD 4106
- Paragon Furniture, 34 Annerley Rd, Woolloongabba QLD 4102
- Brims Wood Panels Pty Ltd, Station Road, Yeerongpilly QLD 4105
- Proveneer, Shed 4/17 River Rd, Redbank QLD 4301
- Gerard Gilet and Guitarwood, Booralee Street, Botany NSW 2019
- Ochoteco Guitars, 115 Gotha St, Fortitude Valley QLD4006
- Doug Eaton and Dale Jacobsen River Music, PO Box 456, Maleny QLD 4556
- Trend Timbers Pty Ltd, Cuneen St, Windsor NSW 2756.
- Lazarides Timber Agencies, 15 Hurricane St, Banyo QLD 4014
- Weisner Timber Threads, Toowoomba

Questionaries

SURVEY QUESTIONNAIRE

1. What is your activity?

Furniture	Yes	No
Instrumental	Yes	No
Supplier	Yes	No
Import-Export	Yes	No
Cabinet kitchen	Yes	No
Merchant	Yes	No
Veneer	Yes	No
Joinery	Yes	No
Other	Please specify:________________	

2. Are you using African mahogany timber? Yes No

If Yes, from where is it sourced? _________________________________

If Yes go to question **3**, if No go to question **9**

3. Which sort of products?

____
____
____
____
____
____
____
____
____
____
____
____
____

4.

Strengths	Weaknesses

5. Wood appearance?

Colour	Good	Average	Poor
Aesthetics' aspect	Good	Average	Poor
Texture	Good	Average	Poor

6. Comments on wood properties (eg stability, density, strength, shrinkage, hardness, other properties)

____

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7. Do you export your products? Yes No

8. If yes, to which countries?

____

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____

____

9. Do you think there is a potential domestic market? Yes No

10. Do you think there is a potential export market? Yes No

11. From your knowledge, what is the African mahogany timber worth on the domestic and export market?

Have you an idea concerning wholesale prices and retail prices for this timber?

____

____

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____

12. Are you interested in testing plantation grown African mahogany? Yes No

13. Which dimensions would you require for testing? (Thickness, Width, Length)

____

____

____

____

____

____

14. Do you require dressed or rough sawn timber?   Dressed   Rough

15. Could you tell me which grade you require? (e.g. totally clean, some sound defects, other)

END

ASSESSMENT QUESTIONNAIRE

1. Comments on utilisation potential and possible end-uses?

2. Grade, quality Good Average Poor

Comments:

3. Density

Comments:

4. Blunting? Good Average Poor
Effect on blades and tools?

5. Sawing Good Average Poor

6. Machining Good Average Poor

7. Fastening (nails/screw) Good Average Poor

8. Gluing Good Average Poor

9. Mortising and Tenoning Good Average Poor

10. Wood appearance?

Colour	Good	Average	Poor
Aesthetics' aspect	Good	Average	Poor
Texture	Good	Average	Poor

11.

