# J. W. GOTTSTEIN MEMORIAL TRUST FUND

The National Educational Trust of the Australian Forest Products Industries

GOTTSTEIN
TRUST

## EVALUATION OF AUSTRALIAN TIMBERS FOR USE IN MUSICAL INSTRUMENTS

**ANDREW MORROW**

2007 GOTTSTEIN FELLOWSHIP REPORT

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# JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are:

1. Fellowships and Awards - each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

Further information may be obtained by writing to:
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Andrew Morrow has worked in the biofibre processing group within the CSIRO Division of Materials Science & Engineering (Forest Polymers & Fibre group, formerly Division of Forestry and Forest Products) from 2002-2009, involved in research into processing and drying of plantation and native forest resources.

His Gottstein Fellowship enabled him to visit a number of ‘tonewood’ processors and luthiers, and undertake an evaluation of some material properties of a number of species in current use or with the potential to be used in this role.

An additional evaluation of wood species was undertaken at a laboratory level, with materials subsequently followed through and evaluated in instrument form, to determine the contribution of wood properties upon final sound ‘quality’.

Andrew has a Bachelor of Environmental Science (Natural Resource Management) from Deakin University, graduating in 1996.

# ACKNOWLEDGEMENTS

I would like to thank the J.W. Gottstein Trust Fund for the Fellowship grant enabling the work and report to be completed. The opportunity to undertake this work focussing on a value-adding and emblematic use of wood resources has been a privilege in combining work with a personal passion.

It has also been an honour to have met many skilled artisans working in an area where art and science intersect, embracing the challenge that new materials impose on instrument design, and in doing so keeping the art of luthiery alive.

The scientific evaluation of tonewoods has always been preceded by an alternate methodology employed by luthiers who have empirically demonstrated the capacity to identify materials and maximise their acoustic potential. It is freely acknowledged that this process has in many ways guided scientific understanding of musical acoustics and contributed to the focus of scientific evaluation upon the measurement of specific species and wood properties, already known to luthiers.

I was received with both hospitality and interest by many luthiers and people involved in the processing industry, too numerous to thank individually, and would like to thank all concerned.

The scientific side of the project would not have been possible without the practical assistance and encouragement of many who deserve acknowledgement,

Mr. Dung Ngo, Dr. Voichita Bucur, Dr. Robert Evans, Mr. Winston Liew, Mr. Nicholas Ebdon, Ms. Sharee Harper (all from CSIRO Division of Materials Science and Engineering), Mr. Graeme Caldersmith (luthier/scientist), Mr. Patrick Evans (Maton Guitars). Mr. David Chin developed and supplied the spectrum analysis equipment and methodology used in the evaluation of the guitars produced for the project.

Great practical support and inspiration was gained from both Chris Wynne and Fiona Mitchell (Thomas Lloyd Guitars) and William Hancock (Kymatix Productions) who drove the story into the public domain through his journalistic persistence.

Finally I would like to thank my wife Claudia and daughter Adina who have endured my absences, and obsession with this project with ongoing support.

# EXECUTIVE SUMMARY

This report outlines the present use of Australian native timbers in stringed instruments and identifies species with the potential and availability for utilization in instrument construction. It also describes component product quality criteria, as required by instrument makers, and examines the acoustic characterisitcs of Australian tonewoods both in laboratory tests and in finished instruments.

It is evident that many Australian tree species produce wood with physical properties suitable for use in musical instrument construction, in backs and sides, soundboards, necks, fretboards, bridges, and other components. Currently a combination of global decline in the availability of many tonewood species, emergent markets for 'Forest Stewardship Council' certified components, and the transfer and growth of instrument manufacturing bases to south-east Asia, provide a growth potential for providers of tonewood components.

Blackwood (*Acacia melanoxylon*) represents one species which has consolidated its reputation both within Australia and abroad as a world class tonewood. Both in terms of prices paid and the calibre of instruments it is being used in, blackwood has emerged as a flagship for Australian timbers in this domain. A number of other species have been embraced by luthiers domestically and have empirically proven to be excellent tonewoods in a range of instruments.

In instrument back and sides, suitable timber species include myrtle beech (*Nothofagus cunninghamii*), black-heart sassafras (*Atherosperma moschatum)* black and silver wattle (*Acacia mearnsii and A. dealbata*), satinwood (*Phebalium squameum*), tulip satinwood (*Rhodoshpaera rhodanthema)*, Queensland maple *(Flindersia brayleyana)* and mountain ash (*Eucalyptus regnans*), amongst many others. A range of high density and aesthetically-diverse dryland *Acacia spp*., have provided excellent, stable material for fretboards, bridges and other ancillary parts.

A number of species have proven to be excellent alternatives to spruce and cedar commonly used in soundboards. These include bunya pine (*Araucaria bidwillii)* hoop pine *(Araucaria cunninghamii),* King William pine *(Athrotaxis selaganoides),* pencil pine *(Athrotaxis cupressoides),* huon pine *(Lagarostrobus franklinii),* Australian red cedar *(Toona australis*), kauri pine *(Agathis robusta*) and 'pines' in the *Podocarpus* genus. Although functionally successful, the suitability of several soundboard species for larger scale production is uncertain given the limited availabilty of the remaining resource.

With appropriate management, a number of other species have the potential to provide both continuity of supply and product quality in the volumes required for medium scale manufacturing. The use of both mountain and alpine ash in backs, sides and necks opens the door for the examination of a range of native forest hardwood resources in this role.

The management of regrowth forests in Tasmania, focussing on the production of relatively fast-grown *Acacia* species, also provides a potential future resource separated from tropical hardwood production by better defined and regulated forestry management.

A reference is given of many species currently used, or suitable for use in, luthierie, with some preliminary data on their wood and acoustic properties. An additional evaluation in collaboration with Maton Guitars, examined relationships between the sound characteristics of instruments, and the variation in wood properties of bunya pine soundboards used in their construction. It demonstrated the potential to produce high value and acoustic quality instruments from a wide range of wood properties evident within bunya pine

The listing and testing of timbers in this report represents a preliminary step in the evaluation process. The species listed are not necessarily endorsed for a particular use, or species omitted unsuitable for use in instrument construction. Whilst a species may produce material useful for a specific purpose, the variability of wood as a raw material, the stringent quality demands of instrument makers, and the variety of instruments being made, demands assessment of materials in greater detail. The report will hopefully function as a reference for both processors and luthiers in identifying species which may provide tonewood material, product quality criteria and some wood properties on a number of species.

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# 1. INTRODUCTION

The production of solid wood components for musical instruments (tonewoods) represents a typical low volume, high unit value utilisation of forest resources. Importantly in this case, high prices are maintained for short product lengths in contrast to many appearance grade markets where lengths less than 1.8 metres would be subject to significant discounts.

In just two plant genera, Australia has around 700 species of eucalypts (Brooker & Klienig 1994) and over 900 hundred species in the *Acacia* genus. The south-west region of Western Australia alone has over 300 endemic *Acacia* species (Australian National Herbarium 2008). A number of these and other species have been used in a variety of instruments with excellent results.

The potential of Australian species as tonewoods is dependent upon an understanding of the narrow range of wood properties and aesthetic requirements of specific instrument components, and subsequent evaluations of both woodworking properties and empirical assessments in the hands of skilled luthiers.

Embracing new materials may also require modifications to design principles, aesthetic expectations, and preconceptions as to how instruments should sound.

Several Australian species are currently providing components into this market, with timbers such as blackwood (*Acacia melanoxylon*), bunya pine (*Araucaria bidwillii*) and Queensland maple (*Flindersia brayleyana*) being widely utilised by luthiers throughout Australia, and in the case of blackwood, throughout the world.

There has also been considerable growth in the use of Australian timbers as both a raw material and in finished instruments, both domestically and from export markets. The product is separated in the market because it is endemic to Australia and increasingly by end-users seeking alternatives to tropical hardwoods because of scarcity of supply and concerns with harvesting practices. Restricted supply of many tropical hardwoods has also driven price increases, creating opportunities in the use of ‘alternative’ woods in instrument making.

The terms ‘traditional’ and ‘alternative’ as applied to tonewoods are merely an indication of the usage of one species preceding another. If functional and aesthetic requirements are met, many species may be interchanged.

The transition to materials obtained from new species requires time for manufacturers to adjust to different material properties, optimisation of their use, but also an investment in establishing new product credibility in an area where timber species and quality may override brand loyalty.

The profitability of providing products into this market requires a thorough analysis of process cost information, industry competitiveness and value chain models, to quantify the product quantities, prices and costs entailed in delivering final products to the marketplace.

Whilst it is beyond the scope of this report to undertake such a rigorous economic analysis, it will hopefully provide a practical reference in terms of what species can provide such products, and processing strategies which fulfil end-user criteria.

The information presented on the current usage of tonewoods, emerging markets, and the prices paid for products, toward the value chain end, may assist processors to make basic comparisons with other value adding opportunities.

## 1.1 Background information

### *1.1.1 Tonewoods*

Luthiers (stringed instrument makers) place great importance on the selection of tonewoods, particularly for use in soundboards (tops), backs and sides, bridges, necks and fretboards of instruments (see Figure 1).

The term tonewood is used to describe instrument parts which contribute to the final sound quality and in the context of this project will be confined to the above-mentioned components.

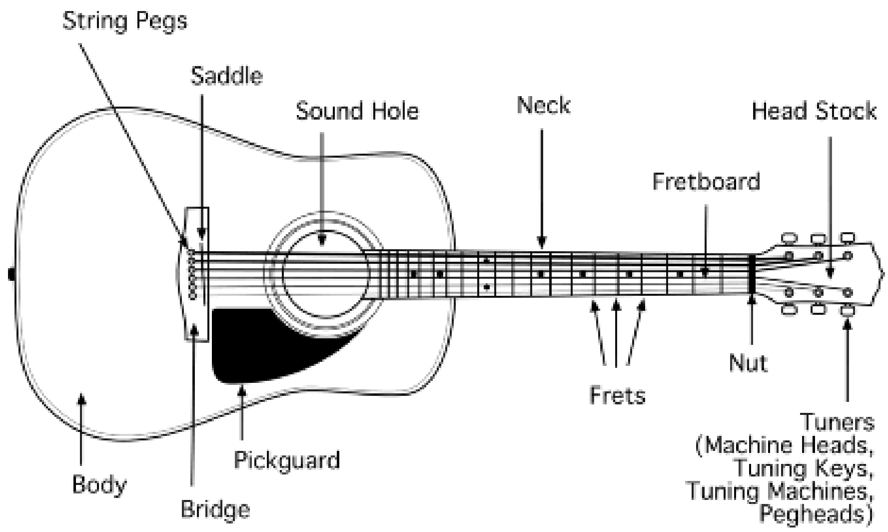



Figure 1 Diagram of an acoustic guitar

Tonewoods in their widest application would also include material used in solid body electric guitars, piano soundboards, harps, flutes, xylophones, violin bows, castanets, drum sticks and mouth organs, with each requiring a specific set of wood properties.

A hierarchy of importance is attributed by luthiers and scientists to the 'acoustic' contribution of instrument parts, with the soundboard (stringed instruments) usually ranking foremost in most appraisals.

### *1.1.2 European tonewoods*

With the development of modern luthierie in Europe, the choice of materials initially focussed upon, and refined the use of, species which were both locally available and acoustically functional.

The use of European spruce (*Picea spp*.), for soundboards, and maple/sycamore (*Acer spp*.) for the back and sides of violins, was a consequence of this process, and has produced countless examples of fine instruments as a result of both the inherent potential of the raw materials, and the many years spent refining their use.

The several spruce species used in soundboards produce an appealing and responsive instrument, particularly in the middle to higher frequency range in which listener/player appraisals are often biased toward.

The success of spruce as a soundboard timber results from a number of well-understood (and measurable) wood properties, which can be used to guide the selection and evaluation of alternative soundboard species.

These characteristics result from the structure of spruce at an anatomical level, producing a material with high along-grain stiffness relative to its mass. However the characteristic sound of spruce as a species, which has become somewhat embedded in the player's mind, may also present an obstacle in the acceptance of soundboards produced from other species, which will produce a different sound as a consequence of a different set of underlying wood properties.

### *1.1.3 Tonewoods from the Americas and Equatorial Forests*

As luthierie extended, and is today an international endeavour, it has been empirically demonstrated that many additional species can deliver equally pleasing (yet different) results.

Combinations of a variety of American spruce and cedar soundboards, with tropical hardwoods such as the rosewoods (*Dalbergia spp*.), mahogany (*Swietienia spp*.), granadillo (*Buchenvia capitata*) and koa (*Acacia koa*) have been widely utilised to produce many fine classical, flamenco, steel-string guitars and other instruments.

The use of North American walnut and cherry in a variety of instrument back and sides has also proved successful.

The more recent use of African timbers such as sapele, ovangkol and bubinga as rosewood substitutes, have emerged as a result of restrictions in the availability and rising cost of many *Dalbergia* species.

Many other hardwood species from both tropical and temperate forests have been used in instrument back and sides, necks, fretboards, and bridges, with a combination of resource continuity, quality and cost, determining manufacturer's preference of material choice. These species have been embraced for their functionality and aesthetic qualities, demonstrating the potential for alternate species to be utilised in many instrument types.

### *1.1.4 Tonewood markets*

The annual world-wide production of solid wood products specifically for use as tonewoods is difficult to quantify. Whilst a number of processors cater specifically to this market, material is often sourced opportunistically from conventional processing streams and also from illegal harvesting. A recent Australian Institute of Criminology report (Ecos 2008) estimated the illegal timber trade from the Asia-Pacific region alone, at around $2 billion. The report estimates 73 percent of timber exported from Indonesia and 35 percent from Malaysia is sourced from illegal logging.

Estimations of tonewood usage are therefore better based upon the collective intake of larger instrument manufacturers. Whilst this information is disparate, and often the subject of commercial confidentiality, it is possible to envisage volumes involved based on available information.

### South-east Asia

China has become the principal manufacturer of musical instruments in the world, with around 70% of guitars and pianos now being made there. By focussing on the Asian region, a reasonable estimate of tonewood usage in luthierie can be made. World-wide, in the production of guitars alone, (classical, acoustic and electric) it is estimated that around 2.2 million units are produced annually (American Forest and Paper Association 2004). A guitar is made of approximately 90% wood, so volumes of solid wood components are far from trivial.

In order to put the volumes used within Chinese guitar manufacturing into perspective, Indonesia produces over 600,000 electric and acoustic guitars into US, Japanese and European markets.

The Indonesian production requires approximately 4,800 $m^3$ of solid wood products per year in the production of the back, sides and bodies of guitars. Another 4,800$m^3$ is used for necks, neck blocks, soundboards and ancillary parts, representing a total of around of 9,600 $m^3$ in guitar production alone (United States Department of Agriculture 2002).

Based upon these figures the current Chinese production would require in excess of double the Indonesian intake of 9,600 $m^3$ in the manufacturing of guitars alone.

In South Korea, the musical instrument industry is the third largest end-use market for wood products. In 1990, musical instrument production was estimated to be $475 million, with approximately 50% being exported (Centre for International Trade in Forest Products 1994). The Korean forest products industry has traditionally relied on tropical hardwood species, however log export restrictions in S.E. Asia have reduced tropical hardwood log imports and forced the restructuring of the wood processing industry. As a result, it is expected that the demand for high quality wood and veneer from both hardwoods and softwoods is anticipated to increase.

The distribution of the manufacturing base of U.S. owned Cort Guitars across China, Indonesia and South Korea, typifies growth of the instrument making industry in the region. Cort produces around 500,000 instruments annually from three manufacturing bases, and through contract production for other manufacturers, it produces around 25% of guitars globally.

The migration of industrial-scale manufacturing bases from North America and Europe into the Asian region has been inevitable as an inherently labour-intensive industry searches for a lower cost labour source.

The process of leading manufacturers relocating to Asia has initially involved overseas production management overseeing local workers, in order to maintain quality control standards.

In the case of China, a by-product of this manufacturing presence has been a ‘technology transfer’ resulting in the development of instrument making precincts with entirely local workforces, producing high quality instruments from imported materials. This is also occurring in other south-east Asian countries in the production of pianos, violins, violas and cellos.

## Opportunities

Whilst this represents a competitive dilemma for the instrument manufacturing sector, it also represents a potential market for producers of wood-based products, as the growth in this area is considerable.

North American and European manufacturers are receptive to new resources with several leading acoustic guitar manufacturers seeking figured Australian blackwood for high-end instrument backs and sides. This is indicative of the acceptance of this species both in mainstream manufacturing and at the retail end of the market.

The development and consolidation of new markets is contingent upon a clear understanding of the end-user’s requirements in order to best represent a new species in a market that has rigorous quality standards and is quick to revert to familiar materials. It is also important that there is continuity in product quality, and for volumes and prices to match market expectations.

### *1.1.5 Environment and resource management*

Whilst the production of wood-based components for musical instruments represents a small volume (less than 1%) of total forest product output (Ellis & Saufley 2008), the reliance on older tropical hardwood and slow grown temperate coniferous species, makes the sector vulnerable to changes in forest management practices.

Today many tropical hardwoods are no longer readily available as a result of CITES (Convention on International Trade in Endangered Species) listing because of their past over-utilisation, and present dramatic declines in distribution.

This decrease in the availability of many tonewood species has given further impetus to the examination of alternative timbers and those derived from forests with better defined and implemented management practices.

Brazilian rosewood *(Dalbergia nigra*), a highly-esteemed tonewood for guitar backs and sides, was already difficult to source in suitable sizes as early as the mid 1960's. An export embargo implemented by Brazil in 1969 gave rise to the widespread adoption of Indian rosewood (*Dalbergia latifolia*) as a substitute (Ellis & Saufley 2008). In 1992 Brazillian rosewood gained endangered species status under CITES legislation further restricting its use.

The decimation of cam-lai (*Dalbergia cochinensis)* in Vietnam also resulted from its utlisation far exceeding sustainable levels, with many high-value end uses competing for this prized resource.

Hawaiiian koa (*Acacia koa*) a highly sought after material for guitars and ukeleles, has been protected under a moratorium which prohibits taking it from government land without a permit. Private land owners can cut, sell or store koa without restriction, but its ongoing commercial utilisation is unlikely

The resurgence in the use of Australian blackwood (*Acacia melanoxylon*), both within Australia and by manufacturers overseas, is in part attributed to its visual similarity with koa, and its excellent tonal and wood working characteristics (Figures 2 & 3).

Blackwood is being adopted as a substitute for koa at the high end of the acoustic guitar market and the demand for figured boards has driven price increases over recent years.

Figure 2  koa (*Acacia koa*) guitar back and sides

Figure 3  Blackwood (*Acacia melanoxylon*) guitar back and sides (Guitar made by Jack Spira)

Many Australian timbers, such as the *Acacia spp*., silver wattle (*Acacia dealbata*), black wattle (*Acacia mearnsii*) and lightwood (*Acacia implexa*), although not widely utilised at present, also have the potential to fill a role (backs & sides) within relatively short rotation times (around 30-50 years) in contrast to many 'traditional' tonewood species (Figure 4).

Figure 4. Silver wattle log; 59cm large end diameter of approximately 48 years from southern Tasmania. (Phillips Sawmill, Geeveston 2007)

Progressive large scale manufacturers have responded to resource declines by examining alternative species, modifying traditional designs (introducing 3 or 4 piece backs) and marketing instruments made from 'sustainable' or Forest Stewardship Council (FSC) certified components.

Four of the largest U.S guitar manufacturers, Taylor, Martin, Gibson and Fender have responded to resource limitations and consumer-driven demands, by forming the MusicWood coalition. One of the aims is the production of FSC certified instruments, requiring 70% of the instrument to be made from wood harvested within the FSC guidelines (Hay 2007).

Gibsons Les Pauls 'Smartwood' electric, Martins 'sustainable wood series' dreadnought and OM, Seagull, Art & Lutherie, Simon and Patrick, are all recognising the implications of future resource restrictions and the opportunities that this creates.

Stringed instrument manufacturing is also highly dependent upon spruce (*Picea spp*.) for soundboard material, which generally requires logs in excess of 200 years of age based on currently-preferred growth ring widths and two-piece soundboard construction.

The majority of sitka spruce (*Picea sitchensis*) supplied to the North American market is obtained from old-growth forests managed by the logging company Sealaska. Although only around 150 logs are dedicated to soundboard production each year, the overall harvesting rate is anticipated to result in a shortage of large diameter logs (required for two-piece acoustic guitar tops) within 15-30 years (Leslie 2007).

Presently there is no FSC certification for sitka spruce logs preventing the manufacture and marketing of ‘ethically sourced’ acoustic instruments.

The current availability of the native *Araucaria* plantation resource (bunya and hoop pine), presents manufacturers with an opportunity to position a product (steel string acoustic guitars) with perceived better environmental credentials than other instruments in the retail sector.

The production of conventional soundboard dimension products (210mm wide quartersawn) from the plantation *Araucaria* resource may be achieved within 80-100 years, and substantially less if four-piece tops are adopted.

## Dryland Acacias

Declines in the availability of quality ebony (*Diospyros spp)* and rosewoods (*Dalbergia spp.)* used in fretboards and bridges (Appendix 3), has focussed attention on a number of dryland *Acacia* species.

They are functionally and aesthetically the equivalent of many timbers used as fretboards and bridges, with many luthiers believing them to be superior in terms of stability and aesthetic diversity. Their very high densities, slow growth rates and resistance to wear (high surface hardness), combined with a diversity of colour and figure make them highly sought after by instrument makers.

An interesting example is prickly acacia (*Acacia nilotica),* introduced from Pakistan, and now classified as a class 2 weed, infesting several million hectares of the Mitchell grass plains in Queensland.

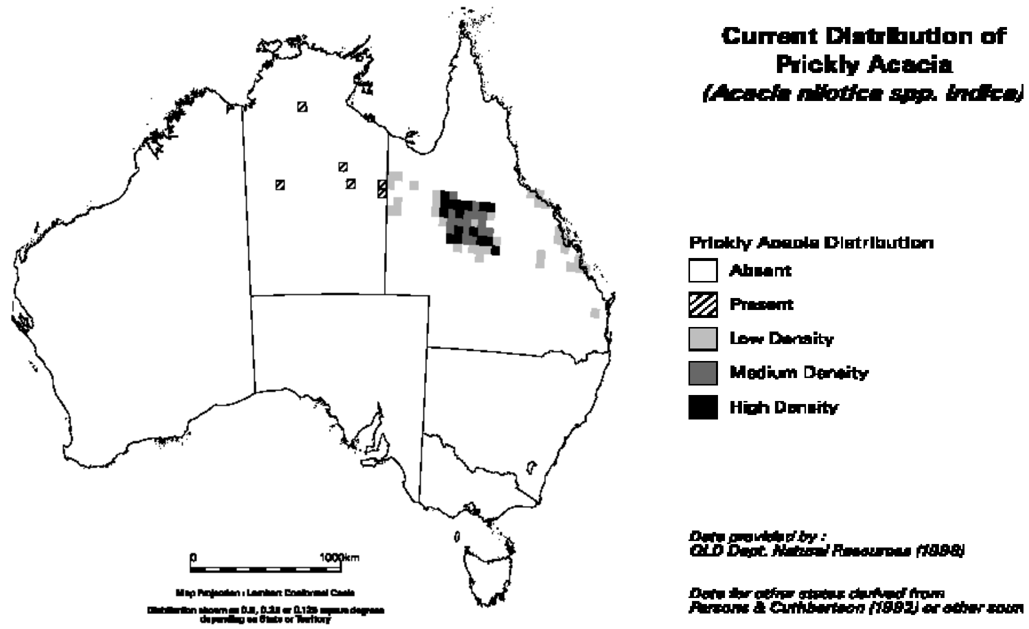



Figure 5. Distribution of *A. nilotica* in Queensland and Northern Territory. Source Qld Dept. of Natural resources 1988

Like many dryland species, the tree form is often poor, but the wood is high in density and comparable to other useful species such as gidgee and mulga.

The extensive distribution of prickly acacia shown in Figure 5 gives an indication of the woody biomass at present. Expensive control measures may be partially offset if even small volumes of tonewood products can be retrieved.

### *1.1.6 Plantation resources*

As the availability of large diameter, older forest resources declines, the complex issues involving forest management, broader ecosystem preservation and the allocation of resources that are harvested from older native forest stands will impact on all end users.

It is likely that finite resources will in the future impose limitations on the mass production of solid wood musical instruments, resulting in the increasing use of composite products such as the laminated ‘stratabond’ necks on the Martin X-series guitars, plywood veneer components, and the integration of plantation-grown materials into the manufacturing process.

The past reliance on old, slow-grown trees, whilst practically and aesthetically warranted in many respects, will collide with the future reality that the resource is no longer available or prohibitively expensive.

Plantation grown wood properties from a given species will be different from native forest material, as a result of faster growth rates and less genetic diversity within the plantation. Changes in wood density and structure are known to affect strength properties and consequently acoustic characteristics of boards. The magnitude of this impact on instrument sound needs to be examined and design solutions explored.

Shrinkage and swelling rates (unit shrinkages) of plantation wood may also differ from slower grown resources, and need to be established in order for manufacturers to adopt such materials with confidence. Fundamental research at a species level is required to quantify the wood properties of new resources in order to optimise their use.

Three or four piece backs and tops, using faster grown plantation resources with wider growth rings, would require both a modified aesthetic and a consequent engineering adjustment by luthiers to the change in material properties.

Forward thinking in the establishment of plantations and management of existing resources, may enable transitions to be better implemented.

#### Araucaria plantations

Australia has two native species in the *Araucaria* genus, bunya pine (*Araucaria bidwillii*) and hoop pine (*Araucaria cunninghamii*), both with a history of utilisation from plantation resources.

Whilst hoop pine continues to be planted and has an exisiting plantation area of around 44,400 ha in Queensland (Huth, Last & Lewty 2001), bunya pine is no longer a designated plantation species, and plantations are confined to around 400ha managed by the Queensland Department of Primary Industries and small plots under private management (Huth and Holzworth 1998).

Plantation bunya pine has been largely replaced by faster-growing slash pine *(Pinus elliotii*), Carribean pine (*Pinus caribaea)*, hoop pine and hybrid species, which are harvestable on shorter rotations (Huth and Holzworth 1998).

Plantation establishment is governed by a basic economic rationale, where rotation times (plantation establishment to harvest date), internal rates of return, and commodity product prices dictate site establishment and species selection.

The comparatively slow growth rate of bunya pine and the general overlap in target products with faster grown species has contributed to the abandonment of its planting.

The relatively recent use of bunya wood in guitar soundboards and bunya nuts in ‘bush tucker’enterprises, has reignited the debate on its future as a plantation species.

Bunya pines are more frost tolerant and marginally less fire sensitive than other plantation species and could therefore be considered on sites where other species are unlikely to thrive (Huth and Holzworth 1998).

Hoop pine is generally managed on rotations not exceeding 60 years, at which point log diameters are below the requirement to produce 210mm quartersawn boards. The existence of well-established solid wood and plywood/veneer markets for logs in the 350-450 mm DBH range dictates current harvesting practices.

Plantation establishment and rotation times are contingent upon the discounted value of products arising over the number of years of growth. This will continue to be a deterrent to potential investors unless it can be demonstrated that high-value product-driven longer rotations can be economically competitive with shorter rotation commodity-driven scenarios. The use of narrower materials in 3 or 4 piece tops and backs if accepted in the marketplace would dramatically reduce harvest age, in both native forest and plantation scenarios.

Both klinki pine (*Araucaria hunsteinii*, native to New Guinea/Irian Jaya) and several species of kauri pine (*Agathis spp.* also within the *Araucariacaea* family*)* have been previously established in trial plots in Queensland. The growth rates and form of both species were reported to be good, however kauri was subject to insect infestation and klinki was reported to have been susceptible to wind damage. (Huth and Holzworth 1998).

Native forest klinki pine in particular, has wood mechanical properties and a density range likely to be of use in acoustic guitar soundboards. Given material from plantation-grown bunya pine has demonstrated utility in soundboard production other plantation grown species may also be useful in this regard.

Interestingly the recently discovered ‘fossil’ tree wollemi pine (*Wollemi nobilis*, also within the *Araucariacaea* family) may also be a candidate for future utilisation in this area.

## Acacia plantations

Traditionally blackwood and black and silver wattle logs have been primarily sourced from native forests in Tasmania and the Gippsland and Otway regions of Victoria. Restricted access to resources in the Otways (which represented 89% of blackwood logs in Victoria), and the transfer of production forest in Tasmania to reserves, has seen the establishment of silvicultural management of regrowth stands and pure stands in plantation situations.

Although blackwood is susceptible to browsing marsupials and requires genetic improvement and management to ensure good stem form and clearwood logs, it has demonstrated potential in plantations both in Australia and overseas (Beadle 2006).

Preferences for material from older slower grown trees will generally produce boards with the colour preferred by makers, however faster-grown plantation material which tends to be lighter in colour may also have a place in future markets.

Figure 6 shows a classical 'Fleta' style guitar utilising a young fast grown blackwood tree (around twenty years) in the back and sides. Although lower in density than material commonly sourced from older trees, the wood exibits both good colour variation and fiddleback grain, characteristics highly regarded in luthiery. Most importantly the sound quality of this instrument was exceptional (King William pine soundboard) indicating the potential to incorporate a range of wood properties with appropriate ajustments to instrument construction.

Figure 6. Wood from a twenty year-old blackwood used in classical guitar back and sides. Photo courtesy of Thomas Lloyd guitars, Melbourne 2009

# 2. CURRENT DOMESTIC USE

The use of Australian timbers in luthiery is by no means a new phenomenon. Fine examples of instruments made prior to the Second World War are a testament to the recognition of the resources potential.

Pre-war violins have utilised King William pine (*Athrotaxis selaganoides*), pencil pine (*Athrotaxis cupressoides*) and huon pine (*Lagarostrobus franklinii*) soundboards, with blackwood (*Acacia melanoxylon*) or Queensland maple (*Flindersia brayleyana*) backs and sides.

In more recent years the use of Australian species has broadened to include timbers such as bunya pine, Queensland maple and Queensland walnut, in larger-scale manufacturing of steel-string acoustic guitars.

Timbers such as myrtle, black-heart sassafras, black and silver wattle, Australian red cedar, coachwood, silky oak, rose mahogany, mountain ash, messmate, Australian rosewood, beefwood and many others, have been utilised in limited amounts to produce a variety of instruments of note.

The dryland acacias have been recognised and utilised for the highly dense, stable and richly coloured timber they produce. These desert timbers have been used in bridges, fretboards, bushings, tuning pegs and bows because of their unique wood properties.

## King William and huon pine

Two species which have been used as a soundboard material are King William pine and to a lesser extent huon pine. Both trees typify very slow growth rate resources, with in excess of 250 years growth generally required to produce logs of sufficient diameter for two piece guitar tops.

Whilst it is true that the huon and King William pine currently available, is primarily obtained from the Tasmanian ‘hydro-scheme’ stockpiles (i.e. long dead trees) their utilisation represents a one-off opportunity. Ongoing usage is dependent upon the stockpile size, as commercial logging is limited to salvage of ‘downers’ (fallen senescent trees) for either species.

The huon pine reserve is considerably larger than the King William pine stockpile and may provide material into speciality markets for the foreseeable future (at current rates of demand). The availability of King William pine is less certain as the remnant resource declines in both size and quality.

The limited resource availability prevents utilisation beyond custom workshop or limited-edition runs in production situations. The resource size also limits the volume of the highest quality material required from a lutherie viewpoint.

Naturally sustainable harvest of such slow growth rate species requires rotation times in the region of several hundred years. Even if sustainable harvest volumes could be established it is likely that luthierie would be one of several competing end-uses of regulated yields.

# 3. SPECIES EVALUATED

As a first step in the evaluation process, a number of instrument makers were surveyed to present a summary of species currently utilised, and as such a starting point in the selection of material for intensive testing. A copy of the survey is included in Appendix 3. It also provided a body of anecdotal information regarding the 'empirical' results of using Australian timbers in a range of instruments. These responses will be summarised later in the report.

# 4. SPECIES USED

A summary of some Australian timbers which have been used by luthiers and the role they play in the finished instrument is presented in this section (Table 1-5)
The list is by no means definitive, in terms of what has been tried, and in what instrument or component, (nor an endorsement of a particular species), but simply brings together the experiences of a number of luthiers throughout Australia.
This is presented as a reference, with further data on wood and acoustic properties tabulated in Tables 12 & 13 (section 6.2.2 pp 66-71) and Appendix one.

Table 1

| **Soundboards** | | | |
|---|---|---|---|
| **Common name** | ***Genus*** | ***species*** | **instrument** |
| Blackwood | *Acacia* | *melanoxylon* | acoustic guitar, ukelele |
| Kauri pine | *Agathis* | *robusta* | acoustic guitar, violin, cello |
| Bunya pine | *Araucaria* | *bidwillii* | acoustic guitar |
| Hoop pine | *Araucaria* | *cunninghamii* | acoustic guitar, violin |
| Sassafras | *Atherosperma* | *moschatum* | acoustic guitar |
| King William pine | *Athrotaxis* | *selaginoides* | class.& acoustic guitar, |
| Cypress pine * | *Cupressus* | *macrocapra* | acoustic guitar |
| Jarrah | *Eucalyptus* | *marginata* | ukelele |
| Qld. maple | *Flindersia* | *brayleyana* | ukelele arch-top guitar |
| Huon pine | *Lagarostrobos* | *franklinii* | class.& acoustic guitar, |
| Satinwood | *Phebalium* | *squameum* | acoustic guitar |
| Celery-top pine | *Phyllocladus* | *aspleniifolius* | mandolin acoustic guitar |
| Black pine | *Podocarpus* | *aramus* | violin |
| Brown pine | *Podocarpus* | *neriifolius* | violin |
| Australian red cedar | *Toona* | *australis* | acoustic guitar |

*Non native – available from farm wind-break clearance

Table 2

| Fretboards/bridge | | |
|---|---|---|
| **Common name** | ***Genus*** | ***species*** |
| Brigalow | *Acacia* | *harpophylla* |
| Myall | *Acacia* | *papyrocarpa* |
| Boree | *Acacia* | *pendula* |
| Mulga | *Acacia* | *aneura* |
| Gidgee | *Acacia* | *cambagei* |
| Northern silky oak | *Cardwellia* | *sublimis* |
| Cooktown ironwood | *Erythrophleum* | *chlorostachys* |
| Jarrah | *Eucalyptus* | *marginata* |
| Crows ash | *Flindersia* | *australis* |
| Beefwood | *Grevillea* | *striata* |
| Wandoo | *Eucalyptus* | *wandoo* |

Table 3

| Necks/Heel | | | |
|---|---|---|---|
| **Common name** | ***Genus*** | ***species*** | **instrument** |
| Blackwood | *Acacia* | *melanoxylon* | acoustic guitar |
| Warren river cedar | *Agonis* | *juniperina* | acoustic guitar |
| Cypress pine * | *Cupressus* | *macrocapra* | acoustic guitar |
| Rose mahogany | *Dysoxylum* | *fraseranum* | acoustic guitar |
| Victorian ash | *Eucalyptus* | *regnans* | guitar, mandolin, Irish bouzouki |
| Jarrah | *Eucalyptus* | *marginata* | acoustic guitar |
| Qld. maple | *Flindersia* | *brayleyana* | violin, acoustic & class. guitar |
| Silver ash | *Flindersia* | *schottiana* | violin, acoustic guitar |

*Non native – available from farm wind-break clearance

(a)


(b)

Figures 7 a-b. Queensland maple acoustic guitar neck blanks and one of two new CNC routers (Maton Guitars 2008)

Table 4

| **Backs & sides** | | | |
|---|---|---|---|
| **Common name** | ***Genus*** | ***Species*** | **instrument** |
| Gidgee | *Acacia* | *cambagei* | acoustic guitar |
| Silver wattle | *Acacia* | *dealbata* | acoustic guitar |
| Lightwood | *Acacia* | *implexa* | acoustic guitar |
| Blackwood | *Acacia* | *melanoxylon* | acoustic guitar, violin |
| Black wattle | *Acacia* | *mollissima* | acoustic guitar |
| Western myall | *Acacia* | *papyrocarpa* | acoustic guitar |
| Hoop pine | *Araucaria* | *cunninghamii* | violin |
| Sassafrass | *Atherosperma* | *moschatum* | acoustic & classic. guitar |
| Northern silky oak | *Cardwellia* | *sublimes* | acoustic & classic. guitar |
| Black bean | *Castanospermum* | *australe* | acoustic guitar |
| W.A. she-oak | *Casuarina* | *fraserana* | acoustic guitar |
| Coachwood | *Ceratopetalum* | *apetalum* | mandolin |
| Rose maple | *Cryptocarya* | *rigida* | violin |
| Cypress pine * | *Cupressus* | *macrocarpa* | acoustic guitar |
| Rose mahogany | *Dysoxylum* | *fraseranum* | violins, |
| Silver quandong | *Elaeocarpus* | *grandis* | acoustic guitar |
| Qld walnut | *Endiandra* | *palmerstonii* | acoustic guitar |
| Alpine ash | *Eucalyptus* | *delegatensis* | acoustic guitar, violin |
| Messmate | *Eucalyptus* | *obliqua* | acoustic guitar ,violin |
| Mountain ash | *Eucalyptus* | *regnans* | acoustic guitar, violin |
| Jarrah | *Eucalyptus* | *marginata* | acoustic guitar |
| Wandoo | *Eucalyptus* | *wandoo* | acoustic guitar |
| Silver silkwood | *Flindersia* | *acuminate* | acoustic guitar |
| Crows ash | *Flindersia* | *australis* | acoustic guitar |
| Qld maple | *Flindersia* | *brayleyana* | violin, acoustic/class guit |
| Silver ash | *Flindersia* | *schottiana* | acoustic guitar |
| Silky oak | *Grevillea* | *robusta* | acoustic guitar |
| Beefwood | *Grevillea* | *striata* | acoustic guitar |
| Huon pine | *Lagarostrobos* | *franklinii* | acoustic guitar |
| Native olive | *Notelaea* | *ligustrina* | acoustic guitar |
| Myrtle | *Nothofagus* | *cunninghamii* | acoustic guitar |
| Satinwood | *Phebalium* | *squameum* | acoustic guitar |
| Tulip satinwood | *Rhodoshpaera* | *rhodanthema* | acoustic guitar |
| Red tulip oak | *Tarrieta* | *peralata* | acoustic guitar |

*Non native – available from farm wind-break clearance

Table 5

| Other | | | |
|---|---|---|---|
| **Common name** | ***Genus*** | ***species*** | **instrument** |
| Gidgee | *Acacia* | *cambagei* | tuning knobs |
| Ironwood ,wattle | *Acacia* | *excelsa* | tuning knobs |
| Western myall | *Acacia* | *papyrocarpa* | bows |
| Brush ironbark | *Bridelia* | *exaltata* | pegs |
| Black bean | *Castanospermum* | *australe* | headstock/ rosette veneers |
| Belah | *Casuarina* | *christata* | pegs |
| Huon pine | *Lagarostrobos* | *franklinii* | bindings |
| Jarrah | *Eucalyptus* | *marginata* | bindings |
| Jarrah | *Eucalyptus* | *marginata* | headstock/ rosette veneers |
| Qld maple | *Flindersia* | *brayleyana* | back and side bracing |
| Qld maple | *Flindersia* | *brayleyana* | neck block/end block |
| Beefwood | *Grevillea* | *striata* | bindings |
| Ivorywood | *Siphonodon* | *australis* | bindings |
| Satinwood | *Phebalium* | *squameum* | bindings |
| Cheesewood | *Pittosporum* | *bicolor* | bindings |

Figure 8. Blackwood guitar side with jarrah and huon pine bindings

## *4.1 Anecdotal assessments*

The species listed above represent a sample of materials having been used by luthiers in Australia.

Several species rated positively in many luthiers' assessments, whilst others were highly regarded by single survey respondents, and untried by the remainder.

The following information is presented merely to encapsulate the survey sample responses, and does not constitute any form of statistically-based data.

It is also difficult to generalise about the performance of any species given the small number and diversity of instruments made, and the variation in wood itself.

**Blackwood (*Acacia melanoxylon*)**

Blackwood has consolidated its reputation as a highly-regarded and often-utilised tonewood by many luthiers throughout Australia. It has been used in a range of instrument types over a sufficiently long time period to have demonstrated its stability and acoustic qualities.

Its use is also growing rapidly in international tonewood markets, with a number of local processors responding to demand from luthiers and larger manufacturers overseas.

**Dryland species**

Similarly a range of high density dryland *Acacia* species and Cooktown ironwood have gained general acceptance, and were rated as excellent substitutes for fretboard, bridge, chin rest and tuning knob materials.

**Queensland maple (*Flindersia brayleyana*)**

Queensland maple as a substitute for mahogany is also widely used and versatile in providing material for necks, neckblocks, end-blocks, kerfing, backs and sides, back and sides bracing, and soundboards for arch-top guitars and ukeleles.

***Eucalyptus* spp.**

Several users reported good results with Mountain ash (*Eucalyptus regnans).* *Eucalyptus obliqua (*messmate*)* has also been used in similar roles as *E. regnans.* The use of both *E. regnans* and *E. obliqua* in necks and backs and sides, opens up the examination of other *Eucalyptus* species which luthiers have generally been wary of because of concerns with wood stability in service.

Several respondents believed *E. regnans* was an excellent material for instrument necks.

The very high density wandoo (*Eucalyptus wandoo),* has been used in the back and sides of acoustic guitars and for fretboard material.

**Cypress pine (*Cupressus macrocarpa*)**

Wood from this non-endemic tree widely established as a farm windbreak, has been tried successfully in guitar necks and backs and sides and as a soundboard material.

Although much of this resource consists of multi-stemmed trees with poor form, it is largely approaching senescence and if processed correctly may produce material useful to luthiers

### Miscellaneous species

Tulip satinwood, Western Australian she-oak, rose mahogany, myrtle, blackheart sassafras, silver silkwood, satinwood, lightwood and silver wattle, are amongst many others, highly regarded timbers for use in backs and sides of a variety of instruments.

### Soundboard species

Several Australian species have been interchanged with 'traditional' tonewoods such as spruce and cedar in soundboards. King William pine in orchestral instuments, classical and steel-string guitars, bunya pine in steel-string guitars and huon pine to a lesser extent in steel-string guitars and violins, have all been utilised by instrument makers.

Australian red cedar (*Toona australis*) has been used in acoustic guitars with good results, and is considered as an excellent substitute for Cuban mahogany tops used on many vintage instruments.

Blackwood has been used in soundboards of acoustic guitars and ukeleles where koa had previously been used. The higher density of blackwood in tops is reputed to impart a distinct sound which improves over time.

Similary, the high density satinbox (*Phebalium squameum*) has been used as an acoustic guitar soundboard with pleasing results (Figure 9). The use of blackwood, blackheart-sassafras, celery top pine and satinbox in this manner, highlights the possibility of experimentation in steel-string construction.

Figure 9. Acoustic guitar made entirely from satinbox (*Phebalium squameum*) Photo courtesy of Maton Guitars Melbourne.

The soundboard is often viewed as the ‘heart and soul’ of the instrument by luthiers, and functionally contributes a great deal to the ‘characteristic’ sound. Therefore, it is not surprising that opinions on the performance of Australian soundboard species are many and varied, and inevitably benchmarked against traditional species such as spruce.

That Australian soundboard species sound different is not surprising, and with the exception of bunya pine (which has benefited from wider market exposure through large scale acoustic guitar manufacturing) responses indicate that some resistance to their use exists both within luthiery, and in the higher end of the retail market place.

### Material availability

This issue is central to both the evaluation and the extent of the use of Australian timbers in luthiery.

Several respondents found it difficult to source high quality materials from selected species. Queensland maple was one species that some smaller luthiers expressed difficulty in obtaining suitable material.

Many of the ‘boutique’ species such as tulip satinwood, beefwood, coachwood, silver ash etc) were also placed in this category. Australian red cedar and King William pine are also both limited in availability for larger scale use.

In most cases this reflects the absence of a resource, species protected from commercial exploitation, or products being directed to other value-adding opportunities.

The difficulties in obtaining appropriate materials, is also an impediment in the evaluation of many species with potential as tonewoods.

It is also evident that the degree to which Australian timbers are embraced by overseas markets will impact upon the domestic affordability, with the likelihood that higher prices will be obtainable from niche buyers in overseas markets.

### Initial processing

Initial milling was also identified as problematic for several luthiers, as for many processors their main objective is maximising recovery of appearance products, with backsawn and nominally quartersawn boards a consequence of this. The relatively small volume demands of instrument makers in comparison to commodity markets are the principal reason for this.

### Bracing material

Several respondents questioned whether there were alternatives to spruce, which is generally favoured for (soundboard) bracing in instruments, because of its unqiue combination of high along-grain stiffness (modulus of elasticity or MOE) relative to a low density (low mass for a given board volume). High quality spruce will generally have a higher stiffness to mass ratio than comparable native species.

High quality bunya pine also has relatively high along grain stiffness and low density, and may have utility as a bracing material. Providing the grain is straight and parallel with the material edges, species with an along grain MOE of around 14 GPa or more, and a low density (450 kg $m^{-1}$ or less) are likely to be functionally equivalent.

In the case of bunya pine, darker brown material is likely to have lower stiffness values and higher density than lighter material, which is preferred for bracing.

The use of composite wood/carbon fibre in bracing does dramatically alter this equation, where materials like balsa wood have had their MOE greatly increased without substantial addition of mass. However for solid wood materials, high quality bracing spruce represents a known material with bracing dimensions reflecting the inherent strength properties of the wood.

**Market acceptance**

Opinions were divided on the market acceptance of instruments made primarily from Australian tonewoods. The high-end production of orchestral instruments such as violins, violas and cellos is more dependent upon the use of spruce/maple/sycamore combinations where musical repertoires and player expectations influenced material choices.

Similarly the production of classical/Spanish guitars is steeped in tradition and material familiarity, however recent departures from orthodoxy in the use of composite materials (carbon–fibre lattice bracing, kevlar double tops, cross-ply veneer backs and sides) and use of Australian tonewoods represents a new direction.

The high investment in labour and input of purchasers in commissioned instruments tend to direct makers to familiar materials and designs, where sound characteristics are better regulated.

It is the realm of steel-string acoustic, arch-top, and electric guitars where traditional criteria are still evolving and generally less resistance to alternative materials exists (Figures 10 & 11).

Figure 10. American manufactured - figured blackwood bass guitar

Figure 11 Burled Myrtle electric guitar ‘cap’

The bunya top, blackwood/Queensland maple/walnut back and side combinations have been accepted domestically and appear to have potential in export markets.

Several respondents felt that greater familiarity with materials and refinements in their use would assist greatly, as traditional tonewoods had the benefit of ‘centuries’ of optimisation.

There was a general consensus regarding the potential of a number of Australian species for use as material for instrument backs and sides, where decorative characteristics become a factor in the marketplace. Inroads have been made into European and North American markets by both tonewoods suppliers and instrument makers.

The use of dryland species in other components, although representing small volumes, has also been widely embraced within luthiery.

# 5. PRODUCT QUALITY CRITERIA

Each instrument component requires a specific set of wood properties both functional and aesthetic, which contribute to its role in the instrument. Many aspects of tonewood product quality are dependent on the initial log selection and processing, and will be dealt with as such.

It is hoped that the information will provide a set of basic product criteria enabling decisions made by processors to maximise the recovery of products in this market, and meet the specifications of the the end-user.

## 5.1 Log selection

The first question revolves around whether the log being evaluated is suitable for producing instrument-quality components. The decision-making process will be initially influenced by the log species, size, features and quality, but ultimately be driven by the economics of processing strategies, final products prices and continuity of end markets.

Notwithstanding, Table 12 & 13 (section 6.2.2 pp 66-71) and Appendix one present a selection of Australian tree species either currently utilised, or with characteristics making them worthy of consideration as potential instrument component producers.

Whilst it is possible to retrieve small volumes of tonewood products from many logs of many species, the commitment to a quartersawing strategy and the time consuming process of defect docking to retrieve suitable products can seriously diminish recovery volumes and increase the cost of target products. Final product thicknesses may also be as little as 4mm, meaning significant product volume is lost to saw kerf alone.

The financial viability becomes dependent upon the cost of processing, prices paid for target products and the market for the downfall product, i.e. what do you do with what is left over.

It is worth noting that many processors catering to this market are often using logs or (segments of logs) that are out of grade (in terms of industrial sawlog specifications), or have limited commercial value in there entirety.

Figure 12 shows remnants of the unprocessed King William pine resource in Tasmania. Much of the existing resource consists of hydro-salvage logs such as those pictured. The potential to recover high-value short length products from such logs still drives the decision making process to convert them into tonewood and other specialty products.

A low quality Brazilian rosewood log (likely to yield small volumes of target product) would still be sought after by tonewood suppliers because end-products command prices several times that of other tonewoods species.

The prices paid are a function of the reverence with which this species is held in by guitar makers, but also the fact that market demand exceeds a diminishing supply. Brazilian rosewood instruments in the retail sector have an established market and are priced accordingly, which naturally flows back to decisions made at the point of processing.

Figure 12. The King William pine stockpile (Tasmanian Specialty Timbers, Queenstown 2007)

This highlights the pre-requisite of market acceptance as a mechanism for establishing tonewood prices, and ultimately governing log values and processing decisions. Put simply processors will take notice if significant volumes of high-value product can be directed into established markets.

### 5.1.1 Log species

The species list in Table 12 & 13 and Appendix one, includes both currently used woods, and those with the potential to fulfil the requirements of specific components in instrument design. Some species are also annotated with regard to restrictions on their availability.

The ability of some of these species to provide the volumes required for larger markets both domestically or in export situations is doubtful, nevertheless individual trees invariably become available for processing for a variety of reasons, and could be opportunistically directed toward such an end-use.

It is also important to understand the variability of wood as a biological material both within a species, as a result of environmental and genetic factors, but also the variation arising from a board's location within the tree and its subsequent processing.

From a processing viewpoint, the following sections summarise basic characteristics of log selection and processing required for the production of tonewood components.

### 5.1.2 Log size

#### Diameter

Because soundboards and backs and sides of steel-stringed acoustic guitars require quartersawn boards around 220mm in width, this imposes a lower diameter size restriction at the log selection stage. This encompasses stringed instruments equal to or smaller in size than a dreadnought (steel-string acoustic guitar).

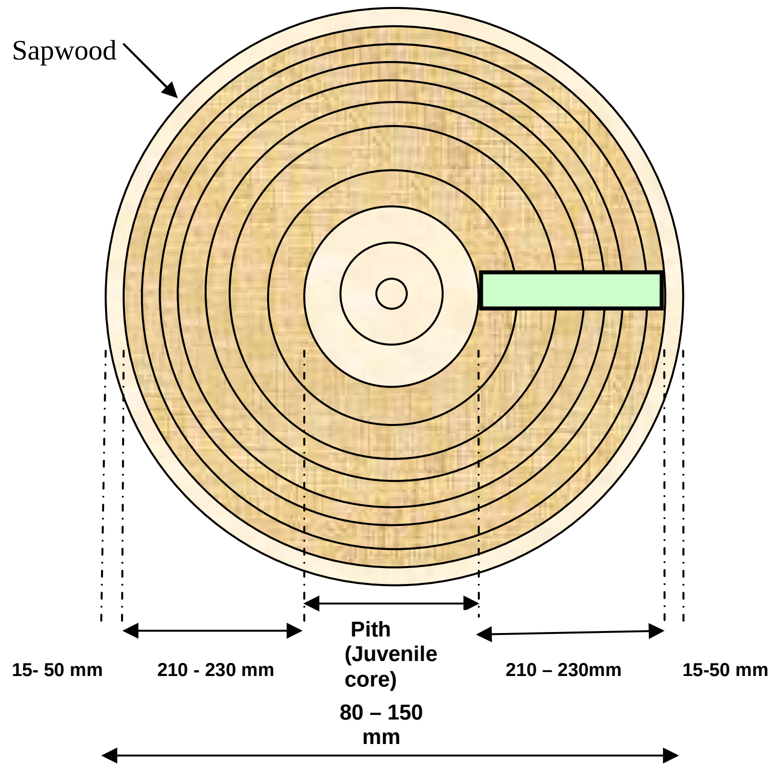
In general, the necessity of avoiding lower quality juvenile wood in the pith (log centre), and colour variation or lyctid susceptible sapwood (around the log periphery), requires logs with diameters of around 600mm (at breast height) and upwards as shown in Figure 13.

Logs at the lower end of this range may not produce sufficient quartersawn board width beyond about 2.5 to 3.0 meters in height dependent on the degree of log taper.

Where logs at the lower end of the diameter range are considered, it is important that they are dealt with in their entirety. From a processor’s viewpoint, a downfall product from the residual log (above the bottom 2-3 metres) is often required to make the processing strategy viable.

This probably requires the identification of an alternative product for, and diversion of the upper log to another processing stream (mill) and sawing strategy.

As previously outlined, the required board width, and consequent log diameter requirement, is largely the product of an aesthetic convention which prefers the symmetry of book-matched pairs rather than 3 or 4 piece constructions, the latter being equally acceptable from both acoustic and engineering viewpoints




**Total minimum log diameter (under bark) 600mm or larger, to produce book-matched quartersawn guitar soundboard or back sets**

Figure 13. Log diameter diagram

Figure 14. Silver wattle (*Acacia dealbata*) 150mm wide boards with around 24 years of growth within the board width (Phillips Sawmill, Geeveston 2007)

## Juvenile wood

The wood from the pith (log centre) in many species may contain shorter fibres, lower density and strength material, with highly variable grain angle relative to the tree axis (spiral grain) (Bootle 2004).

Spiral grain is more likely to produce twist prone material in seasoned boards and is also avoided because it will contribute to grain run-out in processed boards. The combination of these factors is likely to decrease the stiffness and acoustic potential of this material.

The size of this 'juvenile core' is variable dependent upon species and growth rate, but will generally be confined within a 100-150mm cylinder in the log centre.

Thereafter, wood formed will generally have more uniform mean density, grain closer to parallel to the trees axis and regular growth ring structure, all indications of more uniform elastic and consequent acoustic properties.

## Sapwood – *Lyctus* borer

The decision to exclude sapwood will depend upon the individual species' susceptibility to lyctid borer, or whether the material has been boron diffusion treated.

Many Australian and imported species are susceptible to lyctus attack, because the wood vessel size is large enough for the female beetles ovipositor to introduce eggs into the sapwood, where the life cycle begins. The sapwood provides a food source for the emerging young, which bore tiny holes throughout the sapwood zone. (Cookson 2004)

Australian mills producing appearance-grade products from lyctus-susceptible species will generally treat or remove such material.

It is advisable to check the susceptibility status of a species, or where uncertainty regarding treatment exists, it is recommended that sapwood is trimmed from final products.

### *5.1.3 Log length*

The length of logs required is determined by the final length of the products being targeted. The majority of stringed instruments do not require lengths greater than around 800 - 880mm (for sides). For soundboards and backs, 600mm covers the majority of end-users.

Therefore by allowing for end-degrade (end-splitting etc.) in both log and board drying, log sections as short as 700mm (soundboards) may be suitable if they contain defect-free wood matching the component width requirements.

Typically many south-east Australian hardwood sawmills producing appearance-grade products would discount boards under 3 metres in length by around 10%, and by as much as 50% for lengths under 1.8 metres (Washusen *et al* 2005)

What constitutes defect-free wood from a luthier's perspective may also vary from maker to maker. The following section will outline both quality and aesthetic characteristics given consideration.

(a)

(b)

Figures 15a-b. (a) Huon pine ‘shorts’ diverted to tonewood processing (b) Burnt huon pine logs from the stockpile fire awaiting processing (Corinna Sawmill, Burnie 2007)

### *5.1.4 Log quality*

Once a log has been earmarked in terms of species and diameter/length as a potential source of tonewood material it must also have the potential to yield ‘clear’ sections of sufficient length and width to meet end-users requirements.

The majority of luthiers prefer material that is ‘defect’ free. Defects from luthiers view-point include knots, splits and checks (external and internal), insect damage, decay (or other voids), gum vein, and excessive sloping grain (‘run-out’).

Whilst the absence of defects is universal to materials used in tonewoods, as a result of the differing functional aspects of soundboards and backs and sides, log quality characteristics (and subsequent processing) are perhaps more stringent in the selection of soundboard material.

## Growth ring characteristics

European or North American tonewood processors of spruce and cedar for soundboards will often assess grain straightness and growth ring distribution in standing trees before committing to harvesting.

Grain direction can be inferred by examinination of the direction of bark fissures, drying checks in dead trees, or splits in trees that have received lightning strikes. Straight grain is paramount in producing high stiffness soundboards without grain run-out the impact of which will be described in greater detail later in the processing section of the report.

Wood cores are also frequently taken from standing trees (spruce and cedar) in order to assess growth ring ‘tightness’(number of growth rings per cm/inch) and uniformity, as a pre-harvesting screening process.

Growth ring characteristics in harvested logs can naturally be assessed from cross-cut log ends.

## Aesthetic features

In addition to conventional log assessments, additional (decorative) wood characteristics are important to identify where demand and higher prices are being paid for by the end-user.

There are several suppliers into the tonewood market who presently utilise ‘out of grade’ logs (based on state grading criteria) and express a preference for logs with feature *grain* or *colour*. This is more applicable to the backs and sides of instruments where the decorative aspects are highly valued.

### *Grain*

Logs with feature grain like fiddleback, quilting, broken stripe and raindrop figure are highly sought after and often identifiable in log form.

Typically blackwood back and side ‘sets’ will be graded (and priced) on the severity and extent of the grain ‘rippling’ (Figure 16). Fiddleback in myrtle, Queensland maple and several eucalypt species are all highly sought after and prices paid are in accordance with the degree of fibre corrugations.

‘Quilting’ as occasionally seen in fully quartersawn soundboards where ray cells are presented parallel to the board face, is a sought after grain feature in several soundboard species. It is also indicative of material sawn to maximise cross-grain stiffness.