Strengths	Weaknesses

12. Do you think there is a potential domestic market? Yes No

13. Do you think there is a potential export market? Yes No

14. Could you give the volume for domestic and export market?

____

____

____

15. Have you an idea concerning price and value of this timber?

____

____

____

____

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____

____

16. If you already used African mahogany from Africa or other sources, how does this timber compare?

END

Appendix E. Log properties data

Provenance	Tree N°	Bark thickness (mm)	End-split score bottom log	Pith offset (mm)	Heartwood proportion (%)
New Caledonia D522	11	10	**3.25**	24.5	56.3%
Ghana d500	12	9.5	**4.25**	36.0	50.6%
Senegal D417	122	9	**2.63**	51.5	61.9%
Senegal S10066	14	10	**9.00**	21.3	47.0%
Ghana d500	15	8.5	**6.88**	55.5	45.3%
Senegal S10066	150	7.8	**7.50**	19.0	31.4%
New Caledonia D487	151	9	**3.25**	31.0	52.6%
New Caledonia D488	152	8	**4.88**	21.0	52.0%
Nigeria D486	153	10	**3.88**	16.5	46.2%
Sudan S9687	154	7	**2.75**	7.0	43.2%
Senegal D417	155	8	**4.25**	17.5	63.1%
Senegal D417	156	6	**4.88**	19.5	36.7%
Senegal D417	157	8	**3.50**	15.0	64.8%
Upper Volta D416	158	8.5	**5.63**	16.0	55.2%
Uganda S10053	16	9.75	**4.88**	52.8	57.5%
New Caledonia D487	18	8	**2.50**	30.5	38.2%
New Caledonia D487	19	7.5	**7.50**	20.0	48.7%
Sudan S9687	25	7	**1.38**	30.0	56.8%
Ghana d500	3	8	**4.88**	39.5	47.3%
Ghana d500	4	8	**7.75**	28.8	42.2%
Senegal D417	70	11.5	**4.88**	44.5	30.5%
Senegal S9392	77	9.5	**4.88**	24.5	50.9%
Togo D411	80	10	**1.88**	42.5	63.8%
Central Af Rep D391	84	7.5	**3.38**	32.0	42.9%
Upper Volta D415	86	9	**4.50**	18.0	55.4%
Senegal S9392	96	8	**6.50**	16.0	46.8%
Senegal D417	H1	7.5	**4.75**	29.0	32.9%
Senegal D417	H10	7	**5.38**	13.5	45.0%
Senegal D417	H11	7	**6.50**	25.5	58.2%
Senegal D417	H12	7.5	**0.75**	26.0	51.07%
Unknown	H13	6	**5.25**	47.5	81.1%
Unknown	H14	6.5	**3.88**	17.7	38.2%
Senegal D417	H2	7.5	**4.75**	30.0	41.0%
Senegal D417	H5	5.5	**3.38**	23.5	39.5%
Senegal D417	H6	6.5	**2.00**	29.0	47.9%
Senegal D417	H7	8.5	**2.00**	48.5	55.8%
Senegal D417	H8	8	**3.75**	17.0	66.7%
Senegal D417	H9	6.5	**4.00**	30.5	66.3%
Av		**8.1**	**4.4**	**28.1**	**50.3%**
Std. Dev.		**1.3**	**1.7**	**12.2**	**11.0%**
Max.		**11.5**	**9.0**	**55.5**	**81.1%**
Min.		**5.5**	**0.75**	**7.0**	**30.5%**
Med.		**8.0**	**4.4**	**25.8**	**49.7%**
Count		**38**	**38**	**38**	**38**

Appendix F. GOS Recovery

Tree	Log	Tag number	New log	Length	Diam. L	Diam. S.	Vol	GOS Rec	GOS vol
H7		277		4.18	400	295	0.405	45.3%	0.184
H6		276		5.5	300	200	0.281		
H6			A	2.7	300	225	0.149	41.2%	0.062
H6			B	2.76	225	200	0.098	42.8%	0.042
77		153		2.98	340	235	0.200	29.7%	0.059
152		135		3.8	335	260	0.268	38.5%	0.103
158		268		3.38	315	195	0.182	31.7%	0.058
H14		280		5.7	285	185	0.258		
H14			A	2.87	285	210	0.141	32.4%	0.046
H14			B	2.8	210	185	0.086	44.7%	0.039
155		157		3.61	305	215	0.197	41.1%	0.081
H8		278		4.41	385	305	0.418	34.1%	0.142
25		144		4.19	395	225	0.340	31.4%	0.107
19		137		5.89	475	310	0.744		
19			A	2.77	475	385	0.407	45.4%	0.185
19			B	3.05	385	310	0.293	42.3%	0.124
H10				4.52	340	230	0.299	31.1%	0.093
122A				3.49	545	405	0.632	50.6%	0.320
122B				3.48	410	410	0.459		
11		132/133		4.9	525	405	0.846	39.2%	0.331
H9		279		4.16	330	250	0.280	38.4%	0.108
12		928		3.9	385	305	0.369	33.0%	0.122
H11				4.75	380	270	0.405	68.2%	0.277
H2		270		5.34	370	255	0.423	36.3%	0.154
156		159		4.7	285	195	0.220	25.3%	0.056
H12A		271		3.62	375	285	0.315	42.7%	0.135
H12B		272		3.57	300	240	0.207		
157		158		4.7	350	248	0.340	38.5%	0.131
84		154		3.9	395	265	0.347	30.5%	0.124
H5?		275		4.68	355	250	0.346	38.2%	0.132
3		921		4.9	395	290	0.462	46.6%	0.215
15		931		4.2	490	365	0.616	39.0%	0.240
H1		269		4.82	520	355	0.750	34.7%	0.260
16A		129		3.56	610	525	0.906	50.9%	0.461
16B		130		3.29	495	480	0.614		
96		160		3.84	270	175	0.156	37.3%	0.058
14		126		5.06	505	365	0.771		
14			A	2.8	505	400	0.456	45.9%	0.210
14			B	2.33	400	365	0.268	41.5%	0.111
150		124		3.61	335	250	0.248	31.6%	0.078
153		145		4.4	335	215	0.274	26.0%	0.071
80		150		3.49	485	375	0.515	51.8%	0.267
H13				4.77	520	300	0.675	35.2%	0.238
70		156		3.57	500	355	0.527	39.2%	0.206
4A		924		3.65	490	355	0.525	39.4%	0.207
4B		926		3.59	365	360	0.371		
18		140		3.56	445	335	0.434	41.0%	0.178
154		147		3.87	280	195	0.177	39.5%	0.070
151		139		3.88	385	345	0.407	36.3%	0.148
86		155		4.22	360	260	0.327	50.9%	0.166