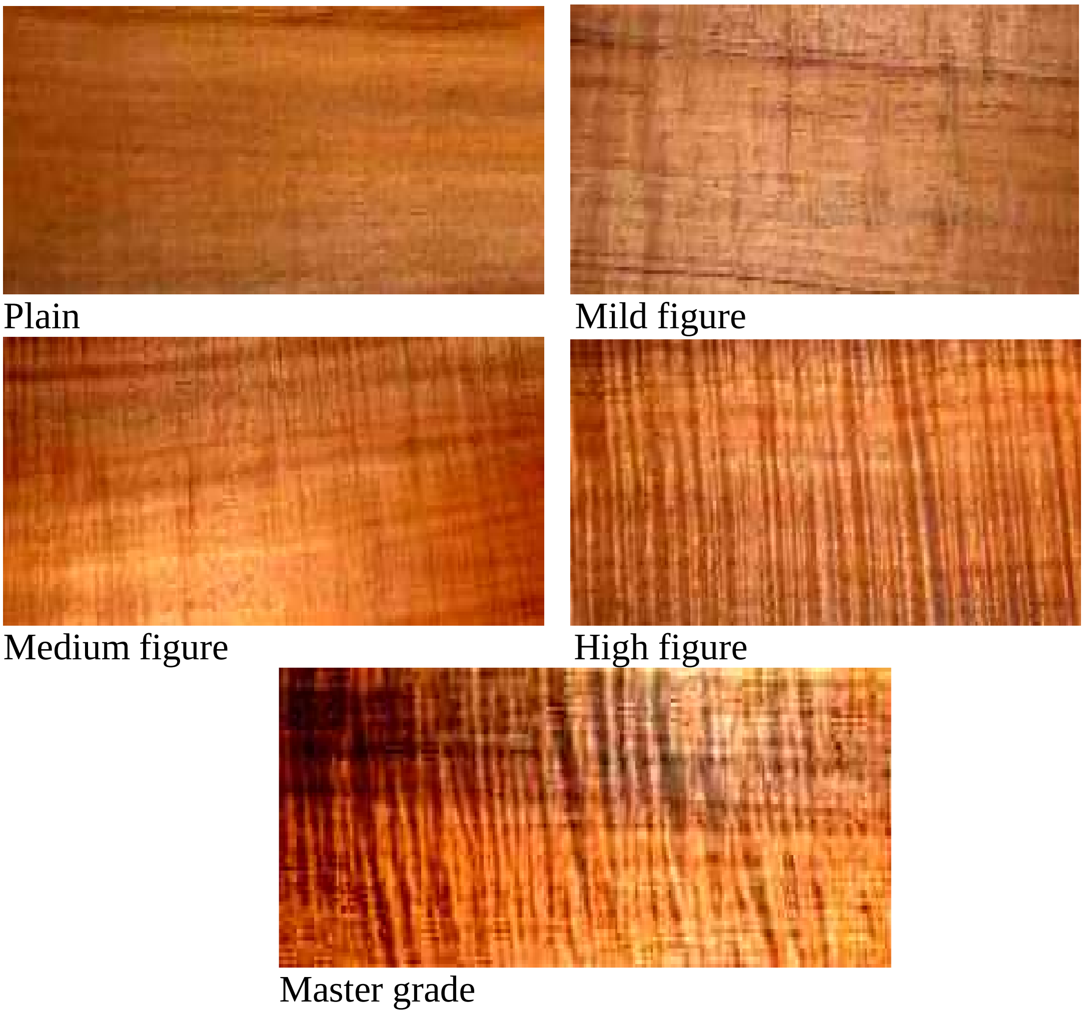



Figure 16. Typical grading of figured grain or ‘fiddleback’ blackwood with value increasing with extent of corrugation and colour (images courtesy of Tim Spittle; Australian Tonewoods W.A.)

### *Colour*

Variations in wood colour such as the fungal staining associated with ‘black-heart’ in sassafras (Figures 17-19) and ‘tiger’ myrtle are also evident from cross-cut log ends. The colour variation imparted by these biological processes command premium prices in a number of decorative wood uses. Highly-figured blackwood back and side sets, in final component sizes (nominally 215mm x 550mm x 5mm; backs and 110mm x 850mm x 5mm; sides) may fetch over $240 AUSD, representing around $95,000 m$^3$.

Tiger-figured myrtle ‘sets’ also containing fiddleback grain (Figures 20 & 21), may cost well in excess of $300 AUSD. Prices are variable according to a perceived rarity or saleability but the appeal of these ‘exotic’ products to overseas markets cannot be overstated.

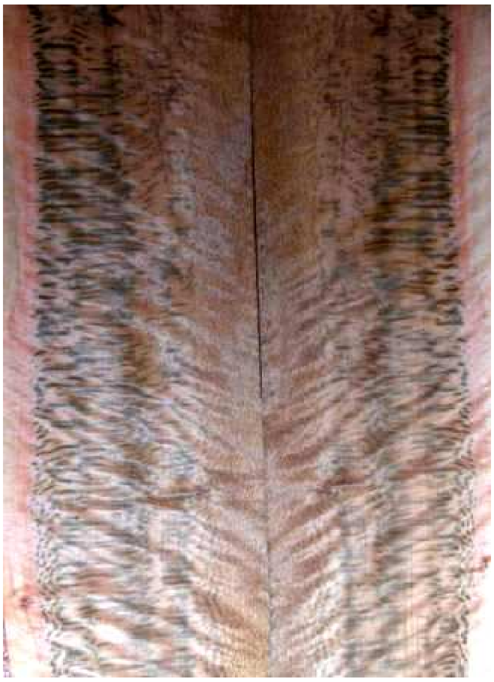
Figure 17. Blackheart sassafras log – 60cm large end diameter

Figure 18.  Sassafras log during processing

Figure 19. Sassafras back & sides. Bateson Guitars U.S.A. wood supplied by Tasmanian Salvaged Resurrection Timbers Pty. Ltd.



Figure 20. Myrtle log (without tiger colouration) 1.1m diameter large end
Part of log tender at Forestry Tasmania's Island Specialty Timbers in Geeveston.

(a) (b)

Figures 21 a-b. Book-matched myrtle set with tiger colouration and fiddleback grain and guitar under construction.

Other species known to produce colour variations in the heartwood are native olive or dorral (Figure 22), coachwood, yellow carabeen, silver quandong, yellow cheesewood, blush alder, mountain tea-tree, and white birch.

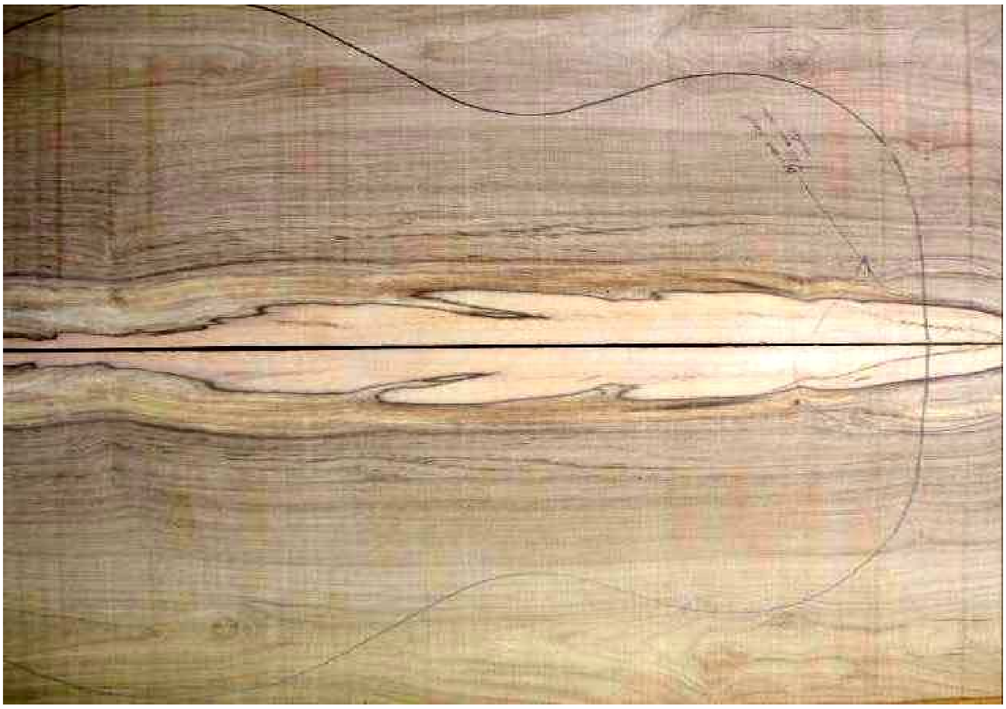


Figure 22 Native olive or dorral (*Notelaea ligustrina)* acoustic guitar back under construction

### *5.1.5 Height in tree*

The requirement of a quartersawn board of around 220mm in width, limits processors to either an advanced age, larger diameter class of trees, or material available from the lower (wider) section of butt-logs.

For soundboard material it is far preferable to obtain material from above-breast height (1.2m) where wood properties (in particular grain direction) are more uniform, the cross-section contains a higher percentage of mature wood and strength properties may also increase. In short, the chances of obtaining the best soundboard wood the tree contains is diminished in the lower trunk.

Material for the back and sides (hardwood species) will also be more variable in wood properties in the lower log, however the decorative grain and colouration of material found in this area often overrides the functional aspects of its use.

## Reaction wood

The term reaction wood is given to material formed arising from a combination of the effects of wind and a gravitropic response to slope and/or crown asymmetry (Bootle 2004).

Because of the declining diameter class of resources being processed, significant volumes of material are obtained from the lower stem (below breast height or 1.2m) where the mechanical stresses exert a larger influence on the formation of wood. This results in the increasing likelihood of the presence of ***reaction wood*** in this region.

Reaction wood in softwoods is present in the form of ***compression wood***, and in hardwoods is termed ***tension wood***. Compression wood forming on the lower side of a lean or slope, and tension wood forming on the upper side (Figure 23).

Figure 23. King William pine lower butt logs. (Tasmanian Specialty Timbers, Queenstown Tasmania 2007.)

The extent of the reaction wood present is often dependent on the degree of lean or growth asymmetry, but genetic factors may also play a role in its formation.

The selection of 'balanced' trees with straight stems, grain, and a central pith will minimise the chances of obtaining such material, as will focussing on material above breast height, where log diameter permits.

Reaction wood is generally avoided by luthiers in the selection of soundboard material from 'traditional species' such as spruce and cedar, because of the potential effect the underlying wood properties have on the materials processing, strength, stability and most importantly acoustic properties.

In the case of material for backs and sides, the lower log and buttresses are often where sought-after feature grain is more prevalent (Figure 24), resulting in substantial volumes of material being derived from the first two metres of a log.

Feature grain such as fiddleback is more likely to be found in a lower blackwood log, and generally dissipates with height. Occasionally trees will exhibit fiddleback grain throughout the stem height.

The demand for highly decorative grain from this region is dictated by the recognition that in the retail market premium prices are commanded for instruments with highly figured backs and sides.

It should be emphasised however that from purely acoustic viewpoint, the corrugation of fibres associated with fiddleback grain does nothing to assist the instrument functionally. That fiddleback grain has been universally embraced in luthiery world-wide, is probably more a reflection of the visual appeal it creates.

Figure 24. Older buttressed blackwood logs are more likely to produce fiddleback material in the lower butt. (Corinna Sawmill, Burnie Tasmania 2007.)

### ***Compression wood***

As shown in Figures 25-27 reaction wood in softwoods is described as compression wood, and is often associated with a tree growing with a lean or subject to a prevailing wind, with the compression wood forming on the side the tree is leaning toward.

An oval or eccentric shaped (non-circular) log end with an asymmetric-pith (log-centre) is often indicative of the presence of a compression wood zone on the larger radius of the log end.

In terms of wood properties, the tracheids (wood fibres) are shorter, the speed of sound is reduced along the grain, and the lignin content and density both increase. This can contribute to a decrease in along-grain wood stiffness, with resultant changes in acoustic characteristics.

When present, such wood is believed to contribute to a reduction in the potential of spruce and cedar as a soundboard material.

Compression wood areas may also be evident as variations in wood colour (generally darker regions) causing luthiers to prefer uniformly-light sets when selecting spruce or cedar soundboard material.

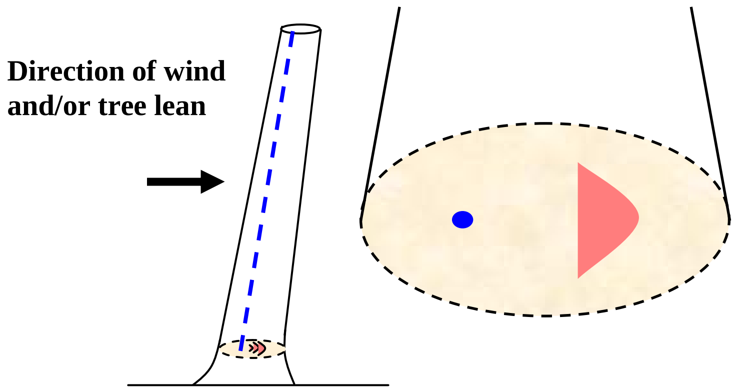



Figure 25.Compression wood zone indicated in red. The off-centre pith (blue line) can be indicative of a compression wood zone within the large radius.

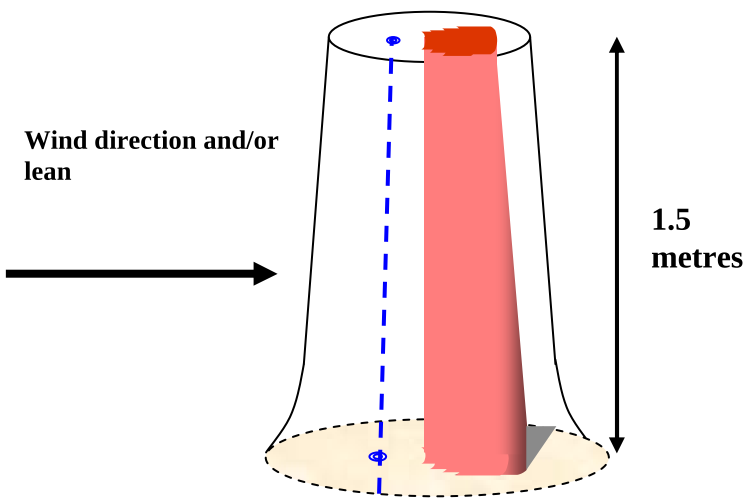



Figure 26. Representation of compression wood (softwoods) would be present as indicated relative to the tree lean or dominant wind direction.

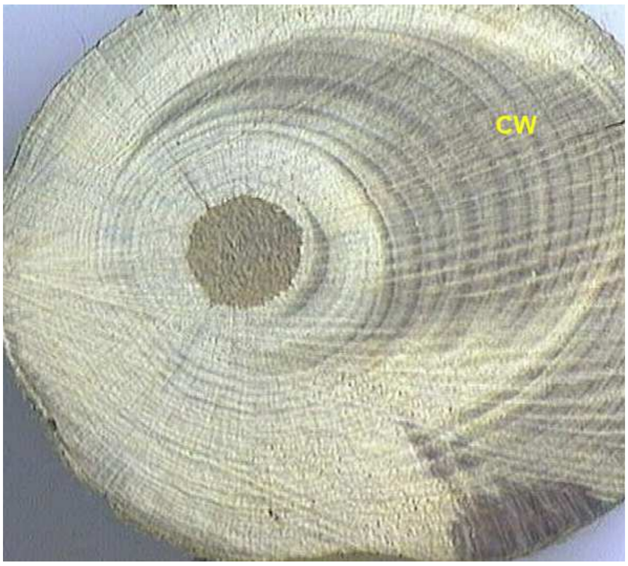



Figure 27. Hoop pine (*Araucaria cunninghamii*) showing compression wood region (photo courtesy of Ilic & Blackwell, Gottstein Wood Science Course 2003)

### *Tension wood*

Tension wood forms in hardwoods on the upper side of a lean or in response to prevailing wind direction. This wood is characterised by longer fibres, a reduction in the size and number of vessels, a decrease in lignin content and an increase in cellulose content.

Tension wood can present significant problems in both sawing and drying, producing areas of high tangential shrinkage which cannot be recovered with steam reconditioning (Washusen *et al* 2002).

These factors in turn impact negatively upon the wood's stability, working and bending properties and acoustic performance.

Tension wood is generally problematic for materials other than soundboards which are generally obtained from softwood species. Tension wood may be evident from a visual appraisal of boards, particularly after drying is completed (Figure 28).

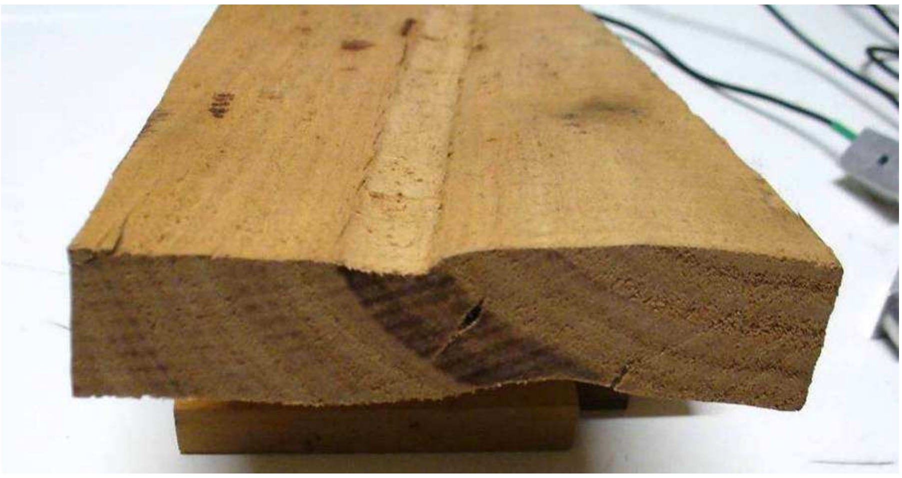


Figure 28  *Eucalyptus* board showing unrecovered dimensional collapse (and internally checked) tension wood band.

## 5.2 Processing and drying

Decisions made at the point of log processing may preclude the production of tonewoods later in the value-adding chain, or produce sub-optimal products from the end-users perspective.

### 5.2.1 Processing

Where a log is considered to have the potential to yield tonewood products, it is important the sawing is conducted in a manner that will maximise the yield of target products.

### Quartersawing

It is important (and universally understood) that solid wood boards used by instrument makers need to be quartersawn.

There are two principal reasons for this, which relate to product stability and maximising cross-grain stiffness of boards. The latter is particulary important for soundboard material.

#### *Ray cell alignment*

Even small deviations from quartersawn result in the ray cell alignment angle increasing relative to the wide board face.
Referring to Figure 29, fully quartersawn wood (board 3) with growth rings at right angles to the wide face will also have rays cells generally parallel to the radial face. This is a factor believed to contribute to the cross-grain stiffness of fully quartersawn boards (Schleske 1990).
The implication of using nominally quartersawn material is that it will reduce the value of mechanical properties (stiffness) across-grain, which is accompanied by increased internal friction (damping) in this direction.

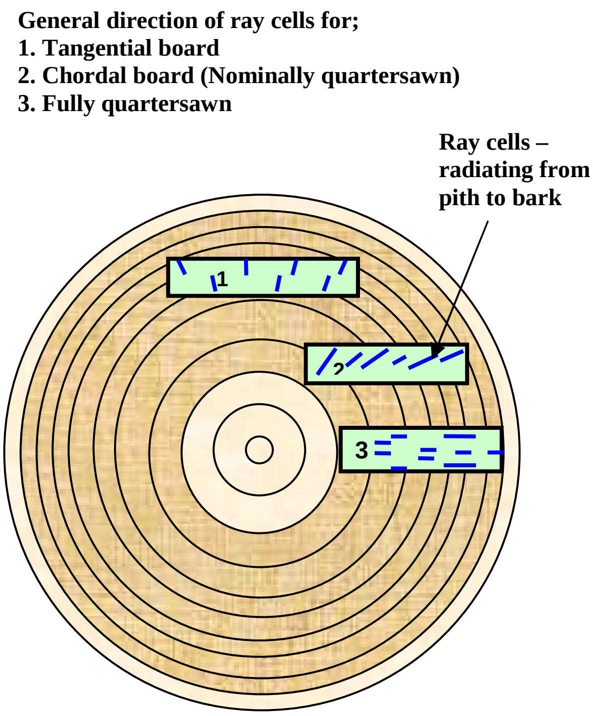



Figure 29. Ray cell direction in 1. backsawn, 2. nominally quartersawn and 3.fully quartersawn boards

Table 6 underlines the significant effect a deviation from growth rings at 90° to the wide face has on the cross-board stiffness and damping characteristics. With growth rings as little as 5° (ß = 5°) from perpendicular to the face, the speed of sound in the cross-grain direction also decreases by around 10%, and where the angle is 11°, the speed of sound decreases by 26%. Importantly this decrease in sound velocity is accompanied by increases in 'damping' (decreases in acoustic efficiency) by 6% and 19 % in the above-mentioned cases (Schelske 1990).

Table 6. Velocity and damping changes with increases in growth ring angle to 90°

| **Across grain** | | | | |
|---|---|---|---|---|
| **Angle** | **Velocity m $s^{-1}$** | **Vel. decrease (%)** | **Damping increase (%)** | **Est. modulus of elasticity (Gpa)** |
| 0 | 1620 | 0.0 | 0 | 3.7 |
| 1 | 1610 | 1.5 | 2 | 3.7 |
| 2 | 1580 | 6.0 | 2 | 3.6 |
| 3-5° | 1480 | 10.0 | 6 | 3.4 |
| 4-7° | 1480 | 14.0 | 8 | 3.4 |
| 6-9° | 1300 | 22.0 | 10 | 3.0 |
| 9-13° | 1200 | 26.0 | 19 | 2.8 |
| 13-17° | 950 | 40.0 | 25 | 2.2 |
| 16-20° | 900 | 45.0 | 28 | 2.1 |
| 35-50° | 600 | 65.0 | 48 | 1.4 |
| 45-64° | 580 | 68.0 | 73 | 1.3 |
| 50-85° | 600 | 65.0 | 70 | 1.4 |
| 85-90° | 1100 | 33.0 | 50 | 2.5 |

(adapted from Schelske 1990).

### *Shrinkage*

An additional reason that quartersawn material is preferred, relates to the differences in the shrinkage of boards in the radial and tangential direction.

#### Overall shrinkage

The overall shrinkage figures tabulated in this report represent mean species dimensional changes from green to air-dry (around 12% moisture content in south-east Australia). The means are derived from samples from a number of trees, with any single board of a given species likely to vary around this mean.

In general, quartersawn boards have around half the overall shrinkage (green to air-dry) than the corresponding figure for backsawn timber. Tangential shrinkages of between 4 and 12%, from green to air-dry are not uncommon for many species, whilst radial figures would be typically around half these values.

Seasoned timber for Australian markets will typically be dried to around 10-12%, (equilibrium moisture content) depending on the market and location. Once it has been delivered to the end-user it will then undergo an equilibration process with the local conditions.

**In service movement of timber - unit shrinkage**

A more direct measure of a board's propensity to move (shrink or swell) in response to changes in temperature and humidity, is a figure known as ***unit shrinkage*.** The unit shrinkage is the dimensional changes in a board (in either the radial or tangential directions) that occur for each 1% change in the equilibrium moisture content (E.M.C.). These figures are representative of the changes likely to occur in the range of conditions a finished instrument is housed in.

In other words, if the conditions in your house or workshop are around 12% E.M.C., a figure not uncommon for south-eastern Australia, running a heater at night may lower the E.M.C. to around 8% E.M.C.

The range of between about 5% and 20% E.M.C. would encompass the majority of environmental conditions found within Australia.

Each 1% change of E.M.C. is simply multiplied by the unit shrinkage rate for a species to determine the likely percentage change for a given board dimension.

Table 7. Comparative unit shrinkage values

| **Species** | **Unit shrinkage 12% - 5%** | | |
|---|---|---|---|
| | **Tangential %** | **Radial %** | **Description** |
| **Regrowth mountain ash** (*E. regnans*) | 0.35 | 0.25 | Fairly high |
| **Silver wattle** (*Acacia dealbata*) | 0.38 | 0.17 | Moderate |
| **Blackwood** (*Acacia melanoxylon*) | 0.27 | 0.16 | Moderate |
| **Queensland maple** (*Flindersia brayleyana*) | 0.25 | 0.17 | Moderate |
| **Maple** (*Acer spp.)** | 0.26 | 0.15 | Moderate |
| **Walnut** (*Juglans regia*) * | 0.27 | 0.2 | Fairly high |
| **Ebony** (*Diospyros spp.)** | 0.3 | 0.27 | Fairly high |
| **Brazilian rosewood** (*Dalbergia nigra*) * | 0.37 | 0.24 | Fairly high |
| **Teak** (*Tectona grandis*) * | 0.18 | 0.1 | Low |
| **Spruce** (*Picea abies*) * | 0.32 | 0.17 | Moderate |
| **Bunya pine** (*Araucaria bidwillii*) | 0.23 | 0.11 | Low |

Source ; Barclay 1997 and Ozarska *et al* 1999
*non-native species

For example bunya pine has unit shrinkage values in the order of 0.11% radially and 0.23% tangentially.Therefore a soundboard half of 200mm in width (radially) which has been previously equilibrated to 12% conditions, undergoes a change in E.M.C. to 8% (i.e. a reduction of 4% ), and a dimensional change of 0.44% would be expected.(4 x 0.11% ). Therefore a 200mm wide board would shrink radially by around 0.88mm (200 x 0.0044).

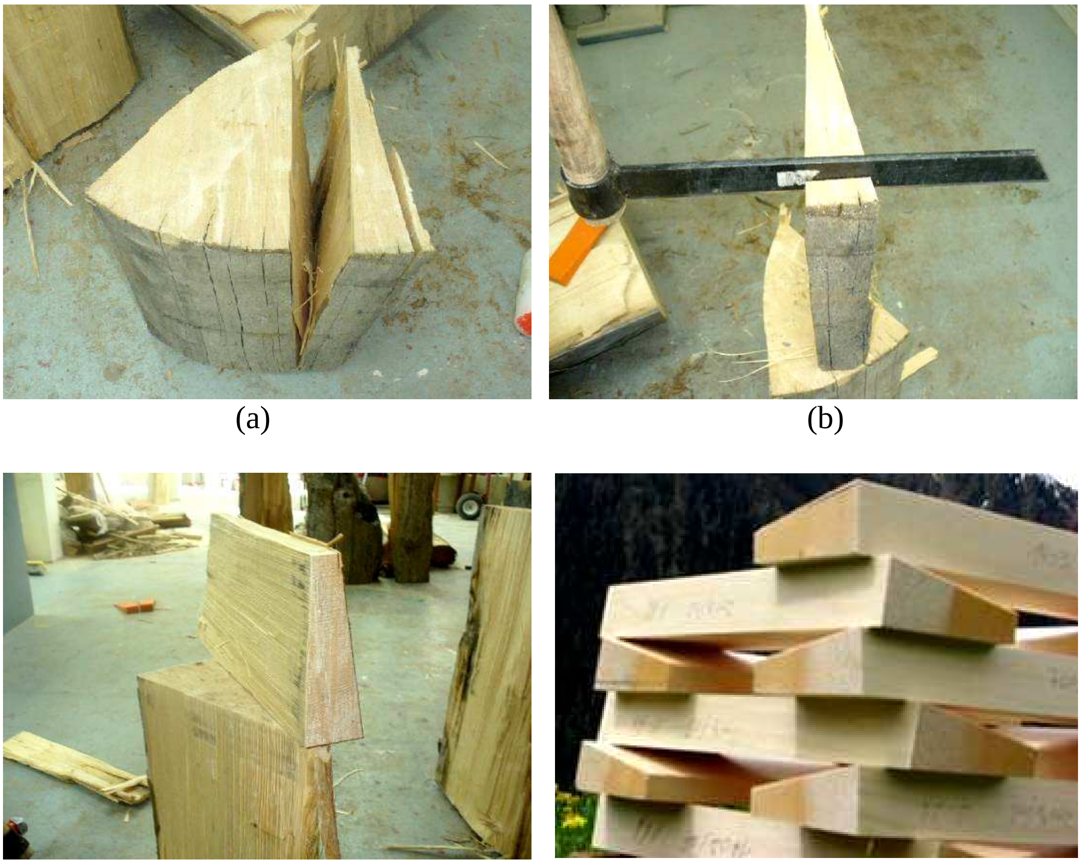
Table 7 shows unit shrinkages for some well-utilised tonewood species. These figures are not absolute with variation likely around these values within a given species. It does however give an idea of the range of values within which tonewood materials would typically lie.

It is interesting to note that native forest regrowth mountain ash (*E. regnans*) and Brazilian rosewood (*D. nigra*) have comparable mean unit shrinkage values.

Both the magnitude and rapidity of the changes in combination with the wood's natural propensity to respond to these, will determine the net effect on the instruments structural integrity.
It is the timber's constant cyclic response to changes in ambient environmental conditions that may ultimately undermine the long-term viability of many instruments.
The constant day/night, heater (or air conditioner) on/off cycle that requires plates to constantly expand and contract, in combination with the static load of string tension can result in plate deformation or separation along vulnerable parts of the material.

## Taper sawing – grain 'run-out'

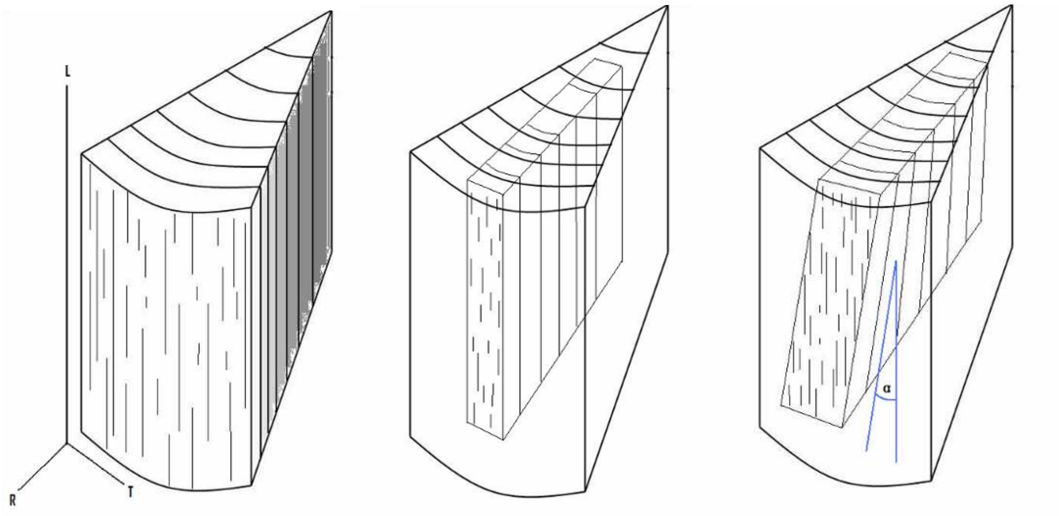
Soundboard 'billets' are traditionally split to establish the presence of straight grain, and a reference plane for subsequent bandsawing into 5 mm 'sets' (see Figure 30 a-d).
Diligent mechanised sawing which follows external grain and log taper can achieve similar results as the traditional splitting of billets. It can however produce more localised grain run-out as the initial reference planes established by splitting can be overridden by conventional sawing.
Splitting billets can also identify localised grain run-out and therefore identify unsuitable material for subsequent processing.



(a) (b)

(c) (d)

Figures 30 a-d. Soundboard splitting with a froe (photo published with permission of Florinett AG Tonewoods Switzerland)



(a) (b) (c)
Figures 31 a-c

Ideally grain in longitudinal plane (L) provides the reference for all subsequent breakdown cuts. As previously mentioned it is also desirable to have growth rings as close to perpendicular to the wide face of the board as possible (i.e. fully quartersawn).
Figures 31 a-c demonstrate what is described as 'grain run-out' ; the deviation of grain angle relative to the board edge, which contributes to significant reductions in the velocity of sound of a board and consequently the along-grain stiffness.
Grain run-out is of highest priority in the production and selection of soundboard material, and is also avoided because it can contribute to board instability in service. Whilst localised grain run-out may not be a significant problem, and in many cases cannot be avoided because of grain variability in logs, it should be avoided if large areas of a board are affected. Table 8 demonstrates the effect of the average angle of grain run-out has on board stiffness (modulus of elasticity) and loss of acoustic potential (damping increases)**.**
It should be noted that these angles represent average grain run-out over the entire board length, whereas a localised occurrence would have a less dramatic impact.

Table 8. Velocity and damping changes with increases in degree of grain runout

| **Along grain** | | | | |
|---|---|---|---|---|
| Angle ° | Velocity m $s^{-1}$ | Vel. Decrease (%) | Damping increase (%) | Est. Modulus of elasticity (Gpa) |
| 0 | 5300 | 0.0 | 0 | 13.5 |
| 0.5 | 5250 | 0.9 | 6 | 13.2 |
| 1 | 5250 | 0.9 | 6 | 13.2 |
| 2 | 5200 | 1.9 | 20 | 13.0 |
| 3 | 5200 | 1.9 | 10 | 13.0 |
| 5 | 4950 | 6.6 | 19 | 11.8 |
| 7.5 | 4800 | 9.4 | 30 | 11.1 |
| 10 | 4400 | 17.0 | 51 | 9.3 |
| 15 | 3900 | 26.4 | 70 | 7.3 |
| 20 | 3250 | 38.7 | 145 | 5.1 |

(adapted from Schelske 1990).

### *5.2.2 Drying*

The drying of tonewood components does not require any dramatic departure from what would normally be applied to other appearance-grade products. Standard end-sealing of billets/boards will minimise end drying degrade of material being air-dried over longer periods.

Well-equilibrated material with an absence of moisture gradients (wet spots), drying stresses or surface/internal checking is important, as moisture variations are known to reduce acoustic efficiency and stiffness properties. Whether this is achieved by kiln-drying or prolonged air-drying is unlikely to have a major impact on the acoustic properties of the resulting material.

It is also well understood by woodworkers and luthiers in particular, that post-purchase, materials should be well equilibrated with the workshop conditions where construction takes place. Equilibration can be ascertained by repeated weighing of materials over several weeks or more, to determine when the mass has stabilised.

## Producing 'sets'

### *Resawing*

Final dry product thicknesses of around 4 mm for backs, and marginally less for sides and soundboards of hollow bodied instruments are achieved through resawing larger boards.

This can be achieved by either resawing material that has been dried in a larger dimension (thickness), or resawing green boards directly after sawing.
Material that has been partially seasoned is likely to contain moisture gradients through the board thickness (wet in the core and progressively drier toward the surface). Resawing material in this condition produces boards with a wet face and a dry face, which can create problems with product distortion (buckling and cupping) as it dries.

***For this reason it is preferable to resaw boards that are either well seasoned or freshly sawn, where in either case the moisture content will be low or high, but fairly uniform through the board thickness***

Drying material that has been resawn green, close to final component size thickness, will naturally dry substantially quicker than oversized boards. Therefore unless the customer requests thick boards for their own resawing, processing to near final product dimensions will expedite the production of finished sets.
Naturally allowances for shrinkage in both the radial (across board) and tangential (board thickness) directions should be accounted for when resawing green material. These figures will vary between softwoods and hardwoods (relatively high) and also between and within species. The overall shrinkage figures (from green to 12% moisture content) shown in appendices 1-3 represent species means for radial and tangential directions, and can be used as a starting point for resawing unfamiliar material.
Tangential shrinkages of around 10% are not uncommon for many hardwood species indicating the potential for a 0.5mm loss in thickness from a 5mm thick green target size, from shrinkage alone. Saw kerf, accuracy and uniformity then become critical factors in controlling product losses to sawdust.
Resaws that minimise saw kerf to around 1mm are achievable for many species, which still represents around a 20% volume loss for a 5mm oversize product.

In addition to the normal practice of placing ‘stickers’ or ‘spacers’ uniformly between layers of drying resawn material, it may be necessary to apply some restraint in the form of top weights or elastic cord (octopus straps or bungee cord).
This will minimise the movement of plates during drying which can then be reflected through the stack, causing deformation in final products. This is less likely to be an issue with well-sawn straight-grained soundboard material, however with the increasing reliance on lower butt log wood for backs and sides, the presence of reaction wood may require management in this manner.

## Kiln dried vs. air dried timber

There are many luthiers who will express a preference for air-dried, over kiln-dried timber. Although there is no direct evidence from differences in subsequent wood structure to support the view that air-dried material is significantly different from kiln-dried wood from an acoustic viewpoint, there is considerable anecdotal support to the contrary from luthiers who prefer air-dried material.

Whilst high temperature drying schedules employed by many industrial mills in producing softwood commodity products can result in reductions in residual strength properties, these schedules are not used in the production of softwood soundboard material. Such material often undergoes a preliminary air-drying process followed by final drying under relatively low dry bulb temperatures.

This is also true of drying less-permeable hardwood species in general, where even standard commercial schedules use relatively low temperatures over extended time periods to dry material.

Providing the drying method employed is conservative and can produce a well-equilibrated product without cracks or drying stresses, the acoustic characteristics should not be greatly compromised.

## Aged *vs* recently-dried timber

Preferences for aged timber, (that has been dried for many years) over recently-dried material is also often expressed by some luthiers. Some research has been conducted (Barducci & Pasqualini 1948 cited in Bucur 2006; Holz 1981) into the changes in wood properties with age suggesting a general decrease in the mechanical integrity of wood beyond around a decade after final processing. This loss of stiffness was accompanied by increases in internal friction (decreasing the duration of ‘tap-tone’) which is believed to negatively affect instrument performance.

It has however been demonstrated that other factors at a molecular level, such as subtle changes in the crystalline structure in cell walls with age, may be positively influencing the instrument sound quality. In one study a ‘crystallinity index’ was observed to reach a maximum after around 300 years in spruce, and subsequently decline from this point.

This is consistent with the approximate age of many high quality violins made by the Italian masters suggesting a ‘peak’ in acoustic performance might also be a function of time (Bucur 2006).

Naturally the practicality of providing volumes of aged, air-dried to timber to an industrial marketplace renders this debate obsolete, although occasionally reclaimed materials enable smaller workshops the opportunity to utilise such materials.

## Moisture content – timber stability

The final moisture content of dried timber will affect its subsequent stability in reponse to changes in atmospheric conditions (relative humidity and temperature)

A general limitation of an air-drying process is that the lowest equilibrium moisture content (E.M.C) the material reaches is a consequence of the ambient conditions of the drying facility or region.

Air dried timber from south east Australia would be unlikely to have an E.M.C. below 10-12%, whereas a controlled kiln drying process (or final kiln) drying can produce material with an E.M.C. of 6% (as required by North American appearance markets).

### *Hysteresis*

The requirement for a product dried to a lower E.M.C. is related to the 'Hysteresis effect' which results in a material that is less reactive to changes in humidity, after it has initially been dried to a lower E.M.C.

Thereafter, the material tends to be more hydrophobic in response to humidity changes and as a result dimensional changes are also minimised (lower humidity expansion coefficient) (Skaar 1988).

Large scale manufacturers will often utilise controlled environment rooms to lower the E.M.C. in the vicinity of 6% and control temperature and relative humidity in the production area itself to stabilise materials during construction.

Final drying to around 6% may be more important when dealing with a species having relatively high unit shrinkage values (such as many eucalypt species) where minimising subsequent dimensional change may mean the difference between failure and sucesss in instrument viability.

In practical terms processors aiming to produce a consistently-stable wood product where minimising movement is critical in instruments worth thousands of dollars, final drying to a low E.M.C. is preferable.

# 6. EVALUATING TONEWOODS

## 6.1. Assessment by luthiers

The processing of tonewood components should be tailored to the requirements of the end-user.

In the absence of laboratory testing equipment, an understanding of the requirements of luthiers is essential in producing quality tonewood components.

A variety of selection criteria exist, with different luthiers placing an emphasis on different aspects of wood quality, based upon the type of instrument they are constructing and previous experiences with similar materials. In short, what has worked in the past is a valuable and persuasive selection tool.
Notwithstanding the variation in assessment criteria employed, universally ‘traditional’ criteria for selecting a wood, is undertaken on the basis of a largely visual appraisal of the material.

This will often be combined with an auditory ‘tap-tone’ evaluation, and in the case of soundboards, may involve a form of rudimentary or quantifiable bending test.

### *6.1.1 Soundboard*

A summary of the critieria typically used for soundboard assessment is presented in Table 9. It should be emphasised that these criteria would be more commonly applicable to the ‘traditional’ materials derived from spruce (*Picea spp*.), and cedar species.

In the case of the southern ‘pines’ King William and huon, the traditional approach probably represents a reasonable approach to selecting soundboard material. The suppressed growth rates are a reasonable match for the corresponding northern latitude species, so colour and growth ring characteristics are likely to represent similar underlying variations in wood properties.

Table 9 Summary of soundboard criteria

| **Soundboard material - up to 210mm wide, book-matched pairs** | |
|---|---|
| **Visual criteria** | **Clearwood –** absence of defects/discontinuities (knots,cracks,holes etc.) |
| | **Growth ring –** uniform radially, axially (width instrument and maker specific) range from 1mm - 3mm |
| | **Colour –** ‘light’ uniform (indicative of absence of compression wood) |
| | **Grain –** straight and uniform, relative to board edges (absence of grain ‘run-out’) |
| | **Quartersawn –** growth rings as close to perpendicular to board width. (More stable and higher cross-grain stiffness than nominally quartesawn material) |
| **Auditory** | **Tap testing –** nodal point restraint and tapping to excite bending modes and assess clarity and duration of ring tone |
| **Stiffness test** | **Bending test –** Hand, or measurable along and cross-grain |

Consideration is given to the size and uniformity of growth ring structure and the absence of blemishes, or colour variation that may indicate the presence of compression wood.

In most cases ‘clear’ sections of wood are preferred, with knots, drying checks, insect damage and any discontinuities in wood structure avoided.

Significant grain run-out (where grain direction deviates from parallel to the board edges) is also avoided as it is known to reduce stiffness and potentially create stability problems.

These criteria are generally accepted but processors should note that luthiers are likely to have developed an individual hierarchy of importance in selecting materials. Many current and ‘vintage’ instruments with soundboards containing wider growth rings, minor grain run-out and imperfections nevertheless produce outstanding tonal qualities from a listener/player perspective.

## Growth ring and grain characteristics

A summary of the critieria typically used for the selection of material for soundboards is presented in Table 10.

A simple method of appraising underlying anatomical structure is to examine growth ring width, uniformity and straightness of grain.

In general terms, straight grain within the board and relative to all board edges is usually recognised as important in maximising the inherent stiffness characteristics of the raw material.

Departures from this are known as ‘grain run-out’, and can dramatically reduce the soundboard stiffness if the ‘run-out’ area is large.

Quartersawn material is critical in minimising dimensional changes in response to atmospheric changes in temperature and humidity (board stability).

Fully quartersawn boards (i.e. with growth rings close to 90° to the wide face) also exhibit higher cross-grain stiffness, contributed to by ray cells being aligned parallel with the radial face.

There is no formal industry standard relating to soundboard grading, with individual processors developing broadly similar in-house criteria. Typical in-house grading of spruce and cedar is shown in Table 10, with grades ranging from master grade to A-grade. Buyers select material which suits personal preferences from within these categories.

It is generally believed that a fine grained, even textured wood with uniform colour throughout will produce a superior sound.

Lack of colour variation, is in itself, can be an effective visual means of avoiding the presence of reaction (compression) wood in softwood species typically used in soundboards.

Typical growth ring widths for violins and violas are around 1mm, cellos 3mm, and double bass 5mm.Whilst many luthiers will adhere steadfastly to these parameters, others may depart from these if other characteristics are suitable.

It is believed that the proportion of latewood to earlywood be in the order of 1 to 4, giving an overall density of about 400-450 kg $m^3$ (Bucur 2006).

As well as ring width criteria, it is generally viewed desirable that growth rings are as uniform as possible both radially (across) and along the soundboard’s length.

Table 10 General spruce and cedar growth ring and grading criteria:

| Growth rings per 25mm | | | |
|---|---|---|---|
| **Wide** | **Medium** | **Tight** | **Very tight** |
| **4-10** | **10-14** | **14-20** | **20+** |

| | |
|---|---|
| **Master:** | Very tight and tight straight evenly spaced grain lines, No colour variation. No run-out. Excellent ring tone and strength. Perfect quarter cut 90 degrees. 100% Clear. |
| **AAA:** | Very tight to tight straight grain lines, slight gradual widening of lines, No colour variation. No run-out. Excellent ring tone and strength. Perfect quarter cut 90 degrees. 100% Clear. |
| **AA:** | Variations in tightest of grain, straight grain lines, No colour variation. No run-out Good to excellent ring tone and strength. Perfect quarter cut 90 degrees. 100% Clear. |
| **Colored:** | Very tight and tight straight grain lines or variations in tightest of grain, contains color variations. No run-out. Good to excellent ring tone and strength. Perfect quarter cut 90 degrees. |
| **A: Factory grade** | May contain color and/or variations in tightest and straightness of grain. Good to excellent ring tone. Quarter cut 80 - 90 degrees. |
| **B: Factory grade** | Contains color and/or variations in grain spacing, twist in grain. May contain small pin knots. Satisfactory to excellent ring tone. Quarter cut 80 - 90 degrees. |

## Australian soundboard species

Whilst there is little doubt that considerable grain run-out presents a problem to soundboard quality regardless of species, it is unlikely that such a dogmatic approach to growth ring width and colour uniformity is applicable in the case of the Northern Australian native softwoods utilised in steel-string acoustic instruments, such as those in the Araucariaceae family.

These species grown under sub-tropical to tropical conditions do not produce the remarkable close ringed anatomical regularity found in the European or North American coniferous species.

It is also apparent to anyone who has worked with these Australian softwood species (shown in Figures 32 a-c) that their inherent colour and grain variation would cause trepidation amongst luthiers unfamiliar with their ‘acoustic performance’.

In short they would be rejected outright if the traditional selection criteria were rigidly applied.


Bunya pine (*Araucaria bidwillii*)

Hoop pine (*Araucaria cunninghamii*)


Kauri pine *(Agathis robusta*)

Figures 32. Australian acoustic guitar soundboards

## Bending test

Some luthiers will conduct a form of stiffness assessment of soundboard material. This may take the form of a rudimentary bending test (hand over knee) or may involve more quantifiable testing procedures.

In either case, the luthier is endeavouring to assess the elastic properties both along and across the grain of the raw material, which may vary considerably from several boards taken from a single tree.
The stiffness of the wood both along and across the grain (relative to a low density) is believed to be of high importance regardless of the species used, as the mechanical load of the strings pulling the bridge is universal in instrument design. It is also believed that a stiffer wood sample (than one of the same density) may have the potential to more efficiently radiate sound than a less stiff, higher density soundboard (Richardson 1994)
Although recent advances in the use of carbon-fibre reinforced bracing and kevlar substrate soundboards, have to some degree lessened the importance of these stiffness characteristics, for the majority of instruments made, it is still of great importance.

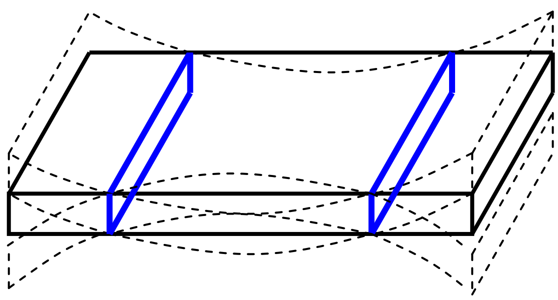
## Tap testing

Luthiers may also employ an intuitive technique known as tap-testing both in the selection of soundboards and back and sides, and also in the process of reducing a soundboard to its final dimensions in the instrument construction process.

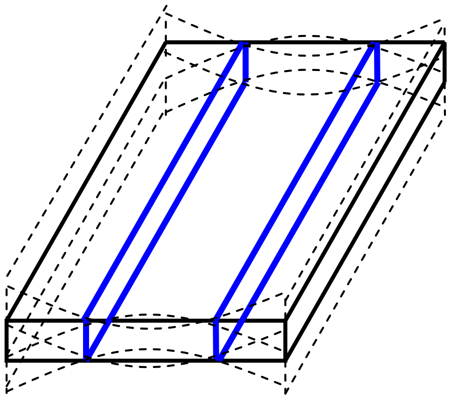
This method would typically involve holding a soundboard (in rectangular form) at a nodal point (one quarter length and width) and tapping the sample to identify the longitudinal and radial (cross-grain) tones. It is generally believed that the higher pitched tap tones (from samples of equal length) with both ‘clarity’ and duration of tone are indicative of materials with higher sound velocity and efficiency in transmitting received energy (string energy via the bridge).

This assessment also enables an estimate of the materials internal damping, where a clearer, longer lasting ring is interpreted to signify low internal damping.

This process is inherently subjective and can lead to variations in assessments, however the process can provide an effective selection tool to experienced luthiers.

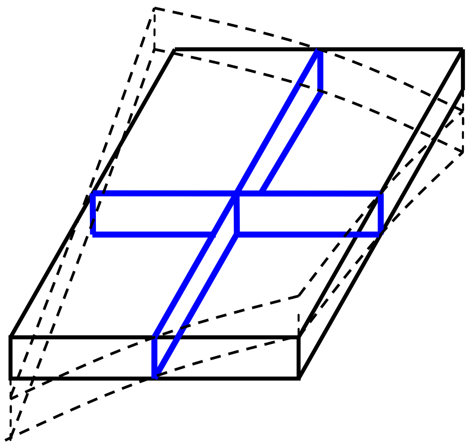


(a)



(b)

*Along and across grain bending vibration* – blue zones represent non-moving nodal points



(c)

*Torsional vibration* – blue zones represent non-moving nodal points

Figures 33 a-c. Principal vibrational modes of a rectangular plate.
(Source Caldersmith 1983).

### 6.1.2 Back and sides

A summary of the critieria typically used for the selection of material for backs and sides assessment is presented in Table 11.

In terms of the processing (quartersawing) and the absence of defects the criteria for backs and sides are generally similar to those listed above for the soundboard.

Ideally a quartersawn board with grain relatively parallel to edges will assist with board stability.

The degree of grain run-out and departures from fully quartersawn material are tolerated to some degree in appraisals of material for back and sides, particularly where striking grain or colouration is present.

The wood must also be responsive to bending (for sides) and possess other basic wood working properties (machining, gluing and polishing)

Table 11

| **Backs and sides** | **Up to 220mm x 550mm long (back)**<br>**110mm x 850mm long (sides)** |
|---|---|
| **Visual criteria** | **Clearwood** – absence of defects/discontinuities (knots,cracks,holes etc.) |
| | **Aesthetics –** attractive grain, colour |
| | **Quartersawn –** minor transition to nominally backsawn accepted |
| | **Grain –** straight and uniform, relative to board edges (absence of major grain 'run-out') Less relevant than for soundboards |
| **Auditory** | **Tap testing –** nodal point restraint and tapping to excite bending modes and assess clarity and duration of ring tone |

Whilst the back and sides are significant contributors to the overall sound of an instrument, it is also true that they are competing visually for the attention of buyers in the market place.

Over one hundred years ago the Spanish luthier Oscar Torres (considered by many to be the Stradivari of Spanish guitar makers) set out to demonstrate the importance of the soundboard relative to the back and sides, by constructing an instrument with paper mache back and sides and a high quality soundboard. The resulting guitar was reputed to have functioned well ‘acoustically’ despite the dramatic departure from design orthodoxy.

The use of a variety of tropical hardwoods and the recent adoption of a number of Australian species in the back and sides of stringed instruments, also confirms that the diverse use of materials in this role, combined with high quality tops is not a major limitation upon sound quality.

## 6.2 Scientific evaluation

The tonewood evaluation in this project involved two parts;

### Part 1 – Preliminary evaluation

The preliminary evaluation involved the measurement and presentation of some material properties of a number of Australian native species used in lutherie, focussing on materials used in soundboards and backs and sides. These are shown in in Table 12 & 13

Species used for components such as necks, fretboards and bridges, are also listed on the basis of their current use, or potential to be used, with data on their basic wood properties (from previously available data sources).

### Part 2 – Instrument material evaluation

This part of the project involved the construction of four steel-string acoustic guitars (bunya pine soundboards with Queensland maple back and sides) and an examination of the relationships between the wood material properties used in their construction and the instrument sound characteristics.

The instrument evaluation was focussed primarily on the relative contribution of the natural variability found in ***bunya pine soundboards*** on instrument sound characteristics.

### Background

The ‘scientific’measurement of wood properties and ‘traditional’ luthiers’ assessments are alternate pathways to appropriate material selection.

The visual and auditory cues utilised by luthiers to assess wood properties known to contribute to acoustic performance, can be viewed as an evaluation of proximate characteristics of the underlying wood structure (and micro-structure) and the way these structural units are arranged within the planes of symmetry in the stem (or board).

Put simply, the building blocks of wood at a very small scale and how they are arranged in three-dimensions, are very important in determining many bulk properties of processed boards. These properties can in turn determine how efficient the material is in receiving and propagating sound energy, and therefore the materials potential as a tonewood.

The following introduction to the relationship between the structural elements of wood and its ‘acoustic characteristics’ provides an insight into the rationale behind many of the ‘traditional’ evaluation criteria employed by luthiers.

It also provides a methodological tool for evaluating new wood species and may also assist with the selection of optimal material from within a species.

### 6.2.1 Wood-structure

#### Macro-structure

Wood is essentially comprised of elongated fibres (tracheids) aligned generally with the axis of the tree trunk. These fibres are hollow (crystalline) tubules bound together by a form of cement known as lignin (Figure 34).

The cell walls are composed primarily of cellulose in a crystalline structure and are highly efficient at propagating received sound energy (along the grain), whereas the cement (lignin) is amorphous (lacking directional structure) and acts as a damping agent to sound energy propagation (Yano *et. al.* 1994).

The (crystalline) walls of these fibres are believed to provide an (along grain) pathway or 'wave guide' for sound waves to travel (Bucur 2006).

Increased fibre (tracheid) length may also assist in the transmission of sound energy along the grain. It has been suggested that in a species with longer fibres, there are fewer obstacles (fibre junctions) along this pathway for a given length of wood, than in a material with shorter fibres (Bucur 2006).

As a result of its cellular components and annual growth variations, wood is structurally different in each plane of symmetry. Wood is thus described as *anisotropic*, unlike many synthetic materials which can be structurally homogenous in all directions.

Consequently the elastic (stiffness) and acoustic properties of wood are also distinct within each plane of symmetry (approximate ratio of 6 : 1.5 : 1 ; along grain, across grain and tangentially).

The ratios of the acoustic/elastic properties in these planes of symmetry can provide a tool for characterising materials, and the resulting indices used to establish relationships with the requirements of particular instrument components.

Generally, amongst materials of equal density, the wood with a higher along grain velocity of sound will also have higher stiffness or modulus of elasticity (MOE) along its length.

The direction of the tracheids, axially in the trunk (along a board length) results in the velocity of sound being significantly faster in this direction, than in either cross-grain or tangential directions.

In the radial plane (across a board in quartersawn material) the ray cells (shown in Figure 34) provide structural support in this direction. The alignment of these cells parallel with the board width is sawing dependent and an important contributor to cross-grain stiffness.

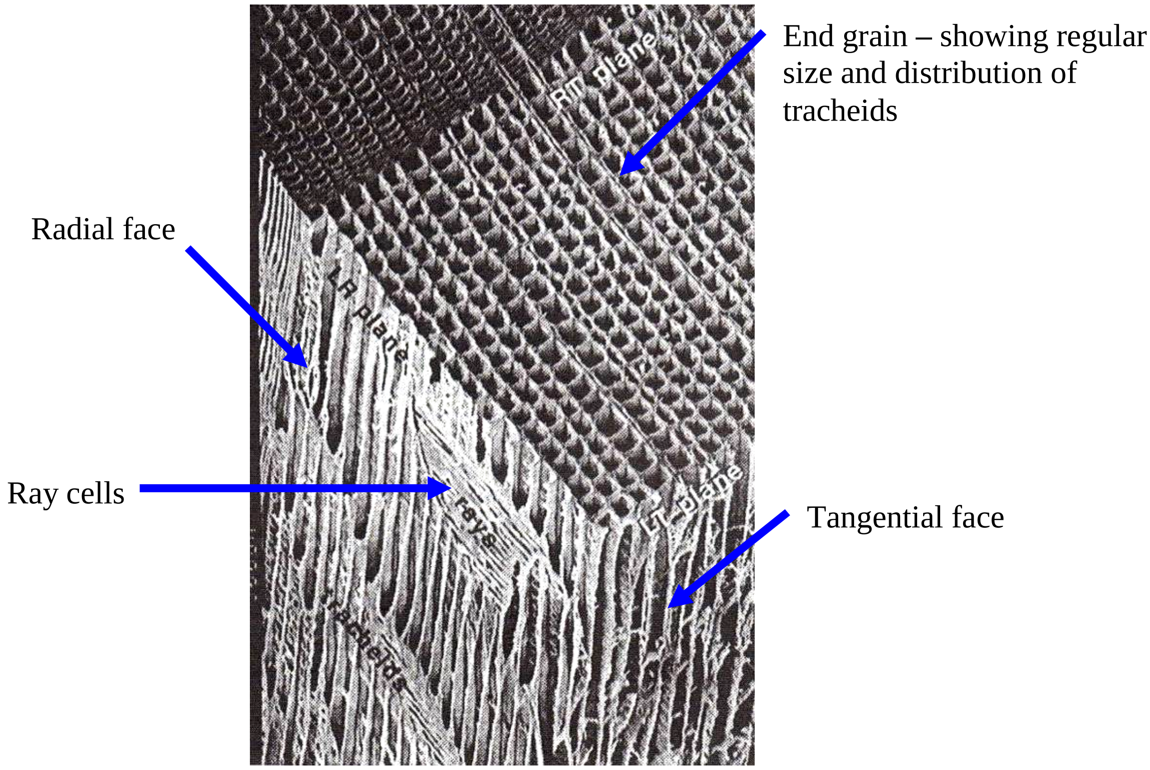



Figure 34.Scanning electron micrograph (SEM) of resonance Spruce (photo courtesy of Bucur 2006)

## Micro-structure

The cell walls of fibres, are in turn composed of crystallized cellulose micro-fibrils (Figure 35), the angle of which (micro-fibril angle or MFA) strongly influences the velocity of sound and the stiffness along a boards length (Yano *et. al.* 1994).

The angle of these micro-fibres (relative to the longitudinal axis of the fibre) can be measured using Silviscan®, an automated wood analysis instrument developed by Dr. Robert Evans at the CSIRO. Materials Science and Engineering laboratories in Melbourne. The instrument is a rapid wood analysis system which can also provide information on the width of cellulose crystals in the fibre wall, fibre dimensions in radial and tangential planes, detailed radial density profiles, cell size and distribution, and fibre coarseness and roughness data.

The high values for along-grain stiffness in resonance spruce are strongly influenced by the relatively low angle of its cell wall micro-fibrils (in the secondary cell wall or S2 layer). In comparison to other woods spruce is remarkably stiff (along grain) relative to its density.

In spruce, the regular arrangement of these structural elements (Figure 34) within the planes of symmetry also produces relatively homogenous elastic/acoustic properties along and across boards. An understanding of these properties can refine the material selection process and assist with the identification of alternative species.