Tree	Log	Tag number	New log	Length	Diam. L	Diam. S.	Vol	GOS Rec	GOS vol
			Sum				**17.382**		**6.397**
			Average	**3.8**	**388.8**	**294.7**	**0.378**	**39.5%**	**0.152**
			Std. Dev	**0.8**	**90.4**	**81.5**	**0.197**	**8.0%**	**0.092**
			Min.	**2.3**	**210.0**	**175.0**	**0.086**	**25.3%**	**0.039**
			Max.	**5.3**	**610.0**	**525.0**	**0.906**	**68.2%**	**0.461**

Appendix G. Wood Property Data

Individual Basic Density

	Disc position			Average
Disc No	**Bottom**	**Mid**	**Top**	
3	567.5		640.0	603.8
4	571.1		653.1	612.1
4b	539.5		565.9	552.7
11	624.7		618.2	621.4
12	676.7		678.5	677.6
14	612.9	601.0	650.9	621.6
15	634.8		695.3	665.1
16	646.1		638.1	642.1
16b	636.0		594.1	615.1
18	696.4		701.6	699.0
19	598.3	608.9	671.6	626.3
25	573.3		620.3	596.8
70	650.6		686.8	668.7
77	667.8		673.0	670.4
80	671.1		601.8	636.5
84	611.5		610.3	610.9
86	597.5		610.2	603.9
96	650.4		662.7	656.5
a122	680.2		696.1	688.1
b122	669.9		725.5	697.7
150	607.6		614.8	611.2
151	691.8		631.5	661.6
152	686.6		687.0	686.8
153	692.3		715.6	704.0
154	602.5		595.5	599.0
155	602.6		642.9	622.8
156	605.5		589.7	597.6
157	569.5		609.7	589.6
158	648.6		639.6	644.1
h1	651.7		659.0	655.4
h2	639.8		686.6	663.2
h5	571.7		546.1	558.9
h6	544.6	551.2	593.1	563.0
h7	569.1		585.8	577.5
h8	674.8		721.7	698.2
h9	629.3		653.2	641.2
h10	639.9		712.2	676.1
h11	594.6		662.1	628.3
h12	650.6		720.1	685.3
h12b	657.0		652.0	654.5
h13	667.8		672.4	670.1
h14	652.8	629.1	675.5	652.5

Individual MoE and MoR

Tree	MoE (Gpa)	MoR (Mpa)
3	7.5	72.6
4	8.3	88.7
11	6.9	62.9
12	8.2	83.5
14	9.1	81.8
15	12.0	102.9
16	9.1	84.3
18	8.0	81.2
19	6.8	72.3
25	4.7	65.7
70	11.0	98.8
77	6.4	75.5
80	8.1	80.8
84	6.4	66.2
86	7.4	76.1
96	8.1	82.9
122	10.3	111.5
150	8.1	81.9
151	7.6	89.0
152	10.2	101.8
153	7.1	69.2
154	7.8	74.6
155	6.4	57.9
156	6.0	60.7
157	6.5	70.1
158	7.8	84.6
h1	9.6	81.1
h2	9.0	82.0
h5	7.4	72.3
h6	8.8	83.6
h7	6.5	67.5
h8	10.1	102.0
h9	8.7	90.7
h10	11.3	87.7
h11	9.5	81.7
h12	7.0	83.0
h13	12.4	98.2
h14	10.3	96.6