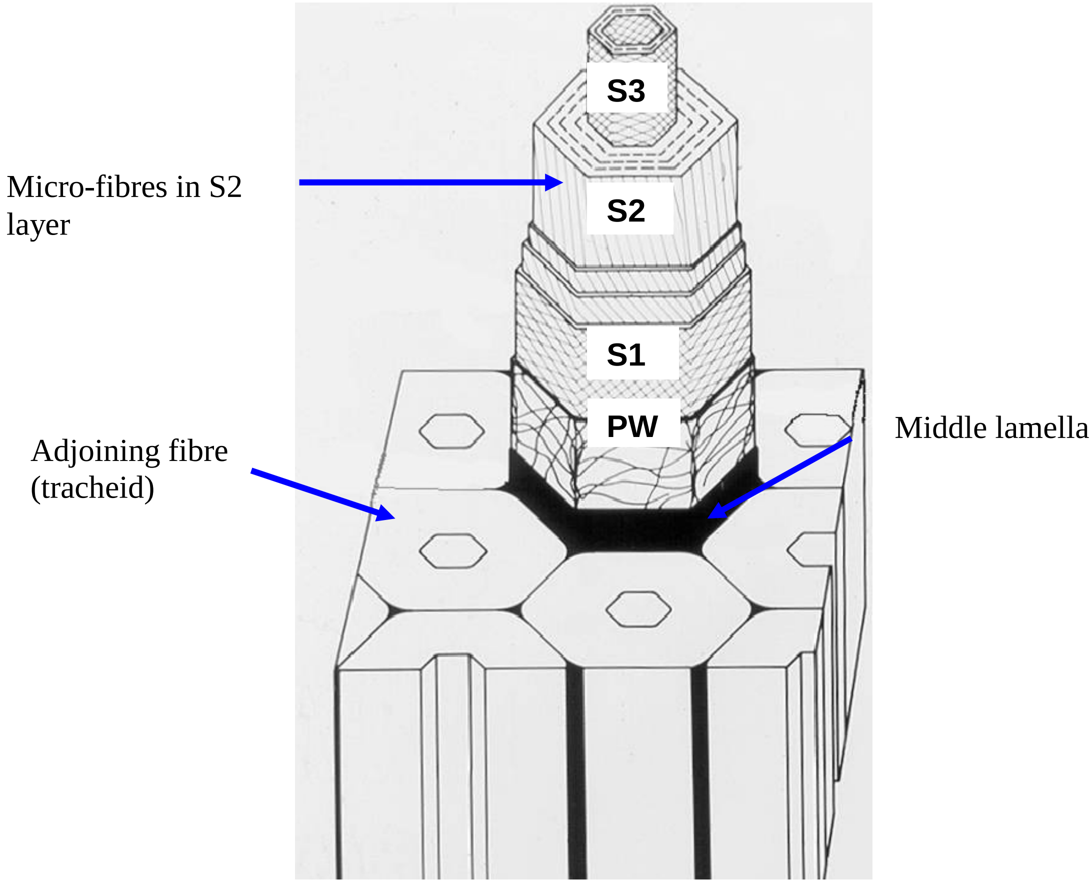



Figure 35 Representation of a fibre wall.  PW indicating primary wall; showing the three cell wall layers. (source Downes *et al* 1997)

## *6.2.2 Preliminary evaluation*

The first stage of the evaluation involved the measurement of a number of relevant wood properties, using;

- Ultrasonic transmission techniques providing;
  - Speed of sound along the measured axis - metres per second (m $s^{-1}$)
  - Merit index - Acoustic radiation (Longitudinal velocity to density ratio) - $m^4$ kg $s^{-1}$
- Tabulation of previously published data on;
  - Overall and unit shrinkages
  - Air dry Density – kg $m^3$
  - Strength (Modulus of elasticity) - GPa

### Data presentation

These data on material used for soundboards and back and sides are shown in Table 12 & 13. The information will hopefully provide a starting point for the existence of a reference of currently-utilised and lesser-known Australian woods for their suitability as tonewoods.

A number of higher density species either currently used, or with potential for use in fretboards, bridges and other ancillary parts, are tabulated separately in Appendix 1.

The table of wood species presented represents a number of species currently used and others with little history of use in instrument making.

Whilst the requirements of classical, steel-string, violin, cello, double-bass, mandolin and countless other makers are variable, there are fundamental wood properties which are common to each.

The 'acoustic data' is a combination of work undertaken within this project that has been matched with pre-existing data on mechanical properties and densities compiled and by the former CSIRO Forestry and Forest Products.

### Interpretation of results

It should be emphasised that the small number of samples measured per species prevents definitive conclusions being made about suitability as a tonewood. This work is also preliminary in nature with more detailed assessments required to gauge the usefulness of the many species available.

That wood is a highly variable material cannot be emphasised enough, and species densities and sonic potential will also vary as a result of the interaction of growing environment, genetics and within tree characteristics.

Densities may range substantially around literature values and elastic properties may also be variable. Basic wood working properties also require evaluation in order to realise the material potential.

### Data tables

Important values in data tables for soundboard material are the ***acoustic radiation***, which is a measure of sound velocity along the grain (contributing to stiffness) relative to density. Higher values indicate a board with higher stiffness, relative to a low density (mass per board volume), representing one generally preferred criterion for soundboard material.

**Table 12**

| SOUNDBOARDS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **COMMON NAME** *Genus species* | **Origin** | **Density (air dry) kg m$^{-3}$** | **Shrinkage** | | | **No. of samples** | **Sound velocity (along grain) m s$^{-1}$** | **Acoustic radiation (m$^4$ /kg s)** | **MOE *GPa* (10$^{6\ lb/sq.\ in.}$)** |
| | | | **Dimension** | **Unit %** | **Green to 12 % MC** | | | | |
| **WATTLE, SILVER** *Acacia dealbata* | **AUS.** | **667** *605-815* | **Tang.** | **0.3** | **6** | **8** | **5270** | **9.5** | **12** *(1650)* |
| | | | **Rad.** | **0.2** | **2** | | | | |
| **BLACKWOOD** *Acacia melanoxylon* | **AUS.** | **640** *629-675* | **Tang.** | **0.3** | **4.2** | **26** | **5190** | **9.1** | **13** (1750*)* |
| | | | **Rad.** | **0.2** | **1.6** | | | | |
| **KAURI, QUEENSLAND, NORTH †** *Agathis robusta* | **AUS.** | **466** *427-504* | **Tang.** | **0.2** | **3.4** | **34** | **4680** | **9.8** | **7.8** *(1130)* |
| | | | **Rad.** | **0.1** | **2.2** | | | | |
| **CANDLENUT** *Aleurites moluccana* | **AUS.** | **465** *450-480* | **Tang.** | ***** | ***** | **2** | **4990** | **11.8** | **9.1** |
| | | | **Rad.** | ***** | ***** | | | | |
| **CHEESEWOOD, WHITE** *Alstonia scholaris* | **AUS, P.N.G.** | **415** | **Tang.** | **0.2** | **2.8** | **10** | **4816** | **11.2** | **9** (1320) |
| | | | **Rad.** | **0.1** | **1.9** | | | | |
| **PINE, BUNYA** *Araucaria bidwillii* | **AUS.** | **458** *442-474* | **Tang.** | **0.2** | **4** | **48** | **5160** | **10.4** | **13** (*1880)* |
| | | | **Rad.** | **0.1** | **2.1** | | | | |
| **PINE, HOOP** *Araucaria cunninghamii* | **AUS. P.N.G. IRIAN JAYA** | **529** *517-541* | **Tang.** | **0.2** | **3.3** | **12** | **5235** | **10.2** | **13** (*1880)* |
| | | | **Rad.** | **0.2** | **2.25** | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **PINE, KING WILLIAM †** *Athrotaxis selaginoides* | **AUS.** | **408** *396-420* | **Tang.** | * | **4** | **17** | **4270** | **10.4** | **6.8** *(990)* |
| | | | **Rad.** | * | **1.5** | | | | |
| **PINE, HUON †** *Lagarostrobos franklinii* | **AUS.** | **543** *509-577* | **Tang.** | **0.3** | **3.2** | **12** | **4420** | **9.1** | **7.9** |
| | | | **Rad.** | **0.1** | **2.4** | | | | |
| **QUANDONG, SILVER** *Elaeocarpus grandis* | **N.S.W. QLD.** | **469** *452-486* | **Tang.** | **0.2** | **4.3** | **6** | **4850** | **9.9** | **11** |
| | | | **Rad.** | **0.1** | **1.4** | | | | |
| **POPLAR, PINK †** *Euroschinus falcata* | **N.S.W. QLD.** | **538** | **Tang.** | * | **4.1** | **5** | **5490** | **10.3** | **11** |
| | | | **Rad.** | * | **1.3** | | | | |
| **PINE, CELERY-TOP †** *Phyllocladus asplenifolius* | **TAS.** | **646** *624-668* | **Tang.** | **0.2** | **3.4** | | **4874** | **7.4** | **12** |
| | | | **Rad.** | **0.12** | **1.6** | | | | |
| **PINE, BLACK †** *Podocarpus aramus* | **AUS PNG** | **495** | **Tang.** | * | **3.5** | **6** | **5160** | **12** | **9.5** |
| | | | **Rad.** | * | **1.5** | | | | |
| **CEDAR, RED †** *Toona australis* | **AUS.** | **450** | **Tang.** | **0.2** | **4.3** | **14** | **4390** | **9.7** | **9.4** |
| | | | **Rad.** | **0.2** | **2.05** | | | | |

Density and unit shrinkage data ; Ilic *et al* (2000)
MOE values; Bootle (2004)
† indicates limited availability

**Table 13**

| COMMON NAME *Genus Species* | Density (air dry) kg $m^{-3}$ | Shrinkage | | | No. of samples | Sound velocity (along grain) m $s^{-1}$ | MOE *GPa* ($10^{6}$ lb/sq. in.) |
|---|---|---|---|---|---|---|---|
| | | Dimension | Unit | Green to 12 % MC | | | |
| **WATTLE, SILVER** *Acacia dealbata* | **667** *605-815* | **Tang.** | **0.34** | **6** | **8** | **5270** | **12** *(1650)* |
| | | **Rad.** | **0.17** | **2** | | | |
| **BLACKWOOD** *Acacia melanoxylon* | **640** **629-675** | **Tang.** | **0.27** | **4.2** | **26** | **5190** | **13** **(1890)** |
| | | **Rad.** | **0.16** | **1.6** | | | |
| **WATTLE, BLACK** *Acacia mollissima* | **746** | **Tang.** | **0** | **0** | | | |
| | | **Rad.** | **0** | **0** | | | |
| **SALWOOD, BROWN †** *Acacia aulococarpa* | **690** *532-848* | **Tang.** | **0.36** | **4.2** | | | |
| | | **Rad.** | **0.14** | **1.4** | | | |
| **WATTLE, Northern Territory †** *Acacia crassicarpa* | **670** *573-767* | **Tang.** | **0** | **2.3** | | | |
| | | **Rad.** | **0** | **1** | | | |
| **WATTLE, GREEN** *Acacia decurrens* | **640** | **Tang.** | **0** | **0** | | | **17** |
| | | **Rad.** | **0** | **0** | | | |
| **LIGHTWOOD †** *Acacia implexa* | **689** | **Tang.** | **0.21** | **3.9** | | | |
| | | **Rad.** | **0.12** | **1.7** | | | |
| **OAK, TULIP RED †** *Argyrodendron peralatum* | **772.5** *725-825* | **Tang.** | **0** | **8.9** | | | **15** |
| | | **Rad.** | **0** | **4.4** | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **SASSAFRAS, SOUTHERN** *Atherosperma moschatum* | **630** *627-634* | **Tang.** | **0** | **0** | | | |
| | | **Rad.** | **0** | **0** | | | |
| **ALDER, BROWN †** *Caldcluvia paniculosa* | **655** | **Tang.** | **0** | **0** | | | |
| | | **Rad.** | **0** | **0** | | | |
| **W.A. SHE-OAK** *Casuarina fraserana* | **734** *674-794* | **Tang.** | **0.22** | **4.5** | | | |
| | | **Rad.** | **0.13** | **1.2** | | | |
| **CALOPHYLLUM, BEACH †** *Calophyllum inophyllum* | **675** | **Tang.** | **0** | **0** | | | |
| | | **Rad.** | **0** | **0** | | | |
| **OAK, SILKY, NORTHERN** *Cardwellia sublimis* | **524** *496-552* | **Tang.** | **0.31** | **4.7** | | | |
| | | **Rad.** | **0.13** | **1.6** | | | |
| **BEAN, BLACK †** *Castanospermum australe* | **711** *668-754* | **Tang.** | **0.4** | **5.8** | | | **15** |
| | | **Rad.** | **0.16** | **1.8** | | | |
| **COACHWOOD †** *Ceratopetalum apetalum* | **620** *604-640* | **Tang.** | **0.34** | **8.1** | | | **14** |
| | | **Rad.** | **0.24** | **4** | | | |
| **MAPLE, ROSE †** *Cryptocarya rigida* | **720** | **Tang.** | **0** | **0** | | | **19** |
| | | **Rad.** | **0** | **0** | | | |
| **WALNUT, QUEENSLAND †** *Endiandra palmerstonii* | **686** *657-707* | **Tang.** | **0.32** | **4.6** | | | |
| | | **Rad.** | **0.19** | **2.1** | | | |
| **MESSMATE** *Eucalyptus obliqua* | **758.7** *751-787* | **Tang.** | **0.32** | **10.9** | | | **15** |
| | | **Rad.** | **0.2** | **4.9** | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **MAPLE, QUEENSLAND** *Flindersia brayleyana* | **580** *565-594* | **Tang.** | **0.25** | **5.55** | | | **10** |
| | | **Rad.** | **0.17** | **2.25** | | | |
| **ASH, SILVER, QUEENSLAND †** *Flindersia bourjotiana* | **624** *605-64* | **Tang.** | **0.29** | **5.5** | | | **13** |
| | | **Rad.** | **0.2** | **3** | | | |
| **ASH, † SILVER,NORTHERN** *Flindersia pubescens* | **675** | **Tang.** | **0.31** | **4.8** | | | **13** |
| | | **Rad.** | **0.21** | **3.1** | | | |
| **ASH, SILVER †** *Flindersia schottiona* | **688** | **Tang.** | **0** | **6.2** | | | **17** |
| | | **Rad.** | **0** | **3.6** | | | |
| **MAHOGANY, BRUSH †** *Geissois benthamii* | **640** | **Tang.** | **0.28** | **7.6** | | | **14** |
| | | **Rad.** | **0.16** | **3.6** | | | |
| **BEEFWOOD** *Grevillea striata* | **990** *959-1021* | **Tang.** | **0** | **3.4** | | | |
| | | **Rad.** | **0** | **1.75** | | | |
| **OAK, SILKY, SOUTHERN †** *Grevillea robusta* | **643** *627-660* | **Tang.** | **0.32** | **5** | | | |
| | | **Rad.** | **0.14** | **1.8** | | | |
| **BEECH, MYRTLE** *Nothofagus cunninghamii* | **705** *681-729* | **Tang.** | **0.32** | **6.8** | | | **14** |
| | | **Rad.** | **0.18** | **2.7** | | | |
| **BEECH, NEGROHEAD †** *Nothofagus moorei* | **755** | **Tang.** | **0** | **9.1** | | | **16** |
| | | **Rad.** | **0** | **3.4** | | | |
| **NATIVE OLIVE †** *Notelea ligustrina* | | **Tang.** | **0** | **0** | | | |
| | | **Rad.** | **0** | **0** | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **SATINBOX †** *Phebalium squameum* | | Tang. | 0 | 0 | | | |
| | | Rad. | 0 | 0 | | | |
| **PINE, CELERY-TOP** † *Phyllocladus asplenifolius* | **646** *624-668* | Tang. | 0.19 | 3.4 | | | 12 |
| | | Rad. | 0.12 | 1.6 | | | |
| **ROSEWOOD, NEW GUINEA † **** *Pterocarpus indicus* | **588** | Tang. | 0.24 | 2 | | | 12 |
| | | Rad. | 0.17 | 1.1 | | | |
| **SATINWOOD, TULIP †** *Rhodosphaera rhodanthema* | **692** | Tang. | 0 | 3.4 | | | |
| | | Rad. | 0 | 1.6 | | | |
| **BIRCH, WHITE †** *Schizomeria ovata* | **650** *633-666* | Tang. | 0.33 | 7 | | | 14 |
| | | Rad. | 0.17 | 3.1 | | | |
| **OAK, TULIP, RED†** *Tarrietia peralata* | **796.8** *735-858* | Tang. | 0 | 0 | | | 15 |
| | | Rad. | 0 | 0 | | | |

Density and unit shrinkage data ; Ilic *et al* (2000)

MOE values; Bootle (2004)

† indicates limited availability

** Imported from New Guinea

### *6.2.3 Instrument material evaluation*

This component of the project involved a collaboration with Maton Guitars in Melbourne, and the manufacture of four steel-string dreadnought style acoustic guitars (with cutaways and pick-ups) using materials subjected to both acoustic testing and wood micro-structural analysis. The small number of instruments made in this study prevents definitive conclusions from being drawn, but establishes a methodology for further appraisals.

***The principal aim of this part of the instrument evaluation was to establish the extent of any relationships between variations in measured material properties and final instrument sound characteristics.***

## Methods

Material for four guitars tops were selected from a commercially utilised native soundboard species;

- 4 plates selected from 30 bunya pine bookmatched soundboards

The 30 soundboards were measured in detail and charactised in terms of their acoustic properties and wood micro-structure (Silviscan®) as shown in Table 14.
The ultrasonic velocity measurements were taken on both the full rectangular plates and a strip (subsequently used for Silviscan analysis) taken from the bottom of one half of each soundboard. The measurement points are shown in Figure 36.

The four soundboards were selected on the basis of extremes of the measured material properties (acoustic/elastic and micro-structural) and combined with seven Queensland maple back and side sets, selected from 30 sets, based on the homogeneity of measured properties (Table 15 & 16).
Minimising the variability of the back and sides focussed on the contribution of soundboard quality to finished instrument characteristics.

Table 14. Soundboard measurements

| | | |
|---|---|---|
| Acoustic properties (Ultrasonic transmission) | Velocity of longitudinal sound waves – full plates and silviscan strips ($m\ s^{-1}$) | Along grain ($V_{LL}$) |
| | | Across grain ($V_{RR}$) |
| | | Tangential ($V_{TT}$) |
| | Acoustic radiation ($m^4\ kg\ s^{-1}$) | Ratio of along grain velocity to density |
| Silviscan® data | Secondary wall micro-fibril angle ( º ) | 5mm intervals radially (along grain stiffness indicator) |
| | Silviscan® derived modulus of elasticity (GPa) | 5mm intervals radially (along grain stiffness indicator) |
| | Radial density profile ($kg\ m^{-3}$) | Continuous data |

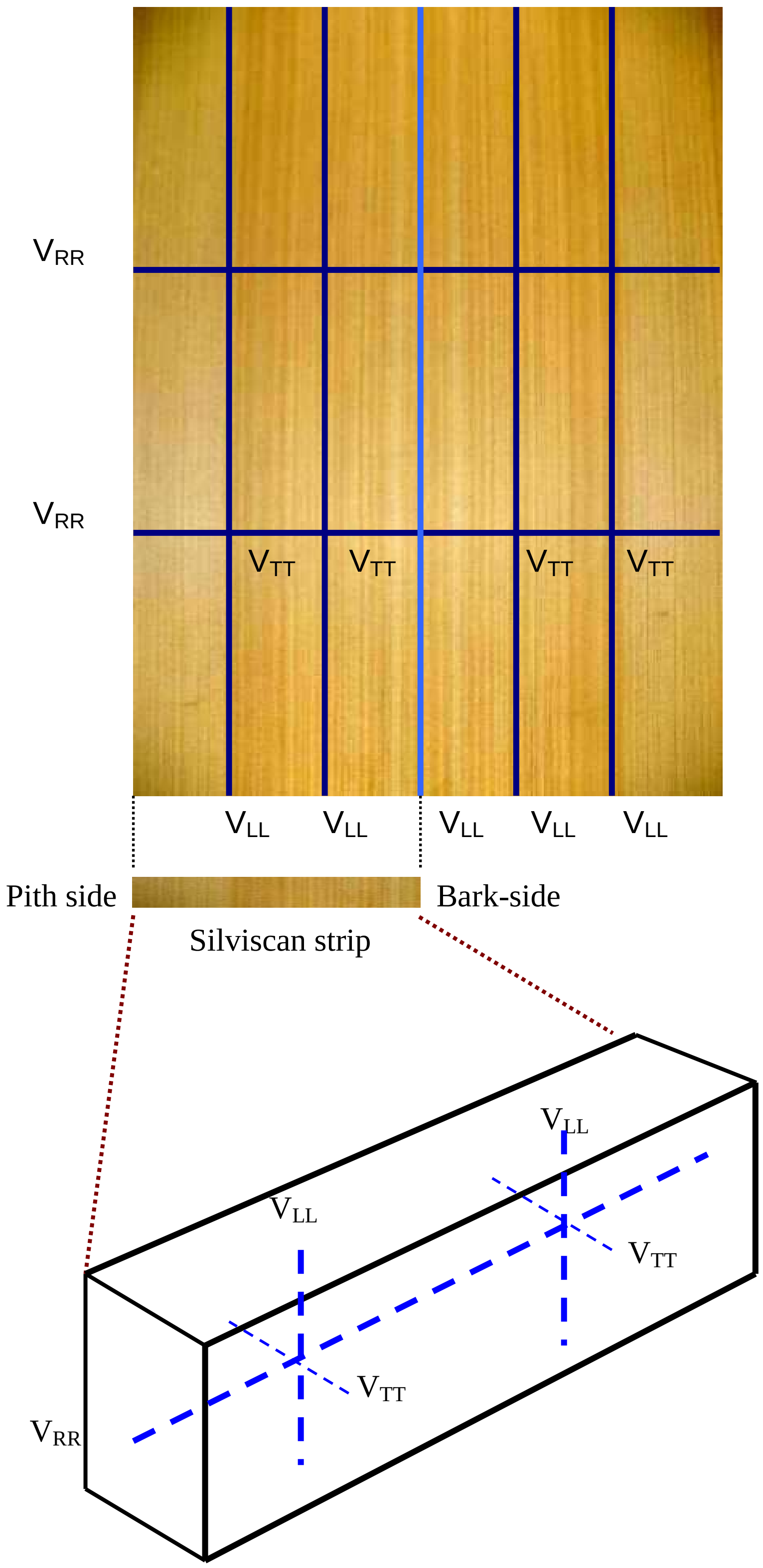



Figure 36  Measurement points on soundboard plates and Silviscan strips.

## Instrument manufacture

All instrument component dimensions (soundboards, back and sides, neck construction, fretboard, bridge, internal bracing material and placement) were controlled by CNC processing methods to minimise the chance of dimensional variations impacting on sound characteristics.

## Plate selection

The four bunya plates were selected on the basis of the extremes of acoustic and Silviscan® wood property data summarised in Table 15. Images of the full plates are shown in Figures 37 a-d.
The variations in density, acoustic velocity and Silviscan® data on wood micro-structure (micro-fibril angle and modulus of elasticity) drove the selection process. Table 15 also shows the same data obtained from 24 kauri pine soundboards subjected to the same testing process. This data provided a comparison between these two species.

Table 15. Summary of soundboard properties

| Species | Plate # | Mean Density $kg/m^3$ | Mean sound velocity along grain ($m\ s^{-1}$) | MeanSilviscan MOE (Gpa) | Mean MFA ° | Acoustic radiation ($m^4\ kg\ s^{-1}$) |
|---|---|---|---|---|---|---|
| kauri pine | 23 | 410 | 4751 | 7 | 19 | 11.5 |
| | 15 | 454 | 4475 | 6.3 | 23.5 | 9.8 |
| | 22 | 483 | 3748 | 5.3 | 30 | 8.1 |
| bunya pine | 5 | 434 | 5610 | 12.7 | 11.6 | 12.9 |
| | 16 | 440 | 5674 | 12.7 | 13 | 12.2 |
| | 18 | 490 | 4974 | 9.8 | 22.4 | 10.5 |
| | 30 | 560 | 3773 | 7 | 30 | 6.8 |

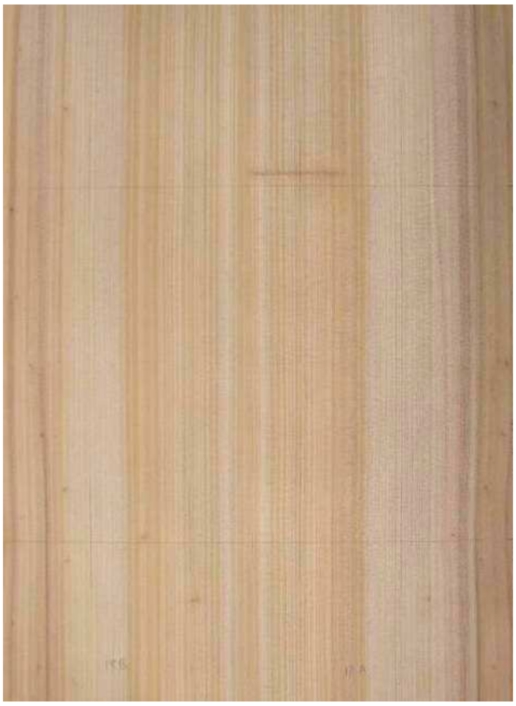
Table 16. Soundboard and back & side combinations used in manufacture.

| Species | Plate # | Guitar # | Species | Plate # | Density $kg/m^3$ | Sound velocity along-grain $m\ s^{-1}$ |
|---|---|---|---|---|---|---|
| bunya pine | 5 | 1 | Qld. maple | 1 | 684 | 5019 |
| | 16 | 4 | | 22 | 690 | 4860 |
| | 18 | 3 | | 23 | 684 | 4919 |
| | 30 | 2 | | 30 | 705 | 4836 |

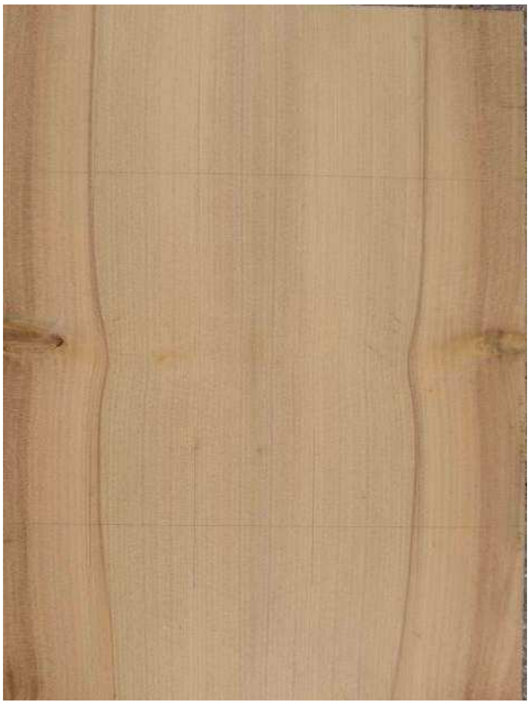
Considerable variation was found both within and between plates of each species. Table 15 shows that the mean plate sound velocity along the grain varied between 3773 and 5674 $m\ s^{-1}$ for bunya and 3748 to 4751 $m\ s^{-1}$ for the kauri soundboards. For both species the plates with a slower velocity of sound along the grain also had higher overall mean densities.
The along grain stiffness (Silviscan MOE) also decreased with decreases in sound velocity and increases in the angle of cellulose micro-fibrils in the secondary cell wall. This underlines the contribution of MFA to the along grain stiffness properties of boards.
Table 16 shows the combination of bunya pine and Queensland maple plates used in the four instruments manufactured.
The plates chosen represent soundboards containing the highest along grain stiffness with the lowest density, through to the lowest along grain stiffness with the highest density.

(a) Guitar 1 – plate 5

(b) Guitar 2 – plate 30



(c) Guitar 3 – plate 18



(d) Guitar 4 – plate 16

Figures 37 a-d The four bunya pine soundboard plates used in the evaluation.

Table 17 shows that the mean along grain velocity and the stiffness (MOE) of the kauri plates was lower than the bunya plates, although there was an overlap with the lower values of the bunya and the higher values of the kauri.
The mean radiation values were similar for both species (9.5 kauri and 9.2 bunya). The lower mean density of the kauri (443 compared to 495 kg $m^3$ for the bunya) contributed to the marginally higher radiation ratio, which is derived from the along – grain velocity divided by the density.

Table 17 Summary of wood properties

| Data on all plates tested | | | |
|---|---|---|---|
| **Sample no's.** | **kauri pine** | **bunya pine** | **Qld. maple** |
| | 24 | 30 | 30 |
| **Mean density (kg $m^{-3}$)** | 443 | 495 | 643 |
| **Mean maximum density (kg $m^{-3}$)** | 732 | 863 | * |
| **Mean minimum density (kg $m^{-3}$)** | 290 | 280 | * |
| **Mean micro-fibril angle ° (MFA)** | 23.8 | 22 | * |
| **Mean maximum micro-fibril angle ° (MFA)** | 31.8 | 29 | * |
| **Mean min. micro-fibril angle ° (MFA)** | 17.2 | 14 | * |
| **Mean modulus of elasticity (MOE) GPa** | 6.2 | 9.6 | * |
| **Mean max. modulus of elasticity (MOE) GPa** | 8 | 13.6 | * |
| **Min. modulus of elasticity (MOE) GPa** | 4.5 | 6.7 | * |
| **Mean velocity-along grain (m $s^{-1}$)** | 4192 | 4538 | 4565 |
| **Mean velocity-across grain (m $s^{-1}$)** | 1622 | 1603 | 1493 |
| **Mean velocity-tangential (m $s^{-1}$)** | 1338 | 1350 | 1105 |
| **Mean acoustic radiation $m^4$ kg $s^{-1}$** | 9.5 | 9.2 | 7.1 |

Table 17 shows a summary of the wood properties of all plates tested for the manufacturing evaluation. The principal differences between bunya and kauri pine are in the mean along grain velocity of sound and the mean along grain stiffness values (MOE), which were both noticeably higher in bunya pine.
There was little difference in the values of sound velocity in the radial and tangential directions and the overall angle of cellulose micro-fibres in the secondary cell wall, which were relatively high (compared to resonance spruce) in both cases.

Focussing on the bunya pine Silviscan data shown in Figures 38 & 39, relationships between density, modulus of elasticity and micro-fibril angle can be seen when images of the corresponding soundboard half are overlaid with this wood property data.

As the material is quartersawn Figures 38 & 39 provide a radial profile of the soundboard half (from the resulting guitar body edge to its centre) with the bark side of the strip oriented to the soundboard middle. This establishes a link between the Silviscan material (microstructural) properties across the soundboard half, and the corresponding visual characteristics (macroscopic).

Figure 38 shows plate number 16 from table 15, representing a relatively low density (440 kg/$m^3$) soundboard, with higher mean along grain stiffness (12.7 GPa) and lower overall micro-fibril angle.
In contrast Figure 39 (plate 30 from table 15) shows a soundboard with a mean density of 560 kg/$m^3$, lower mean along grain stiffness (7 GPa) and relatively high micro-fibril angle.

In Figure 39 the areas of higher density, higher MFA, lower stiffness (MOE) and lower along grain sonic velocity appear to coincide with the darker regions (‘brown wood’) across the soundboard profile.
This highlights the variability of wood properties from within a species (and across a single soundboard) and the potential for these variations to impact upon the bulk properties of plates and consequently the sound of instruments made from them.

It also demonstrates the extent to which readily observable visual cues (brown wood in this case) can reflect substantial varations in underlying wood material properties. Appendices 4-8 show some additional profiles Silviscan profiles of bunya and kauri pine matched with images of the corresponding soundboard strips.

Figures 40-41 focus on the regions outlined in figures 38-39 in higher resolution (1mm step-size), to demonstrate the impact of variation in wood properties has on sounboard mechanical properties.

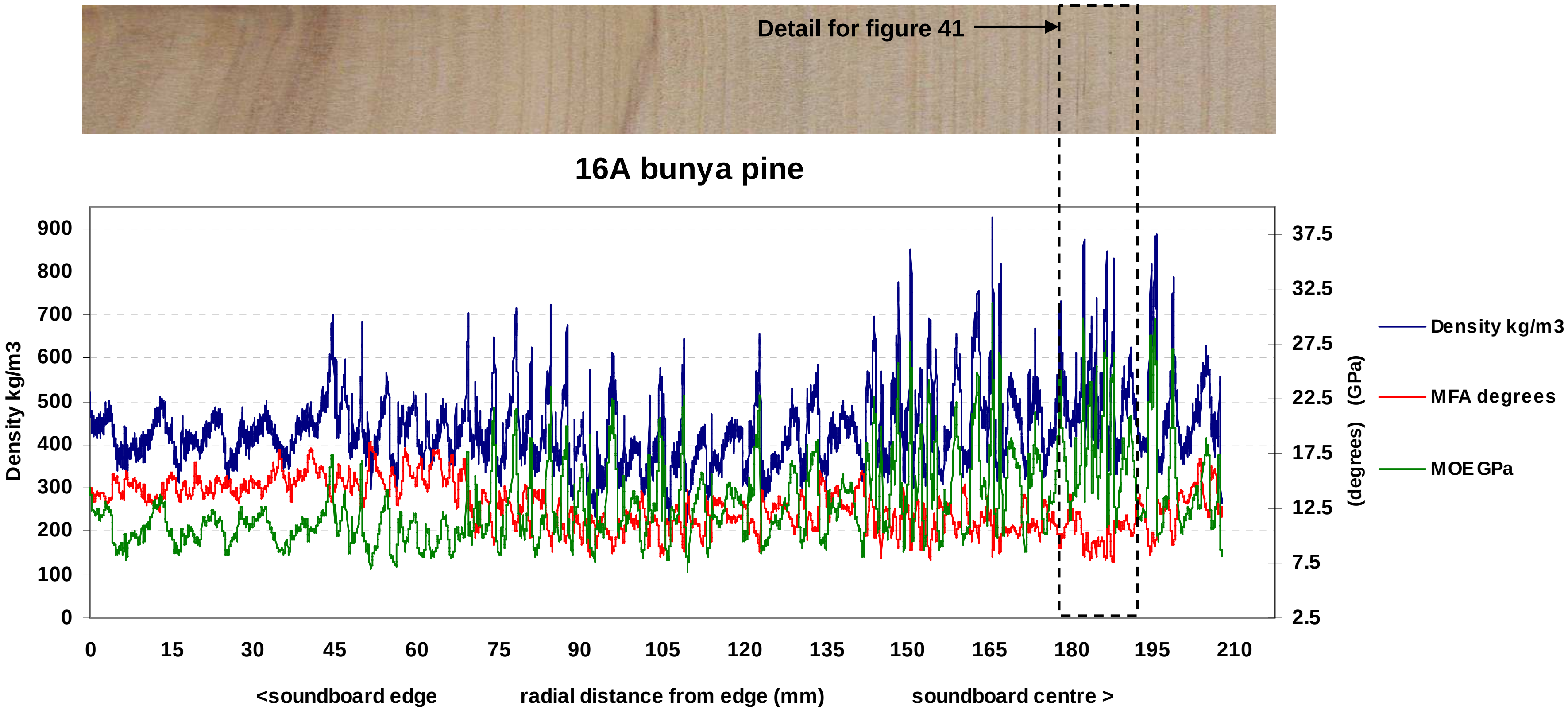



**Figure 38** Plate 16 (guitar four) Mean: density 440 kg/$m^3$ - MOE 12.7 GPa - MFA 13°- along grain sound veloc ity 5674 m/sec.

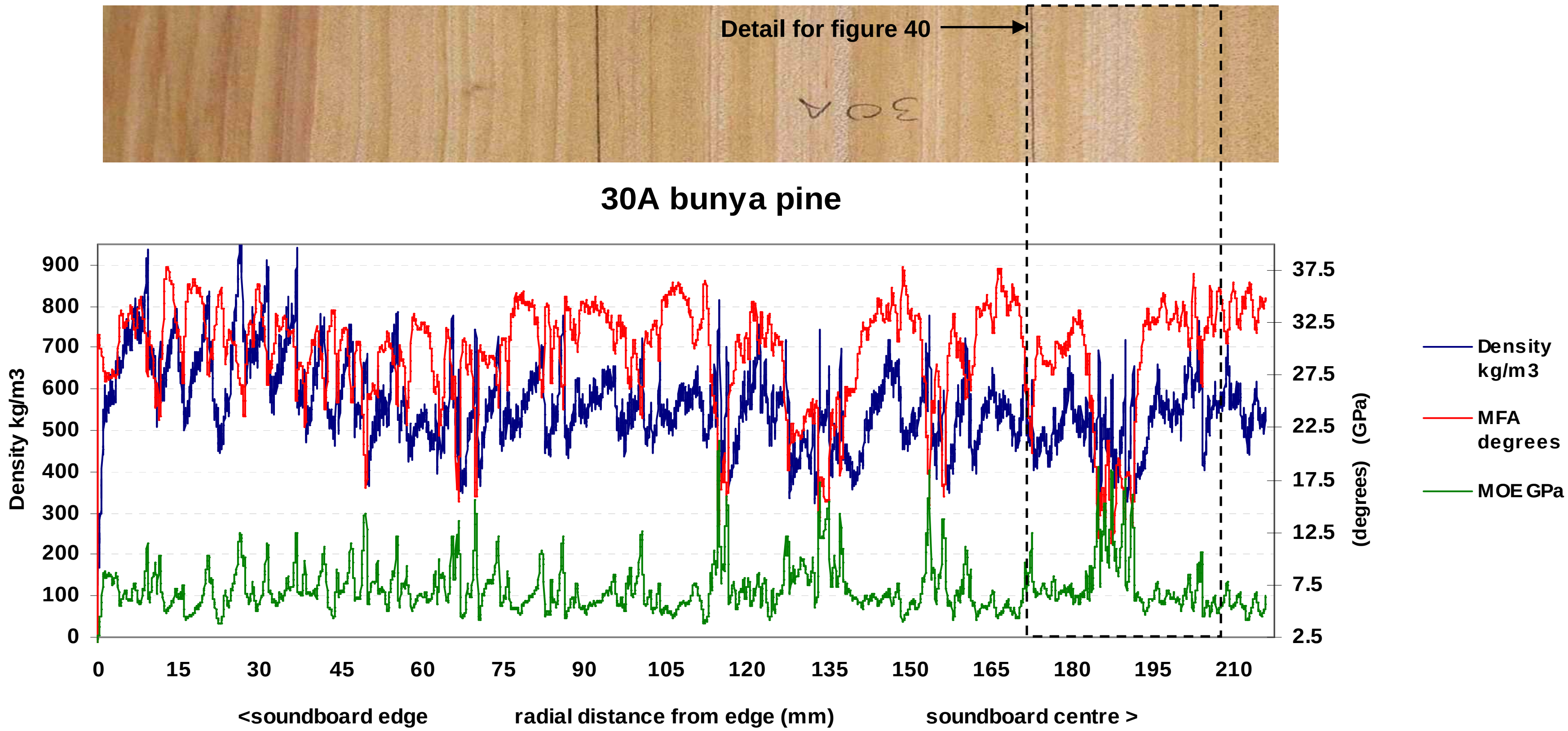



Figure 39. Plate 30 (guitar two) Mean: density 560 kg/m$^3$ - MOE 7 GPa- MFA 30 °- along grain sound velocit y 3773 m/s

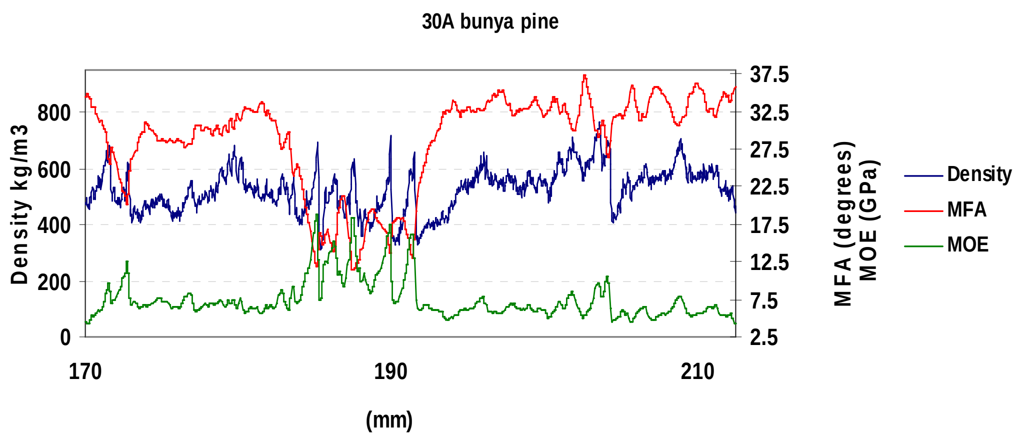



Figure 40  Detail of high resolution (1mm step-size) silviscan radial profile 170mm -210mm from figure 39

The high resolution 'window' above, of Bunya soundboard 30A from figure 39, focuses on regions of compression wood on either side of a band of relatively 'normal' wood. The characteristics of compression are uniformly high density (independent of early/latewood variation) accompanied by very high MFA, and low stiffness (MFA). The central region of normal wood has the expected pattern of early/late wood density variation (peaks in latewood and troughs in earlywood), with stiffness (MOE) peaking within latewood bands, accompanied by the lower MFA characteristic of latewood microstructure.

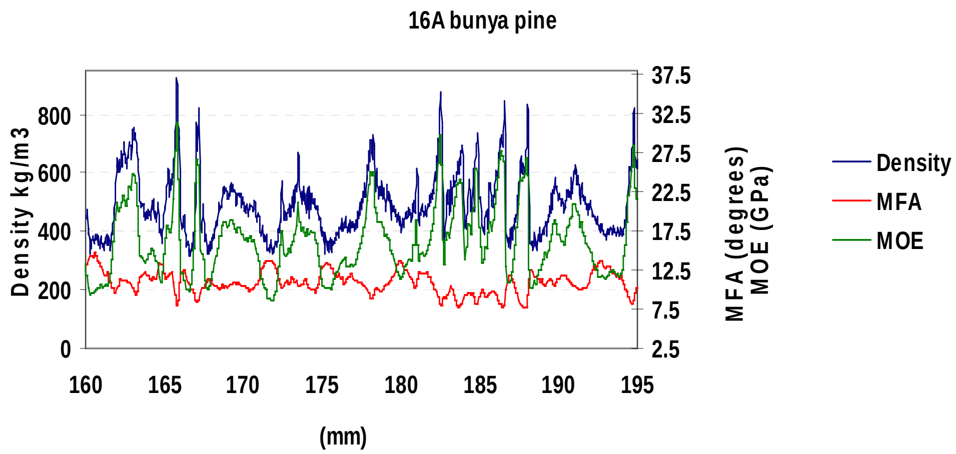



Figure 41 Detail of high resolution (1mm step-size) silviscan radial profile 170mm -190mm from figure 38

In constrast the high-resolution profile of soundboard 16A, from figure 38, demonstrates the contribution that an overall lower cell wall MFA in normal wood has on the along-grain wood stiffness properties (MOE). It also displays the density variation normally associated with ring boundaries (peaks in latewood and troughs in earlywood).

## Instrument evaluation

The evaluation of instruments was undertaken on two levels;

- Subjective ; player appraisal
- Objective ; frequency response method

### *Subjective assessment*

This testing was undertaken in the CSIRO laboratories in Clayton.
Ten accomplished guitarists with previous exposure to steel-string instruments of the type constructed were given the opportunity to rate the four instruments within the species group (Figure 42)
It is freely acknowledged that there is no precise definition of an instruments sound or of its overall 'quality', and evalutions are likely to be personal and a combination of many factors.
Therefore, no attempt was made to direct players into categorical ratings such as attack, sustain or high/low end responses. An overall relative rating of the four instruments within the species group was preferred, with players given the opportunity to note any particular instrument characteristics.
This focussed the player evaluation on any perceived differences between the four instruments rather than any broader comparative aims.
No information was given to players regarding the wood properties of the four soundboards to avoid the formation of preconceived ideas.

Figure 42. David Chin undertaking a 'subjective' assessment of the instruments

The player assessments in Table 18 indicate the ratings given for each of the four instruments. The number of rating ones (an individual players first preference) for each guitar was not markedly different across the four instruments.

Guitars one and four were marginally favoured with three preferred (number one ratings) with guitars two and three receiving two each in this category.

Overall guitar one was rated first or second most preferred, by eight of the ten respondents, and guitar four was rated rated first or second, by six of the ten players.

Guitar two was rated as third or least preferred, by eight of ten players, and guitar three was rated third or least preferred by six of the ten players.

Table 18 Relative player ratings

| | **Instrument number** | | | |
|---|---|---|---|---|
| | **Guitar 1**<br>Soundboard 5<br>Dens. 434 kg $m^3$<br>MOE 12.7 GPa<br>MFA 11.6<br>Along grain sound velocity ;<br>5610 m $s^{-1}$ | **Guitar 2**<br>Soundboard 30<br>Dens. 560 kg $m^3$<br>MOE 7 GPa<br>MFA 30<br>Along grain sound velocity ;<br>3773 m $s^{-1}$ | **Guitar 3**<br>Soundboard 18<br>Dens. 490 kg $m^3$<br>MOE 9.8 GPa<br>MFA 22.4<br>Along grain sound velocity ;<br>4974 m $s^{-1}$ | **Guitar 4**<br>Soundboard 16<br>Dens. 440 kg $m^3$<br>MOE 12.7 GPa<br>MFA 13<br>Along grain sound velocity ;<br>5674 m $s^{-1}$ |
| **Rating 1** | 3 | 2 | 2 | 3 |
| **Rating 2** | 5 | 0 | 2 | 3 |
| **Rating 3** | 1 | 3 | 3 | 3 |
| **Rating 4** | 1 | 5 | 3 | 1 |

It should however be emphasised that it was generally noted that the instrument quality was high and the ‘tonal range’ narrow between the preferred and non-preferred instruments.

It is also noteworthy that the soundboard of guitar four inadvertently contained a knot adjacent to the scratch pad, which appeared to have little impact on the tonal quality of the instrument in terms of the player appraisals.

### *Objective assessment*

Player or listener-based instrument evaluation is an inherently subjective process which can benefit from comparisons with ‘objective’ methods which measure and plot instrument output over a range of frequencies.

Analysis of instrument frequency responses has been previously utilised both within luthierie and in scientific assessments alike.

By overlaying player ratings with measured instrument output across a specific frequency sweep (between 25Hz and 2000Hz in this case), correlations may be observed between guitars perceived to be of ‘high or low quality’, and characteristics of the resulting frequency responses. Previous work in this area (Caldersmith G pers. comm. 2007) has established that instruments highly rated in player assessments generally have frequency responses with observable differences from less favourably rated instruments.

This offers both an instrument evaluation tool and also a potential to guide post-construction improvement through minor structural modifications. This information can then feedback into improvements in subsequent instrument construction.
Figure 43 is a schematic diagram of the 'objective testing' procedure.
An input of pure tone and constant amplititude was generated and delivered to the instrument bridge (2nd string) via a laptop running NCH® tone generater software. An automatic frequency sweep was run through a PC using PoScope® spectral analysis software to record the output of the tonal input using a microphone positioned opposite to the instrument soundhole.
The range of the frequency sweep was from 25 Hz to 2 kHz. The resulting output via the soundhole represents the instruments reponse across this range of frequencies.

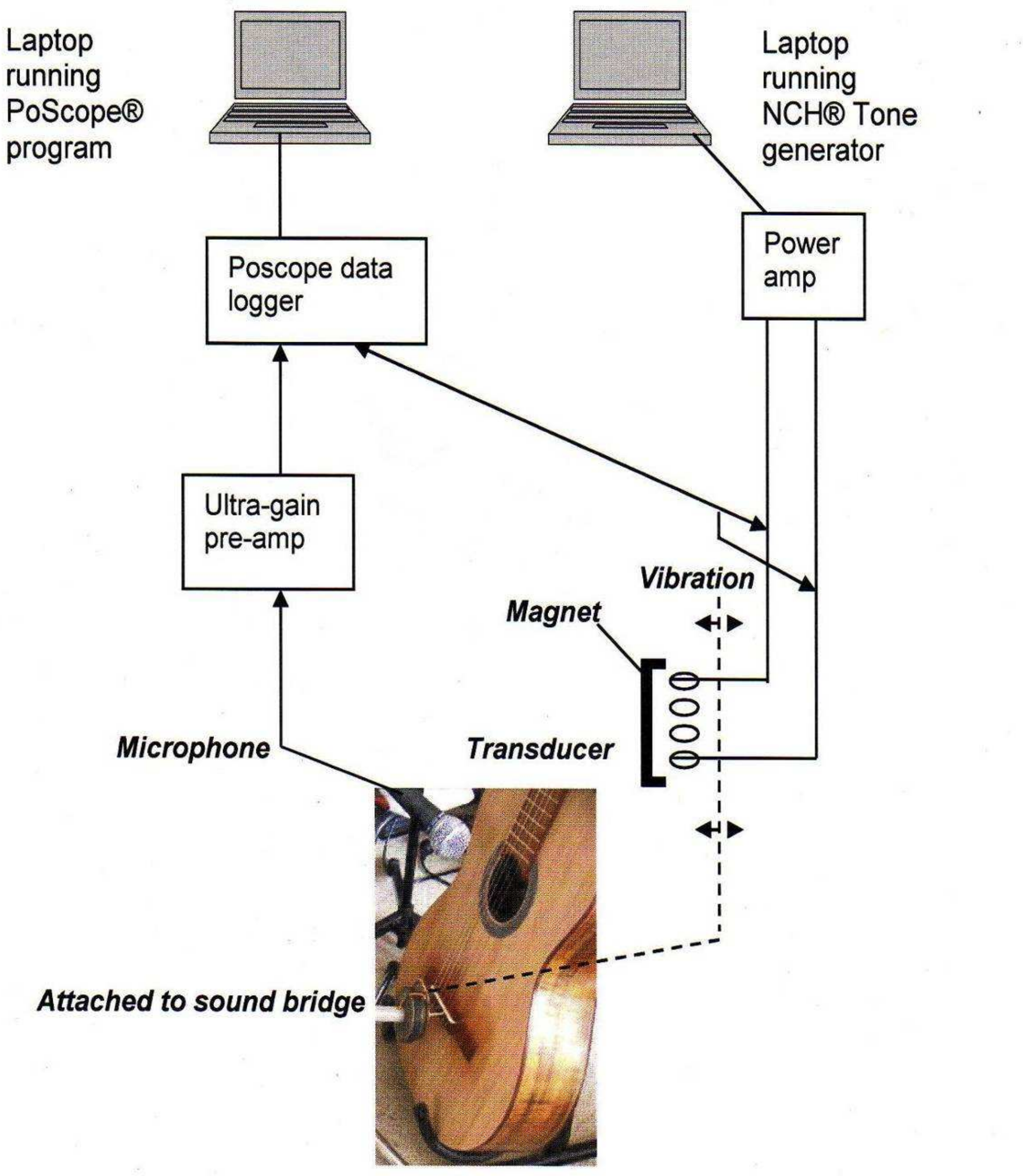



Figure 43. Schematic diagram of spectral analysis used in the objective evaluation of instruments (Equipment and methodology provided by Mr David Chin)

### ***Frequency response testing***

The instrument response to the input of a pure tone is a complex set of vibrations which combines or 'couples' the movement of the top plate, back and internal air cavity. It has been observed that at particular frequencies an instruments vibrational response reaches a maxima (seen as peaks on the sweep) where the net affect of the plate deformations coupled with the internal cavity air-flow is maximised.

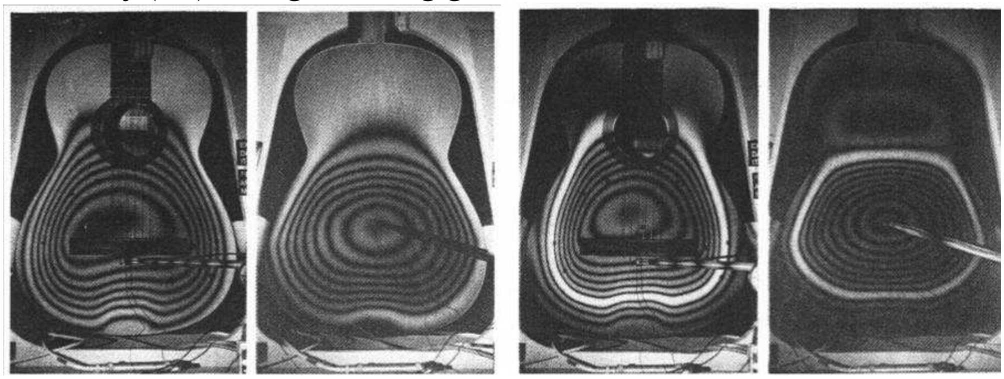
This enables particular peaks on a frequency response chart to be identified as relating to principal vibrational 'modes' of the guitar plates and air volume.

Previous work using holographic interferometry (Molin and Stetson in Jansson 2002) and Chladni patterns (Erndl 2007)) has assisted in establishing relationships between the location and phases of the vibrating guitar parts, in response to specific frequency inputs.

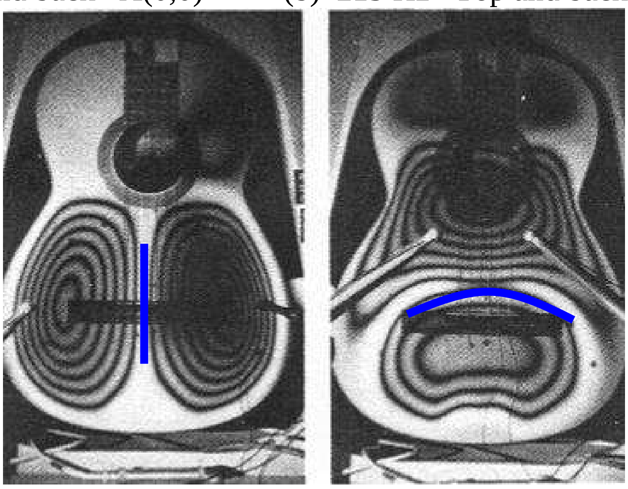
Holographic interferometry uses a laser based measurement of vibrational amplitude which generates a 'contour' map plotting areas of equal vibrational intensity (Richardson 1994). The resulting 'patterns' show areas of the instrument that are vibrating (anti-nodal) or stationary (nodal) and can determine whether they are moving together (co-phase) or in the opposite direction (anti-phase).

Figures 44 a-c represent a collection of images showing some vibrational modes using this technique.

The instrument pictured has modes as follows; air resonance, A(0,0) at 103 Hz, T(0,0) at 215 Hz, T(1,0) at 268 Hz and T(0,1) at 436 Hz. The naming convention (0,1) indicating zero nodes along the soundboard length and one across the grain, or alternately (1,0) having one along-grain node and none across the soundboard.



(a) 103 Hz Top and back A(0,0) (b) 215 Hz Top and back (0,0)



(c) 268 Hz T(1,0) (d) 436 Hz T(0,1)

Figures 44 a-d Hologram interferometery (Images from Richardson 1994). Blue lines showing nodal (non-moving) region.

The corresponding frequency response would display peaks at 103, 215 and 268 and 436 Hz, where these modes are being excited. When a note on the instrument string is plucked which corresponds to these mode frequencies (Figure 45), the energy is efficiently and rapidly converted into sound, which may be perceived as a loud sound of short duration (Richardson 1994).

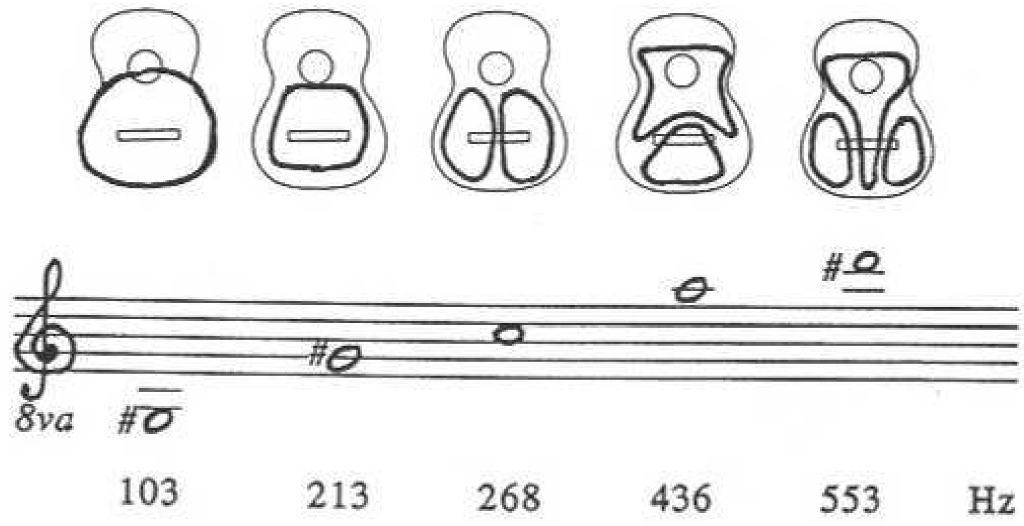



Figure 45. Notes corresponding to principal modes.

The location (frequency) and height (amplitude) and breadth of peaks are determined by a number of factors including instrument size and design, bracing type and placement, bridge design and location, material choice and thicknessing.
The relative height of output peaks is one determinant of radiation efficiency (Caldersmith 1995).
The lower frequency range is dominated by the extent of ‘coupling’ between the top, back plates and the air cavity and is believed to be an important contributor to radiation efficiencies of the instrument. (Russell 2007).
The location and relative postion of these lowest modes (0,0; 0,1; 1;0, 2,0) can therefore provide a ‘compass’ to control aspects of the sound characteristics of instruments, particularly when dealing with new body sizes and materials (Caldersmith 1995).
Work by Richardson 1994, emphasises the importance of the first, third and fourth modes (0,0,  0,1 and 2,0) in the overall guitar function at all frequencies.
The response spectra of the four guitars in the low frequency range (25Hz to 250Hz) are shown in Figure 46.
Some principal mode geometries were identified for the four guitars and are shown in Table 19.

Table 19. Low frequency mode frequencies

| | **A 0 – Air mode** | **Top (0,0)** | **Top (1,0)** | **Back (0,2)** |
|---|---|---|---|---|
| | **Freq (kHz)** | **Freq (kHz)** | **Freq (kHz)** | **Freq (kHz)** |
| **Guitar one** | 102.5 | 190.2 | 309.1 | 375.9 |
| **Guitar two** | 104 | 188.7 | 315 | 382.4 |
| **Guitar three** | 104.5 | 190.2 | 315 | 392.3 |
| **Guitar four** | 104.7 | 215.5 | - | 396.8 |

It was noted that guitar one also had a lower A0 (air resonance) at around 102.5 Hz. The AO of an instrument results from a vibrational synchronisation of the back and top-plates expanding out of phase (away form each other) creating a 'breathing' process as air is drawn into and expelled from the cavity.