Individual Janka Hardness

Load at 5.64 mm indentation (kN) – Tangential

Tree	Test 1	Test 2	Average
3	6.4	6.4	6.4
4	6.3	5.6	6.0
11	4.8	4.0	4.4
12	6.8	7.0	6.9
14	6.0	6.3	6.1
15	5.0	5.2	5.1
16	6.9	6.5	6.7
18	6.6	6.4	6.5
19	5.9	6.0	6.0
25	5.6	5.7	5.6
77	8.6	7.2	7.9
70	6.7	6.6	6.7
84	6.4	5.8	6.1
86	5.7	5.2	5.5
96	7.3	6.8	7.0
122	8.9	8.7	8.8
150	7.8	8.1	7.9
151	6.2	6.3	6.3
152	8.1	8.4	8.2
153	6.4	6.4	6.4
154	6.0	6.1	6.1
155	6.0	6.3	6.2
156	4.5	5.0	4.8
157	5.5	6.1	5.8
158	5.0	5.5	5.3
H1	5.2	5.3	5.2
H2	6.9	7.2	7.1
H5	5.6	5.1	5.3
H6	5.7	5.6	5.6
H7	5.7	6.0	5.9
H8	6.6	6.2	6.4
H9	7.0	7.3	7.1
H10	7.8	7.2	7.5
H11	5.2	5.0	5.1
H12	9.3	9.3	9.3
H13	6.9	8.2	7.5
H14	7.1	7.6	7.4

Appendix H. Tree Rankings

Provenance	Site	Tree	No. of 'top 10s'
Senegal D417	Gunn	122	7
Togo D411	Gunn	80	7
Uganda S10053	Gunn	16	5
Senegal D417	Howard	H8	4
Senegal D417	Howard	H11	4
Senegal D417	Gunn	157	4
New Caledonia D487	Gunn	19	4
New Caledonia D487	Gunn	18	4
Ghana d500	Gunn	15	4
Senegal S10066	Gunn	14	4
Ghana d500	Gunn	3	4
Senegal D417	Howard	H7	4
Senegal D417	Gunn	155	3
Senegal D417	Gunn	70	3
New Caledonia D522	Gunn	11	3
Senegal D417	Howard	H6	2
Senegal D417	Howard	H5	2
Unknown	Howard	H13	2
Senegal D417	Howard	H12	2
Senegal D417	Howard	H10	2
Senegal D417	Howard	H1	2
Senegal S10066	Gunn	150	2
Sudan S9687	Gunn	25	2
Ghana d500	Gunn	4	2
Senegal D417	Howard	H9	1
Unknown	Howard	H14	1
Upper Volta D416	Gunn	158	1
Senegal D417	Gunn	156	1
Sudan S9687	Gunn	154	1
Senegal S9392	Gunn	96	1
Upper Volta D415	Gunn	86	1
Central Af Rep D391	Gunn	84	1
Senegal S9392	Gunn	77	1
Senegal D417	Howard	H2	0
Nigeria D486	Gunn	153	0
New Caledonia D488	Gunn	152	0
New Caledonia D487	Gunn	151	0
Ghana d500	Gunn	12	0

No. of 'top 10's' grouped by Provenance

Provenance	Site		Grand Total
	Gunn	Howard	
Central Af Rep D391	1.0		1.0
Ghana d500	2.5		2.5
New Caledonia D487	2.7		2.7
New Caledonia D488	0.0		0.0
New Caledonia D522	3.0		3.0
Nigeria D486	0.0		0.0
Senegal D417	3.6	2.2	2.7
Senegal S10066	3.0		3.0
Senegal S9392	1.0		1.0
Sudan S9687	1.5		1.5
Togo D411	7.0		7.0
Uganda S10053	6.0		6.0
Unknown		1.5	1.5
Upper Volta D415	1.0		1.0
Upper Volta D416	1.0		1.0
Average	**2.5**	**2.1**	**2.4**