Also identified in the low frequency range is the fundamental top plate resonance T(0,0) at around 190Hz, where the top plate and air at the soundhole move together in phase (Russell 2007). This is often seen as a 'resonance doublet' (two close peaks) with the lower of the two peaks resulting from the back plate moving in antiphase to the top plate motion (Caldersmith 1995).

A back plate (0,2) mode was also present at around 390Hz indicating two cross-grain nodal lines. In this mode there is very little top plate motion (Russell 2007) explaining the lower amplitude of this peak in the sweeps.

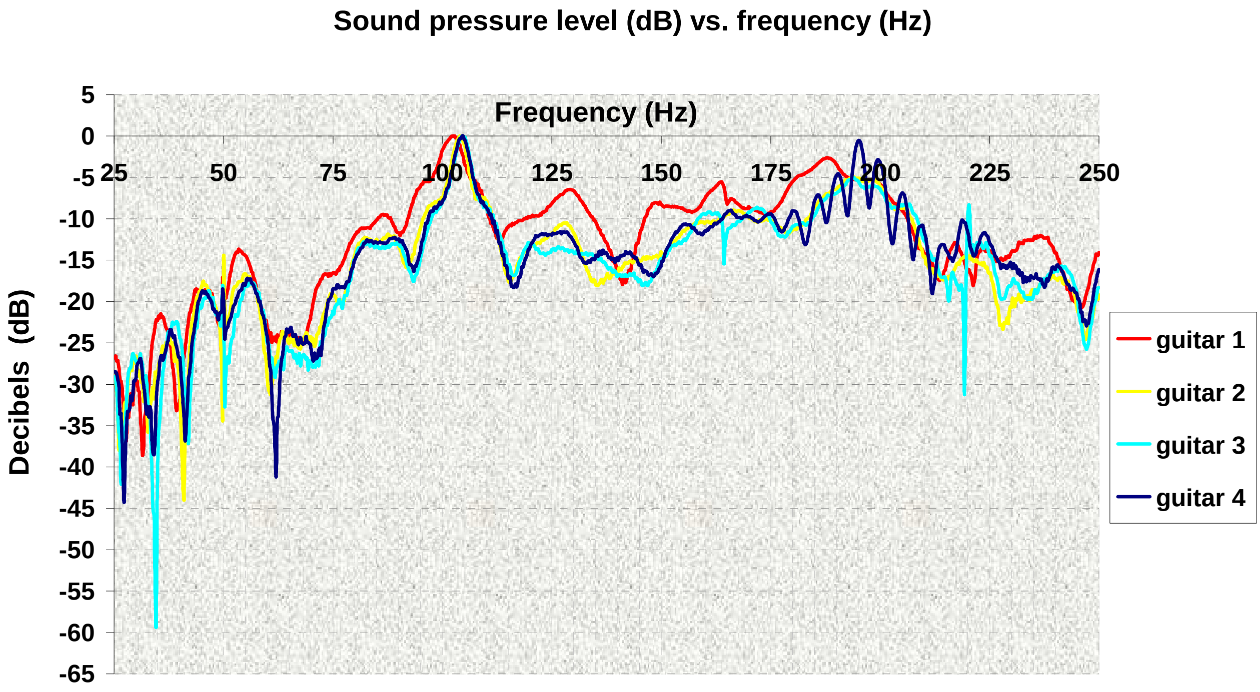



Figure 46. Edited response spectra of the four guitars in the low frequency range (25Hz to 250Hz)

It was observed that the output (dB) was generally higher across the lower frequency range (up to 200 Hz) for guitar one, than the other three instrument Figure 47. There was also a noticeable offset of peaks in this range to lower frequencies for guitar one, whereas the remaining three guitars were broadly similar.

For frequency ranges between 180Hz and 60Hz, guitar one had a measured SPL (sound pressure level) that is approx 4 db higher than the average SPL of guitars two, three and four.

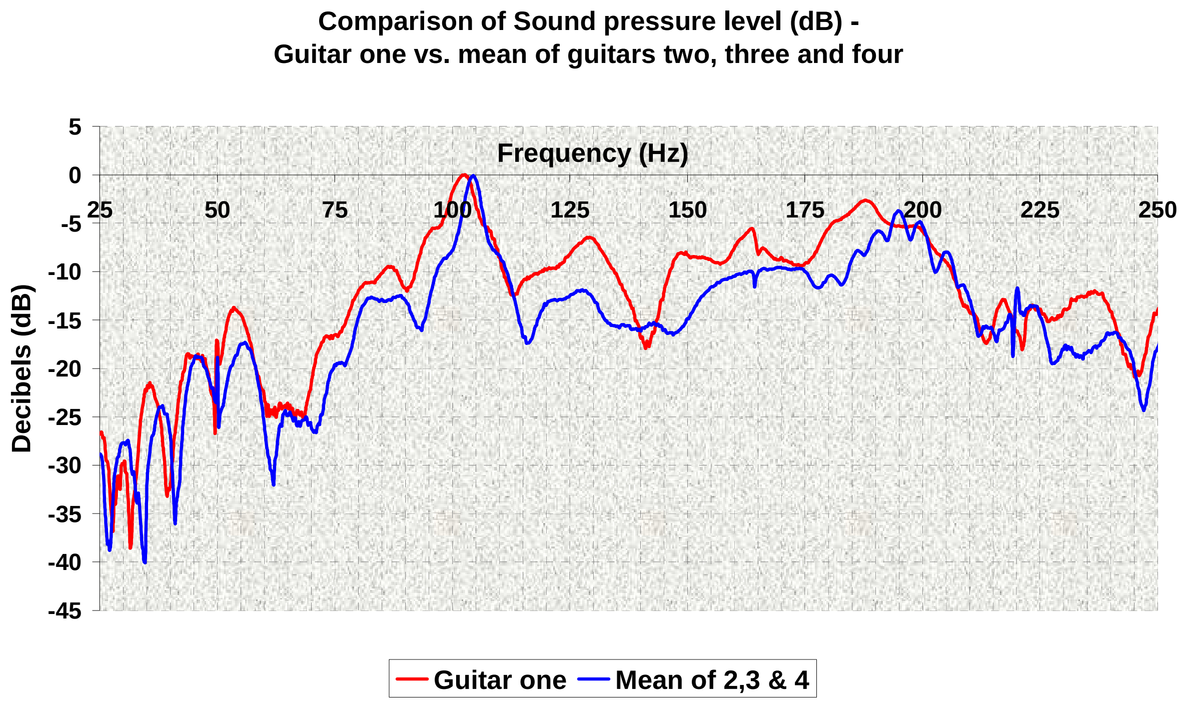



Figure 47. Edited low frequency response of guitar one SPL vs. mean of other instruments.

### *Discussion on frequency response interpration*

Deriving useful information from frequency responses requires both the identification of the various modes of the guitar within the spectra, and comparsions with references obtained from listener/player appraisals.

The testing procedure itself was highly repeatable in terms of the location of principal mode frequencies, whereas the measured sound pressure levels are dependent on the effectiveness of the coupling of the transducer to the guitar bridge and the microphone placement. This is analogous to different top plate modes being triggered by different guitar playing styles.

In other words the sound pressure level measured should only be used in a comparative sense between guitars for a fixed test configuration, which should be maintained between tests (i.e. the method of string excitation will influence the amplitude and decay rate of the components of any note generated (Richardson 1994); The testing is therefore analogous to trying to pluck a string with the same force and in exactly the same way.

In the sweeps of the broader frequency range (300 - 2000 kHz) a general absence of larger amplitude peaks was noted. This did not mean that these resonance peaks did not exist, but may have been absent due to the SPL from the guitars being lower than the level of background noise.

The test equipment may not have been able to distinguish them from the background noise. Therefore, it may be useful to improve the SPL signal to noise ratio by driving the soundboard harder as well as conducting the tests in a low noise environment, such as an anechoic chamber.

### *Conclusion*

Player and listener based instrument evaluation is inherently qualitative and highly personal in its nature.

Frequency sweeps indicate the potential to subjectively capture information relating to the mode geometry of instruments, and shows that variation in response exists even within a highly controlled manufacturing process. This is of little surprise considering the natural variabilty found in wood both in its structure and processing.

Whilst the reponses of guitars two, three, and four were similar, the overall higher 'output' previously noted of guitar one, coincided with favourable player evaluations.

Previous work (Caldersmith 1995, Meyer 1983, and Richardson 1994), have demonstrated the practical benefits of using frequency response measurements during assembly and post-construction to enhance instrument quality and reproducibility of desired acoustic characteristics.

The collection of larger data sets of 'rated' instruments of the same type, and corresponding frequency responses, would enable more robust relationships between human 'quality' perception and measured output to be established.

The variations in wood properties of the selected soundboards also appear to have been broadly identified in the player appraisals. The two higher stiffness/acoustic velocity (along grain) and lower density soundboards (5 & 16; guitars one & four), were rated marginally better within the group, than the low velocity/stiffness, high density soundboards (30 &18; guitars two & three).

## *6.2.4 Application of results*

### *Ultrasonic stiffness testing*

Two important aspects of an instrument manufacturing process are;

- ***reproducibility*** of desirable sonic characteristics
- ***longevity*** of instruments post manufacture

This is of particular relevance to the soundboards in a range of stringed instruments because of its significant contribution to sound characteristics and where bridge rotation or lifting can occur or sound-hole collapse develops over the life of an instrument.

Given the variability of wood as a raw material, and its contribution to both the tonal quality and the longer term structural integrity of resulting instruments, it is important to examine low-cost and effective ways of characterising material properties which may limit sound quality or instrument longevity.

Raw materials of a known density (derived from dimensions and a mass) can be readily assigned a stiffness value (both along and across grain) using a simple non-destructive ultrasonic testing procedure.

Such testing enables large quantities of raw materials to be assessed prior to, or at the point of purchase, and be scrutinised in a measurable manner.

This may be advantageous to both producers and consumers of tonewood products, and particularly large scale manufacturers who are dealing with larger product volumes, high pressure production environments and ongoing product liability issues.

Segregation and stratified pricing of tonewoods already occurs in the production of classical orchestral instrument soundboards where an ultrasonic device known as a Lucchi meter® is often used to quantify along and cross grain stiffness, based on a density input, but has not been universally embraced across other areas of lutherie.

Avoiding, or minimising deformation of soundboards is one obvious advantage of a better understanding of the bulk properties of the raw material. This also allows for the potential to explore instument sound improvements through a reduction in soundboard thickness and/or bracing mass in response to a quantified soundboard stiffness value.

In addition, higher stiffness material may be selected for subsequent breakdown into bracing material.

#### *Frequency response testing*

Establishing the mode geometry of instrument models with preferred sound characteristics can establish references for optimising and maintaining desirable instrument sounds, and also guide the process of developing new models and dealing with new materials.

### *6.2.5 Summary*

There are many wood properties which can be measured that contribute to a materials acoustic characteristics, and the resulting sound of instruments made from them.
As well as the wood properties measured in this report, decay times (damping characteristics), particularly at critical frequencies are acknowledged as important and should be the subject of future investigation.
It is also true that different instruments will require subtly different material properties for the same components in order to produce desired sound characteristics.
However, ultimately the raw material is transformed in both shape and dimension in the hands of a luthier, into something that is more than the sum of its parts, a process which in many ways defies scientific understanding and should be accepted as such.
Instruments have been and continue to be conceived and created without the necessity of a scientific approach and are bought, sold and cherished in the same way.
Blind player/listener assessments often defy attempts to characterise what raw materials have been used in back and sides or soundboard construction, and in many cases throw up suprising results.
The term ‘psycho-acoustics’ has been used to describe human responses to instrument evaluation where a myriad of factors influence opinions not the least being knowledge of the instrument maker, visual cues, cultural factors and the emotional connection to the music and even the way a player/listener is feeling.
Magazine advertisements often link instruments with iconic cultural imagery, when the manufacturing process may be geographically far removed, emphasising that underlying allegiances and purchasing decisions are driven by many things.

Notwithstanding, it is important that innovation both in terms of material use and from a design perspective continues, enabling lutherie to evolve and respond to the reality of changing wood resources and of technologies which may assist in their selection and utilisation.

# 7. AUSTRALIAN TONEWOOD SUPPLIERS

In Australia log processing is not generally undertaken with 'tonewoods' as a specific end-product, as is the case in Europe and North America, where many businesses are catering specifically to this market.

Wood processors in Australia are usually focussed on larger volume commodity products with more established markets and prices, with the production of material that meets tonewood product criteria arising fortuitously in small quantities as a by-product of this process.

Recently however, several businesses have emerged focussing on products for the musical instrument market, and have tailored both log selection (species and feature characteristics) and processing to meet end-user requirements.

A number of tonewood suppliers are not processors (although this distinction is sometimes blurred) but provide a range of products to the instrument making market.

The products range from green rough-sawn billets to close to final size dried components.

The details of some businesss involved in the processing or provision of material suitable for tonewoods are given in Appendix two.

## 7.1 Products

Products range from logs in the round, available through a tender system via Island Specialty Timbers (Forestry Tasmania) through to unseasoned or seasoned slabs, sawn-boards, or products dressed down to near final component form.
Prices paid along this continuum reflect the cost of the value-adding process and the volumes lost through processing, resawing and defect removal.
Log tendering is based upon a whole log figure, usually derived from an estimate of value per cubic metre of log volume and an appraisal of log quality and features. Considering the yields of target product are low and the subject of speculation, and costs of processing/drying expensive and time consuming, this option may not suit some end-users.

(a)

(b)

Figures 48 a-b. Blackheart sassafras and leatherwood *(Eucryphia lucida*) logs. (Island specialty timbers log tender, Geeveston Tasmania 2007.)

(a) (b)

Figures 49 a-b. Dried huon pine slabs and King William pine boards. (Tasmanian Special Timbers, Queenstown 2007.)


(a) (b)

Figures 50 a-b. Myrtle and blackheart sassafras boards (Island Specialty Timbers) and mountain tea-tree boards (Phillips Sawmill, Geeveston.)

Figure 51. Native plum veneer (Cockatoo Timbers, Stanley Tasmania).

## 7.2 Prices

Considerable variation in tonewood prices arise as a consequence of the species concerned, quality and availability of the material and the degree of value-adding in the product.
Feedback from domestic processors also indicates a greater potential for higher product prices in larger overseas markets.
Naturally green unseasoned material requiring drying and resawing attracts lower prices along the value-adding chain. The anticipated volume losses are offset by the expectation of lower initial prices paid.
Rough-sawn seasoned boards are available in dimensions suitable for resawing and several suppliers have emerged catering to the demands of those seeking components in final product dimensions.

***It needs to be emphasised that very few logs have highly figured grain suitable for instrument making, and the subsequent conversion of logs to target product yields very small volumes per log. The investment in drying (energry and time) combined with volume losses to drying degrade, shrinkage, hidden defects and bandsaw kerf (around 30-40% for 5mm thick target product) contribute to the cost of final products.***

The production of one cubic metre of material suitable for instrument back and sides may require well in excess of 10 cubic metres of sawlog. The subsequent breakdown of one cubic metre of hardwood material may yield around 200 back and side sets, which may represent less than 5% of recovery from sawlog to target product.

A general guide to some product prices (AUSD) as of May 2008 follows.
The price continuum reflecting perceived marketability related to the extravagance of the grain and colour. Prices represent retail values with higher volume buyers better positioned to negotiate prices where an ongoing business relationship is sought.

### *Green oversized billets*

For some materials used in soundboards and backs and sides, 215 mm in width; thickness dictated by buyer preference.
Subject to species and quality variation- prices *beginning* at around \$2,500 $m^3$.
Highly-figured material will command substantially higher prices.

### *Dried rough-sawn boards*

Quartersawn boards, width and thickness dictated by buyer preference.
Subject to species and quality variation, prices *beginning* at around \$4,500 $m^3$.
Highest quality figured material may cost in excess of \$20,000 $m^3$.
Products (of equal quality) requiring narrower boards will generally be less expensive.

## *Finished component sizes*

The prices are for thickness sanded products close to final component dimensions

***Soundboards***

(bookmatched pair) 2@210mm x 550mm x 5mm (nominal sizes), grade and quality dependent

| **Species** | **Price range ($ unit$^{-1}$)** | **Price range ($ m$^{-3)}$** |
|---|---|---|
| Bunya pine | 30 - 50 | 21-36,000 |
| Kauri | 20 - 35 | 14-25,000 |
| Spruce; Englemann | 45 - 110 | 32-79,000 |
| Sitka | 45 - 110 | 32-79,000 |
| German | 80 - 180 | 57-125,000 |
| Red (Adirondack) | 70 - 120 | 50-86,000 |
| Carpathian red | 75 - 130 | 54-93,000 |
| Western red cedar | 35 - 95 | 25-68,000 |

***Back & sides set***

(bookmatched pair for back) 2@210 x 550 x 5mm

(bookmatched pair for sides) 2@100 x 850 x 5mm

| **Species** | **Price range ($ unit$^{-1}$)** | **Price range ($ m$^{-3)}$** |
|---|---|---|
| Koa* (Hawaiian) | 125 – 380 | 49-150,000 |
| Myrtle | 120 - 380 | 47-150,000 |
| Blackwood | 90 - 260 | 35-100,000 |
| Queensland walnut | 140 - 280 | 55-110,000 |
| Blackheart sassafras | 120 - 180 | 47-70,000 |
| Queensland maple | 80 - 180 | 30-70,000 |
| Indian rosewood * | 100 - 180 | 40-70,000 |
| Mountain ash | 65 - 140 | 25-55,000 |
| Cypress (*macrocarpa*) | 60 - 80 | 23-30,000 |

*denotes imported

***Fretboards & bridges***

Sizes variable with instrument

Prices given for dimensions/instrument rather than on a species basis

| **Species** | **(mm)** | **Price ($ unit$^{-1}$)** | **Price ($ m$^{-3)}$** |
|---|---|---|---|
| *Fretboards* | | | |
| Ebony * | 515 x 65 x 7 | 20 | 85,000 |
| Indian rosewood* | 515 x 65 x 7 | 10 | 47,000 |
| *Dryland acacias* | | | |
| Acoustic guitar | 520 x 65 x 7 | 15 | 63,000 |
| Bass | 690 x 65 x 7 | 18 | 57,000 |
| Acoustic bridge | 180 x 55 x 13 | 10 | 77,000 |

* denotes imported

***Necks***

Prices given for dimensions/instrument rather than on a species basis

| **Instrument** | **(mm)** | **Price range ($ unit$^{-1}$)** | **Price range ($ m$^{-3}$)** |
|---|---|---|---|
| Classical guitar | 600 x 75 x 25 | 25-50 | 14 – 29,000 |
| Acoustic guitar | 920 x 100 x 25 | 35-70 | 15 – 30,000 |
| Electric bass | 870 x 125 x 25 | 35-70 | 12 – 24,000 |
| Electric bolt-on | 690 x 100 x 25 | 25-55 | 12 – 28,000 |

***Solid bodies (2-3 piece)***

| **Species** | **(mm)** | **Price ($ unit$^{-1}$)** | **Price ($ m$^{-3}$)** |
|---|---|---|---|
| Alder* | 515 x 355 x 50 | 70 - 90 | 7.5 – 10,000 |
| Ash* | 515 x 355 x 50 | 95 – 110 | 10 – 12,000 |
| Primavera* | 515 x 355 x 50 | 90 - 105 | 10 - 11500 |

* denotes imported

# 8. FUTURE DIRECTIONS

Further work in a number of areas is recommended. These include;

- **Economics of processing –** analysis of processing strategies targeting 'tonewood' products vs. other high value products. Bunya pine, presently the basis of industrial scale acoustic guitar manufacturing, is no longer being established in plantations. Its ongoing use is dependent upon the economics of longer rotations and finding markets for the fall-down products.
- **Market development –** linking processors to existing and emerging markets, and promoting the attributes of Australian tonewood species.
- **Plantation resources –** examination of wood properties (density, unit shrinkages, MOE and acoustic properties) of faster-grown plantation resources for use as tonewoods.
  - A number of plantation grown species are worthy of further evaluation for use as tonewoods. Government initiatives to expand the national plantation estate are dependent upon value-adding scenarios as a rationale for their establishment over other land-use options.
  - Detailed data on the acoustic/elastic properties and unit shrinkages of plantation material can establish the suitability of products for a variety of high-value end-uses.
- **Drying schedules**
  - Optimisation of drying/reconditioning schedules of specialty tonewood species both from native forest and plantation resources.
  - Examination of the temperature effects of kiln drying upon the acoustic characteristics of tonewoods
- **Tonewood timbers of the Asia Pacific –** A number of tree species from the Asia/Pacific region show promise of producing tonewood material**.**

  Preliminary testing of forest species of P.N.G, Timor, Irian Jaya and the Asia Pacific region has identified several species with potential in instrument construction.

  Community based forestry in this region is often reliant upon maximising the value of low volume, labour intensive production systems. Tonewood production where possible represents such a scenario.

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## *Appendix 1 Fretboards, bridges*

| FRETBOARDS, BRIDGES | | | | |
|---|---|---|---|---|
| **COMMON NAME** *Genus Species* | **Density (kg/m$^3$) air-dry** | **Shrinkage** | | |
| | | **Dimension** | **Unit %** | **Green to 12 % MC** |
| *Acacia acradenia* | **1050** | **Tang.** | | |
| | | **Radial** | | |
| **JAM, RASPBERRY** *Acacia acuminata* | **1105** | **Tang.** | | **1.8** |
| | | **Radial** | | **1.1** |
| *Acacia adsurgens* | **1030** | **Tang.** | | |
| | | **Radial** | | |
| **MULGA** *Acacia aneura* | **1152** | **Tang.** | | **2.2** |
| | | **Radial** | | **1.8** |
| **WATTLE, FERNY** *Acacia arundefflana* | **895** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia atkinsiana* | **0** | **Tang.** | | |
| | | **Radial** | | |
| **SALWOOD, BROWN** *Acacia aulacocarpa* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **WATTLE, WHITE** *Acacia bakeri* | **895** | **Tang.** | | |
| | | **Radial** | | |

| | | | | |
|---|---|---|---|---|
| *Acacia bidwillii* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia bivenosa* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia brachystachya* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **GIDGEE** *Acacia cambagei* | **1282** | **Tang.** | | **2.3** |
| | | **Radial** | | **1.5** |
| **PURPLEWOOD WATTLE** *Acacia carneorum* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia chisholmii* | **960** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia citrinovirdis* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **CURRACABAH** *Acacia concurrens* | **880** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia coriacea* | **1099** | **Tang.** | | |
| | | **Radial** | | |
| **MULGA, HOP** *Acacia craspedocarpa* | **1030** | **Tang.** | | |
| | | **Radial** | | |

| | | | | |
|---|---|---|---|---|
| **CURRACABAH** *Acacia cunninghamii* | **880** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia dictyophleba* | **885** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia difficilis* | **910** | **Tang.** | | |
| | | **Radial** | | |
| **LANCEWOOD, BROWN** *Acacia doratoxylon* | **915** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia eriopoda* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **WATTLE, IRONWOOD** *Acacia excelsa* | **1106** | **Tang.** | | **2.6** |
| | | **Radial** | | **1.6** |
| **WATTLE, ROSE** *Acacia fasciculifera* | **1120** | **Tang.** | | |
| | | **Radial** | | |
| **GIDGEE, GEORGINA** *Acacia georginae* | **900** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia glaucocarpa* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **MINIRITCHIE** Acacia grasbyii | **1215** | **Tang.** | | **2.9** |
| | | **Radial** | | **1.9** |

| | | | | |
|---|---|---|---|---|
| **BRIGALOW** *Acacia harpophylla* | **1059** | **Tang.** | **0.39** | **4.7** |
| | | **Radial** | **0.28** | **2.6** |
| *Acacia holosericea* | **890** | **Tang.** | | |
| | | **Radial** | | |
| **YARRAN** *Acacia homalophylla* | **1235** | **Tang.** | | |
| | | **Radial** | | |
| **LIGHTWOOD** *Acacia implexa* | **800** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia jennerae* | **862** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia laccata* | **840** | **Tang.** | | |
| | | **Radial** | | |
| **WATTLE, SILVER** *Acacia lasiocalyx* | **795** | **Tang.** | | |
| | | **Radial** | | |
| **NELIA, Broken Hill Gidgee** *Acacia loderi* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia maconochieana* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **PRICKLY ACACIA** *Acacia nilotica* | **875** | **Tang.** | | **1.6** |
| | | **Radial** | | **1.0** |

| | | | | |
|---|---|---|---|---|
| **YARRAN** *Acacia omalophylla* | **1235** | **Tang.** | | |
| | | **Radial** | | |
| **WATTLE, FERNY** *Acacia o'shanesii* | **895** | **Tang.** | | |
| | | **Radial** | | |
| **MILJEE** *Acacia oswaldii* | **1133** | **Tang.** | | |
| | | **Radial** | | |
| **MYALL, Western** *Acacia papyrocarpa* | **1100** | **Tang.** | | **1.5** |
| | | **Radial** | | **1.0** |
| **MYALL** *Acacia pendula* | **1155** | **Tang.** | | |
| | | **Radial** | | |
| **WADDYWOOD** *Acacia peuce* | **1425** | **Tang.** | | |
| | | **Radial** | | |
| **GIDGEE** *Acacia pruinocarpa* | **1096** | **Tang.** | | **2.9** |
| | | **Radial** | | **2.3** |
| **WATTLE, GRANITE** *Acacia quadrimarginea* | **1071** | **Tang.** | | |
| | | **Radial** | | |
| **MULGA, HORSE** *Acacia ramulosa* | **1169** | **Tang.** | | |
| | | **Radial** | | |
| **OLD MAN WODJIL**, *Acacia resinimarginea* | **1157** | **Tang.** | | |
| | | **Radial** | | |

| | | | | |
|---|---|---|---|---|
| **WATTLE, SPEAR** *Acacia rhodoxylon* | **1280** | **Tang.** | | |
| | | **Radial** | | |
| **QUMU** *Acacia richii* | **835** | **Tang.** | **0.39** | **5.4** |
| | | **Radial** | **0.20** | **1.8** |
| *Acacia sclerosperma* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **LANCEWOOD**, *Acacia shirleyi* | **1035** | **Tang.** | | **1.8** |
| | | **Radial** | | **1.0** |
| *Acacia sibilans* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **WATTLE, PILLIGA** *Acacia spectabilis* | **890** | **Tang.** | | |
| | | **Radial** | | |
| **EUMONG - River Cooba** *Acacia stenophyfla* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| *Acacia stipuligera* | **800 +** | **Tang.** | | |
| | | **Radial** | | |
| **GIDGEE, Spreading** *Acacia subtesserogona* | **1274** | **Tang.** | | |
| | | **Radial** | | |
| **CURARA** *Acacia tetragonophylla* | **1090** | **Tang.** | | |
| | | **Radial** | | |

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|---|---|---|---|---|
| **Prickly acacia**<br>*Acacia victoriae* | **804** | **Tang.** | | |
| | | **Radial** | | |
| **SNAKEWOOD**<br>*Acacia xiphophylla* | **1321** | **Tang.** | | |
| | | **Radial** | | |
| **IRONWOOD, COOKTOWN**<br>*Bythrophleum laboucheri* | **1220** | **Tang.** | | |
| | | **Radial** | | |
| **LANCEWOOD, RED**<br>*Albizia basaltica* | **1200** | **Tang.** | | |
| | | **Radial** | | |
| **SIRIS, BROWN**<br>*Albizia thozetiana* | **960** | **Tang.** | | |
| | | **Radial** | | |
| *Allocasuarina acutivalvis* | **941** | **Tang.** | | |
| | | **Radial** | | |
| **TAMMA**<br>*Allocasuarina corniculata* | **970** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, DESERT**<br>*Allocasuarina decaisneana* | **1211** | **Tang.** | | |
| | | **Radial** | | |
| **SHEOAK, Northern**<br>*Allocasuarina dielsiana* | **1045** | **Tang.** | | |
| | | **Radial** | | |
| **SHEOAK, Rock**<br>*Allocasuarina huegeliana* | **885** | **Tang.** | | |
| | | **Radial** | | |

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|---|---|---|---|---|
| **SHEOAK, FLAME** *Allocasuarina inophloia* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, BULL** *Allocasuarina luehmannii* | **1120** | **Tang.** | | |
| | | **Radial** | | |
| **SHEOAK, ROSE** *Allocasuarina torulosa* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **CURRANTWOOD** *Antidesma bunius* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **CURRANTWOOD** *Antidesma dallachyanum* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **CURRANTWOOD** *Antidesma erostre* | **850** | **Tang.** | | |
| | | **Radial** | | |
| **LANCEWOOD, RED** *Archidendfopsis basaltica* | **1209** | **Tang.** | | **4.4** |
| | | **Radial** | | **3.0** |
| **SIRIS, BROWN** *Archidendropsis thozetiana* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **PALM*, PICCABEEN** *Archontophoenix alexandrae* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **PALM*, PICCABEEN** *Archontophoenix cunninghamiana* | **960** | **Tang.** | | |
| | | **Radial** | | |

| | | | | |
|---|---|---|---|---|
| **OAK, TULIP , RED** *Argyrodendion sp.* | **975** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP, BLUSH** *Argyrodendron actinophyllum* | **802** | **Tang.** | **0.31** | **8.7** |
| | | **Radial** | **0.24** | **4.0** |
| **OAK, TULIP , RED** *Argyrodendron peratatum* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , BROWN** *Argyrodendron polyandium* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , RED** *Argyrodendron sp.* | **910** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , BROWN** *Argyrodendron sp.* | **925** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , BROWN** *Argyrodendron trifoliolatum* | **935** | **Tang.** | **0.44** | **7.7** |
| | | **Radial** | **0.27** | **3.3** |
| **OAK, TULIP , RED** *Argyrodendron trifoliolatum* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **IRONWOOD, SCRUB** *Austromyrtus acmenoides* | **865** | **Tang.** | | |
| | | **Radial** | | |
| **IRONWOOD** *Backhousia myrtifolia* | **1042** | **Tang.** | **0.51** | **9.0** |
| | | **Radial** | **0.30** | **4.9** |

| | | | | |
|---|---|---|---|---|
| **BAUHINIA, CARRON'S**<br>*Bauhinia carroniii* | **1390** | **Tang.** | | |
| | | **Radial** | | |
| **BAUHINIA, HOOKER'S**<br>*Bauhinia hookeri* | **1225** | **Tang.** | | |
| | | **Radial** | | |
| **SCRUB IRONBARK**<br>*Bosistoa euodiiformis* | **895** | **Tang.** | | |
| | | **Radial** | | |
| **SCRUB IRONBARK**<br>Bosistoa transversa | **975** | **Tang.** | | |
| | | **Radial** | | |
| ***OCHNA, BROWN***<br>*Brackenridgea australiana* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **OCHNA, BROWN**<br>*Brackenridgea nitida* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **MANGROVE, BLACK**<br>*Bruguiera gymnorrhiza* | **971** | **Tang.** | **0.45** | **5.5** |
| | | **Radial** | **0.21** | **2.5** |
| **MANGROVE**<br>*Bruguiera parviflora* | **900** | **Tang.** | **0.46** | **9.7** |
| | | **Radial** | **0.28** | **3.1** |
| **MANGROVE, BLACK**<br>*Bruguiera rheedii* | **975** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, SILKY , SPOTTED**<br>*Buckinghamia celsissima* | **933** | **Tang.** | **0.44** | **8.1** |
| | | **Radial** | **0.16** | **1.9** |

| | | | | |
|---|---|---|---|---|
| **OOLINE, SCRUB** *Cadellia monostylis* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **OOLINE** *Cadellia pentastylis* | **1105** | **Tang.** | | |
| | | **Radial** | | |
| **BOTTLEBRUSH, Lesser** *Callistemon phoenicius* | **983** | **Tang.** | | |
| | | **Radial** | | |
| **BOTTLEBRUSH, WHITE** *Callistemon salignus* | **975** | **Tang.** | | |
| | | **Radial** | | |
| **BOTTLEBRUSH, DROOPING** *Callistemon viminalis* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **TOURIGA, BROWN** *Calophyllum touriga* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **CURRANT, Native** *Canthium latifolium* | **839** | **Tang.** | | |
| | | **Radial** | | |
| **CURRANT, native, Narrow-leaved** *Canthium lineare* | **925** | **Tang.** | | |
| | | **Radial** | | |
| **CANTHIUM** *Canthium odoratum* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **ORANGE, WILD** *Capparis arborea* | **885** | **Tang.** | | |
| | | **Radial** | | |

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|---|---|---|---|---|
| **ORANGE, WILD** *Capparis mitchellii* | **885** | **Tang.** | | |
| | | **Radial** | | |
| **ORANGE, WILD** *Capparis nobilis* | **815** | **Tang.** | | |
| | | **Radial** | | |
| **BOXWOOD, BLUSH** *Cassine australis* | **850** | **Tang.** | | |
| | | **Radial** | | |
| **BELAH** *Casuarina cristata* | **1142** | **Tang.** | | |
| | | **Radial** | | |
| **SHEOAK, RIVER** *Casuarina cunninghamiana* | **895** | **Tang.** | | |
| | | **Radial** | | |
| **SHEOAK, BEACH** *Casuarina equisetifolia* | **1022** | **Tang.** | **0.56** | **9.6** |
| | | **Radial** | **0.18** | **1.9** |
| **SHEOAK, SWAMP** *Casuarina glauca* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **SHEOAK, FLAME** *Casuarina inophloia* | **944** | **Tang.** | **0.37** | **3.4** |
| | | **Radial** | **0.07** | **0.9** |
| **BELAH** *Casuarina lepidophloia* | **1155** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, BULL** *Casuarina luehmannii* | **1120** | **Tang.** | | |
| | | **Radial** | | |

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| **SHEOAK BEACH, Fijian** *Casuarina nodiflora* | **1064** | **Tang.** | **0.51** | **8.3** |
| | | **Radial** | **0.20** | **2.7** |
| **OAK/BELAH , BLACK** *Casuarina pauper* | **1135** | **Tang.** | | **2.6** |
| | | **Radial** | | **2.1** |
| **SHEOAK, ROSE** *Casuarina torulosa* | **954** | **Tang.** | **0.34** | **6.6** |
| | | **Radial** | **0.15** | **1.6** |
| **BOXWOOD, ORANGE** *Celastrus dispermus* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **MANGROVE, SPURRED** *Ceriops candolleana* | **1025** | **Tang.** | | |
| | | **Radial** | | |
| **MANGROVE, SPURRED** *Ceriops tagal* | **1025** | **Tang.** | | |
| | | **Radial** | | |
| **MANGROVE, SPURRED** *Ceriops timorensis* | **1025** | **Tang.** | | |
| | | **Radial** | | |
| **OLIVE, NORTHERN** *Chionanthus ramiflora* | **875** | **Tang.** | | |
| | | **Radial** | | |
| **BOX, IRONWOOD** *Choricarpia subargentea* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **YASI-YASI** *Cleistocalyx spp.* | **982** | **Tang.** | **0.38** | **8.5** |
| | | **Radial** | **0.26** | **4.6** |

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| **MANILTOA** *Cynometra insularis* | **921** | **Tang.** | **0.42** | **7.7** |
| | | **Radial** | **0.24** | **3.3** |
| **EBONY, AUSTRALIAN** *Diospyros fasciculosa* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **EBONY, AUSTRALIAN** *Diospyros ferrea* | **1213** | **Tang.** | | |
| | | **Radial** | | |
| **TAMARIND** *Diploglottis australis* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **TAMARIND** *Diploglottis bracteata* | **995** | **Tang.** | | |
| | | **Radial** | | |
| **REDHEART** *Dissillaria baloghioides* | **983** | **Tang.** | **0.39** | **7.5** |
| | | **Radial** | **0.27** | **4.6** |
| **dryandra, Yilgam** *Dryandra arborea* | **939** | **Tang.** | | |
| | | **Radial** | | |
| **GREYBOXWOOD** *Drypetes australasica* | **915** | **Tang.** | | |
| | | **Radial** | | |
| **GREYBOXWOOD** *Drypetes lasiogyna* | **915** | **Tang.** | | |
| | | **Radial** | | |
| **PITURI** *Duboisia hopwoodii* | **1074** | **Tang.** | | |
| | | **Radial** | | |

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| **MAHOGANY, BUFF** *Dysoxylum klanderi* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **MAHOGANY, PINK** *Dysoxylum oppositifollum* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **MAHOGANY, SPUR** *Dysoxylum pettigrewianum* | **864** | **Tang.** | | |
| | | **Radial** | | |
| **GREENHEART, QUEENSLAND** *Endiandra compressa* | **1002** | **Tang.** | | **7.3** |
| | | **Radial** | | **4.4** |
| **WALNUT, ROSE** *Endiandra dichrophylla* | **808** | **Tang.** | | |
| | | **Radial** | | |
| **WADDYWOOD** *Endiandra globosa* | **915** | **Tang.** | | |
| | | **Radial** | | |
| **WALNUT, BUFF** *Endiandra longipedicellata* | **975** | **Tang.** | | |
| | | **Radial** | | |
| **WALNUT, SAFFRON** *Endiandra sp.* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **WALNUT, BUFF** *Endiandra sp.* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **WALNUT, CANDLE** *Endiandra tooram* | **850** | **Tang.** | | |
| | | **Radial** | | |

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| **Broombush** *Eremophila interstans* | **941** | **Tang.** | | |
| | | **Radial** | | |
| **SANDALBOX** *Eremophila mitchellii* | **1038** | **Tang.** | | **2.7** |
| | | **Radial** | | **1.3** |
| **IRONWOOD, COOKTOWN** *Erythrophleum chlorostachys* | **1203** | **Tang.** | | **2.7** |
| | | **Radial** | | **2.2** |
| **Ironwood, Cooktown** *Erythrophloeum laboucherfl* | | **Tang.** | | |
| | | **Radial** | | |
| **PLUM, BROWN** *Erythroxylum ecarinatum* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **PLUM, BROWN** *Erythroxylum ellipticum* | **995** | **Tang.** | | |
| | | **Radial** | | |
| **Satinash, Ravenshoe** *Eugenia angophoroides* | **936** | **Tang.** | **0.36** | **7.4** |
| | | **Radial** | **0.23** | **4.0** |
| **SATINASH, GREY** *Eugenia claviflora* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, SCENTED** *Eugenia coolminiana* | **1025** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, SCENTED** *Eugenia cyanocarpa* | **1025** | **Tang.** | | |
| | | **Radial** | | |

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|---|---|---|---|---|
| **SATINASH, RED**<br>*Eugenia hedraiophylla* | **900** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, ROSE**<br>*Eugenia johnsonii* | **815** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, KURANDA**<br>*Eugenia kuranda* | **843** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, GREY**<br>*Eugenia leptantha* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, SCENTED**<br>*Eugenia oleosa* | **1025** | **Tang.** | | |
| | | **Radial** | | |
| **AIMELA**<br>*Eugenia onesima* | **921** | **Tang.** | **0.35** | **7.3** |
| | | **Radial** | **0.29** | **3.7** |
| **SATINASH, PAPERBARK**<br>*Eugenia sp.* | **895** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, PINK**<br>*Eugenia sp.* | **840** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, ROLYPOLY**<br>*Eugenia sp.* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **TINGLETONGUE**<br>*Euodia etythrococca* | **975** | **Tang.** | | |
| | | **Radial** | | |

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| **CHERRY, NATIVE**<br>*Exocarpos cupressiformis* | **835** | **Tang.** | | |
| | | **Radial** | | |
| **CHERRY, BROAD-LEAVED**<br>*Exocarpos latifolius* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **LEOPARDWOOD**<br>*Flindersia maculata* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **LEOPARDWOOD**<br>*Flindersia maculosa* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **MARBLEWOOD**<br>*Garcinia sp.* | **1115** | **Tang.** | | |
| | | **Radial** | | |
| **SATINHEART, GREEN**<br>*Geifera salicifolia* | **995** | **Tang.** | | |
| | | **Radial** | | |
| **WILGA, SCRUB**<br>*Geijera muelleri* | **1120** | **Tang.** | | |
| | | **Radial** | | |
| **WILGA, SCRUB**<br>*Geijera paniculata* | **1120** | **Tang.** | | |
| | | **Radial** | | |
| **WILGA**<br>*Geijera parviflora* | **895** | **Tang.** | | |
| | | **Radial** | | |
| **satinheart, green**<br>*Geijera salicifolia* | **992** | **Tang.** | | |
| | | **Radial** | | |

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| **MARARIE**<br>*Geissois lachnocarpa* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, SILKY , FINDLAYS**<br>*Grevillea baileyana* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, SILKY , HILL'S**<br>*Grevillea hilliana* | **975** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, SILKY , FINDLAYS**<br>*Grevillea pinnatifida* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **BEEFWOOD**<br>*Grevillea striata* | **941** | **Tang.** | | **3.4** |
| | | **Radial** | | **1.8** |
| **OOLINE, SCRUB**<br>*Guiffoyfia monostylis* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **SAFFRONHEART**<br>*Haffordia scleroxyla* | **1105** | **Tang.** | | |
| | | **Radial** | | |
| **NEEDLEWOOD**<br>*Hakea leucoptera* | **953** | **Tang.** | | |
| | | **Radial** | | |
| **NEEDLEWOOD**<br>*Hakea lorea* | **1135** | **Tang.** | | |
| | | **Radial** | | |

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| **NEEDLEBUSH** *Hakea preissii* | **1062** | **Tang.** | | |
| | | **Radial** | | |
| **SAFFRONHEART** *Halfordia drupifera* | **1105** | **Tang.** | | |
| | | **Radial** | | |
| **SAFFRONHEART** *Halfordia kendack* | **1105** | **Tang.** | | |
| | | **Radial** | | |
| **GREYBOXWOOD** *Hemicyclia australasica* | **906** | **Tang.** | **0.38** | **7.2** |
| | | **Radial** | **0.29** | **3.9** |
| **OAK, TULIP, RED** *Heritiera peralata* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , BROWN** *Heritiera trifoliolata* | **925** | **Tang.** | | |
| | | **Radial** | | |
| **ROSEWOOD, INLAND** *Heterodendrum oleifolium* | **1135** | **Tang.** | | |
| | | **Radial** | | |
| **bush, Bulloch** *Heterodendrum oleifolium* | **1091** | **Tang.** | | |
| | | **Radial** | | |
| **kunzea, Granite** *Kunzea pulchella* | **1033** | **Tang.** | | |
| | | **Radial** | | |
| **BOX, SWAMP , NORTHERN** *Lophostemon grandiflorus* | **1075** | **Tang.** | | |
| | | **Radial** | | |

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| **BAUHINIA, CARRON'S** *Lysiphyllum carronii* | **1390** | **Tang.** | | |
| | | **Radial** | | |
| **BAUHINIA, HOOKER'S** *Lysiphyllum hookeri* | **1225** | **Tang.** | | |
| | | **Radial** | | |
| **EBONY, AUSTRALIAN** *Maba fasciculosa* | **880** | **Tang.** | | |
| | | **Radial** | | |
| **EBONY, AUSTRALIAN** *Maba hemicycloides* | **1175** | **Tang.** | | |
| | | **Radial** | | |
| **EBONY, AUSTRALIAN** *Maba humilis* | **1250** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, SILKY , WHELAN'S** *Macadamia whelanii* | **995** | **Tang.** | | |
| | | **Radial** | | |
| **MANIKARA** *Manilkara kanosiensis* | **1001** | **Tang.** | **0.36** | **6.2** |
| | | **Radial** | **0.30** | **3.1** |
| **MANILTOA** *Maniltoa spp.* | **956** | **Tang.** | **0.38** | **6.9** |
| | | **Radial** | **0.24** | **2.8** |
| **PARINARI** *Maranthes corymbosa* | **1010** | **Tang.** | | |
| | | **Radial** | | |

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| **BOXWOOD, ORANGE** *Maytenus disperma* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **TEA-TREE, SILVER** *Melaleuca argentea* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **BOREE** *Melaleuca pauperiflora* | **1088** | **Tang.** | | |
| | | **Radial** | | |
| **TINGLETONGUE** *Melicope erythrococca* | **943** | **Tang.** | **0.39** | **7.9** |
| | | **Radial** | **0.28** | **4.9** |
| **VUGA** *Metrosideros collina* | **958** | **Tang.** | **0.36** | **7.4** |
| | | **Radial** | **0.27** | **4.4** |
| **COONDOO, RED** *Mimusops elengi* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **CONDOO, RED** *Mimusops parvifolia* | **1012** | **Tang.** | **0.33** | **5.1** |
| | | **Radial** | **0.24** | **3.2** |
| **COONDOO, RED** *Mimusops parvifolia* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **SUGAR TREE** *Myoporum platycarpum* | **1023** | **Tang.** | | |
| | | **Radial** | | |
| **PARINARI** *Paranthes corymbosa* | **1010** | **Tang.** | | |
| | | **Radial** | | |

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| **PARINARI** *Parinari corymbosum* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **PARINARI** *Parinari griffithianum* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **QUININE, FOREST** *Petalostigma pubescens* | **1055** | **Tang.** | | |
| | | **Radial** | | |
| **QUININE, FOREST** *Petalostigma quadriloculare* | **1055** | **Tang.** | | |
| | | **Radial** | | |
| **BOXWOOD, HICKORY** *Planchonella euphlebia* | **1034** | **Tang.** | **0.42** | **9.0** |
| | | **Radial** | **0.29** | **4.0** |
| **MALLETWOOD, SILVER** *Rhodamnia acuminata* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **MALLETWOOD, IRON** *Rhodamnia blairiana* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **MALLETWOOD, IRON** *Rhodamnia sessiliflora* | **975** | **Tang.** | | |
| | | **Radial** | | |
| **CHERRY, FINGER** *Rhodomyrtus macrocarpa* | **905** | **Tang.** | | |
| | | **Radial** | | |

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| **SANDALWOOD** *Santalum spicatum* | **976** | **Tang.** | **0.32** | **2.7** |
| | | **Radial** | **0.25** | **2.0** |
| **BOXWOOD, HICKORY** *Sideroxylon euphlebium* | **1044** | **Tang.** | | |
| | | **Radial** | | |
| **TURPENTINE** *Syncarpia glomulifera* | **945** | **Tang.** | **0.35** | **13.0** |
| | | **Radial** | **0.23** | **6.5** |
| **SATINAY** *Syncarpia hillii* | **825** | **Tang.** | **0.35** | **10.0** |
| | | **Radial** | **0.17** | **4.4** |
| **TURPENTINE** *Syncarpia laurifolia* | **949** | **Tang.** | | |
| | | **Radial** | | |
| **TURPENTINE** *Syncarpia procera* | **949** | **Tang.** | | |
| | | **Radial** | | |
| **BOX, IRONWOOD** *Syncarpia subargentea* | **960** | **Tang.** | | |
| | | **Radial** | | |
| **SYNIMA** *Synima cordieri* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **SYNIMA** *Synima cordierorum* | **945** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, SCENTED** *Syzygium coolminianum* | **1025** | **Tang.** | | |
| | | **Radial** | | |

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| *Syzygium curvistylum* | **982** | **Tang.** | **0.38** | **8.5** |
| | | **Radial** | **0.26** | **4.6** |
| **SATINASH, SCENTED** *Syzygium oleosum* | **1025** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, PAPERBARK** *Syzygium papyraceum* | **895** | **Tang.** | | |
| | | **Radial** | | |
| **SATINASH, ROLYPOLY** *Syzygium sp.* | **930** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , RED** *Tarrietia argyrodendron* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **OAK, TULIP , BROWN** *Tarrietia trifoliolata* | **925** | **Tang.** | | |
| | | **Radial** | | |
| **DAMSON, BROWN** *Terminalia arenicola* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **DAMSON, BROWN** *Terminalia malanocarpa* | **800** | **Tang.** | | |
| | | **Radial** | | |
| **BOX, BRUSH** *Tristania conferta* | **883** | **Tang.** | **0.38** | **9.7** |
| | | **Radial** | **0.24** | **4.4** |

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| **BOX, KANUKA** *Tristania exiliflora* | **995** | **Tang.** | | |
| | | **Radial** | | |
| **BOX, SWAMP , NORTHERN** *Tristania grandiflora* | **1075** | **Tang.** | | |
| | | **Radial** | | |
| **BOX, KANUKA** *Tristania laurina* | **951** | **Tang.** | **0.37** | **14.2** |
| | | **Radial** | **0.21** | **7.1** |
| **BOX, KANUKA** *Tristaniopsis laurina* | **1010** | **Tang.** | | |
| | | **Radial** | | |
| **PENDA, SOUTHERN** *Xanthostemon oppositifolius* | **1120** | **Tang.** | | |
| | | **Radial** | | |
| **PENDA, RED** *Xanthostemon pubescens* | **1056** | **Tang.** | **0.36** | **5.8** |
| | | **Radial** | **0.31** | **3.8** |

Density and unit shrinkage data ; Ilic *et al* (2000)

# Appendix 2 Tonewood suppliers

## Queensland

**Australian Luthiers Suppliers (Hancock Guitars)**
Kim Hancock & Sons
Online supplier of guitar materials
Offering high quality guitar parts at competitive prices.
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loggerheads@spiderweb.com.au
www.loggerheads.com.au

## Tasmania

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Large range of specialty timbers and veneers
Largest producer of specialty timbers and veneer products to domestic and export markets. Producing wide figured boards and decorative veneers suitable for instrument makers
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**Cockatoo Timbers**
Chris and Frances Searle
"The Neck" Main Road Stanley 7331 TAS.
Specialising in heart stained and figured timbers, veneers and burls in most Tasmanian specialty species.
Catering to luthiers requirements, producing green rough sawn through to dried instrument 'sets'
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Fax (03) 6458 1337
Email; cockatoo_timbers@hotmail.com

**Corinna Sawmill**
Manager - Terry Groves
43-45 Scarfe Street, Burnie TAS
Suppliers of kiln dried or green blackwood, sassafras, huon pine, myrtle, celery top pine.
Producing wide boards suitable for luthiery.
Phone (03) 6435 1422
A/H (03) 6431 5806
Mob. 0419 158 474
Fax. (03) 6435 2748
Email; corinnatimbers@bigpond.com.au

**Gypsy Timbers**
Manager - Duncan Sproule
Preolena, Tasmania
Business dedicated to luthier requirements, from the small scale maker to larger export markets
Specialising in figured blackwood, myrtle, celery top pine, huon pine and musk.
Can source most specialty timbers.
Providing tonewood components both domestically and world-wide.
Phone +61 03 6445 9189   Mob. +61 0439 871 077
Email; Duncan@gypsytimbers.com.au

**Island Specialty Timbers (Forestry Tasmania)**
Manager Chris Emmet
Cemetery Rd. Geeveston TAS.
Selling logs and burls in many specialty species
Providing bandsawing and circular sawing services
Producing sawn kiln-dried boards suitable for instrument makers
Phone (03) 6297 1479
Fax. (03) 6297 1966
Mobile: 0419 998 452
Email; chris.emmet@forestrytas.com.au

**Phillips Sawmills**
Ted, Leigh and Peter Phillips
Sawmill, 299 Scotts Rd. Geevston
Factory Kermandie Rd. Geevston
Supplying a wide range of Tasmanian specialty timbers in both green and kiln dried forms.
Including blackwood, silver & black wattle, myrtle, blackheart sassafras, mountain tea- tree, and leatherwood.
Wide quartersawn boards available. Large range of kiln dried
timber in stock
Phone (03) 62979987
Mob. (Leigh) 0427 970080

**Tasmanian Salvaged Resurrection Timbers Pty Ltd**
Robert MacMillan
Old Beach, 7017
Tasmania, Australia.
Providing to luthier requirements ; King William pine, Mountain Ash, Myrtle, Black-heart sassafras, Blackwood & most Tasmanian specialty timbers.
E-mail info@tasmaniantimbers.com.au
http://www.tasmaniantimbers.com.au/contact.html

**Tasmanian Special Timbers**
Randal Morrison
Post Office Box 211 Queenstown TAS.
Specialising in huon pine in kiln dried slab and sawn boards. Also selling King William pine, myrtle, blackwood, celery top pine and leatherwood.
Can provide boards to luthier requirements.
Phone (03) 6471 2510
Fax (03) 6471 2205
Email;info@tasmanianspecialtimbers.com.au
www.tasmanianspecialtimbers.com.au

## *Victoria*

**Australian Furniture Timbers**
351 Plummer St. Port Melbourne VIC 3207
Ph. (03) 9646 1081 96465 2376
www.aft**timbers**.com

**Mathews Timbers**
125 Rooks Road, Vermont VIC, 3133
Ph. (03) 9264 8222
Toll free 1800 338 874
www.**mathewstimber**.com.au

**Rare Woods**
24 Greenwood Street
Abbotsford VIC 3067
Telephone: (03) 9427-0570
Facsimile: (03) 9421-2983

**Thomas Lloyd Guitars**
Chris Wynne or Fiona Mitchell
'Montsalvat' 7 Hillcrest Rd. Eltham VIC
School of guitar making and tonewood supplier
Supplying complete kits for classical and acoustic guitars
Individual components also can be purchased separately.
Including bunya pine, King William pine, huon
pine, blackwood, cedar, spruce and Indian rosewood
Office +61 3 9431 2490
Mobile +61 403 910 880
www.thomaslloydguitars.com

## *New South Wales*

**Gilet Tonewoods**
Gerard Gilet
Supplying top quality tone woods, parts,
and tools from around the world for professional
luthiers and hobbyists
Unit 5 / 6-10 Booralee Street, Botany, NSW, 2019
AUSTRALIA
PH: +61 (02) 9316 7467
www.guitarwoods.com.au

## *Western Australia*

**Australian Tonewoods**
Tim Spittle
Specialist luthiers supplier
Wide range of local (including W.A.) and imported tonewoods for a wide range of instruments.
tim@australiantonewoods.com
www.australiantonewoods.com

## *Appendix 3 Luthier survey*

**DATE :**


| | |
|---|---|
| **TO** | **Andrew Morrow**<br>**Projects Officer**<br>**Ensis Wood Quality**<br>**Bayview Avenue**<br>**Clayton ,Vic 3168**<br>**Private Bag 10**<br>**Clayton South, Vic 3169**<br>**Australia**<br><br>**Phone 03 9545 2131**<br>**Mobile 0404 003791** |
| **E-MAIL** | andrew.morrow@ensisjv.com |
| **FACSIMILIE NO**: | **+ 61 3 9545 2133** |


**Participants name (optional)**

**Business Name (if applicable)**

**Type of instruments being made**

| | | | |
|---|---|---|---|
| Steel string acoustic | ☐ | Ukeleles | ☐ |
| Nylon string classical | ☐ | Violins | ☐ |
| Nylon string flamenco | ☐ | Violas | ☐ |
| Acoustic bass | ☐ | Cellos | ☐ |
| Mandolins | ☐ | Double bass | ☐ |
| Solid body electric | ☐ | | |

Other (please specify)

**Quantity of instruments per year**
**How many instruments would you or your workplace produce annually ?**

1 to 5 ☐ 5 to 15 ☐ 15 to 30 ☐ 30 or more ☐

**How much timber ( Australian or other ) would you estimate you would annually;**
**Soundboards - (no. of soundboards, or lineal metres or cubic metres)**

**Backs & sides - (no. of soundboards, or lineal metres or cubic metres)**

**If you have not utilized Australian timbers in instruments what are the primary reasons for this?**

**Do you believe there is a resistance in the market place to instruments made from Australian tonewoods ?**

**If yes, do you believe this translates into higher prices being paid for instruments made from 'traditional' tonewoods with similar production standards ?**

**In what state do you prefer to purchase timber (i.e. roughsawn boards, dressed close to final size, green/dry at a specific moisture content etc.?)**

**In what dimensions do you prefer your raw materials ?**

**Soundboards**
**Thickness** **Width** **Length**

**Backs/sides**
**Thickness** **Width** **Length**

**Necks**
**Thickness** **Width** **Length**

**Fretboards**
**Thickness** **Width** **Length**

**Timbers used**

**Which of the following Australian timbers have you had experience with ?**
**Please cross any of the boxes corresponding to the timbers you have used.**

**Soundboards**

**Have you used any of these woods in soundboards**

King William Pine ☐ Bunya Pine ☐ Huon Pine ☐ Blackwood ☐
Kauri (Agathis spp.) ☐ Klinki Pine ☐ Hoop pine ☐

**Other please specify**

**Are there any specific positive qualities you would associate with any of these species ?**

**Are there any specific concerns you have with using any of these species ?**

**Which of the following Australian timbers have you had experience with as back & sides of instruments?**

Please cross any of the boxes corresponding to the timbers you have used.

**Back & sides**

**Acacias** - Blackwood ☐ Black Wattle ☐ Silver Wattle ☐
Lightwood ☐

**Other** - Queensland maple ☐ Queensland walnut ☐ Silky oak (Grevillia robusta) ☐ Beefwood (Grevillia striata) ☐ Myrtle( Nothafagus cunninghamii) ☐
Sassafras ☐ Celery top pine ☐ Coachwood ☐ Tulip satinwood ☐
Native Olive ☐ Satinwood ☐

**Eucalypts** - Messmate ☐ Mountain Ash ☐ Alpine Ash ☐
Jarrah ☐ Manna gum ☐ Spotted gum ☐ Red stringybark ☐
Apple box ☐

**Other please specify**

**Are there any specific positive qualities you would associate with any of these species?**

**Are there any specific concerns you would have with using any of these species ?**

**Which of the following Australian timbers have you had experience with in your instruments?**
**Please cross any of the boxes corresponding to the timbers you have used.**

**Neck / heel**
Queensland maple ☐ Kauri ☐ Queensland walnut ☐ Jarrah ☐

**Other please specify**

**Fretboards**
Gidgee (Acacia cambagei) ☐ Mulga (Acacia aneura) ☐ Desert Oak (Acacia coriacea) ☐ Ironwood *(Acacia exelsa) ☐ Prickly Acacia (Acacia nilotica) ☐ Lancewood (Acacia shirleyi)) ☐ Leopardwood ☐
Western Myall ☐ Weeping Myall ☐ Waddywood ☐ Nealie ☐
Rasberry jam ☐
Red Lancewood ☐ Cooktown ironwood ☐ Sandalbox ☐
Queensland Yellowjacket ☐

**Other please specify**

**Other instrument components**

**Have you used Australian timbers listed for other purposes, (i.e. saddles, chinrests, bows, bushings, bindings, rosettes ?)**
**If so, list the timber and its use.**

**Synthetic/composite materials**
**Have you used Australian timbers in conjunction with synthetic materials ?**
**Carbon fibre bracing**
**'Double-top' ( using kevlar veneer composite top)**
**Other please specify**

**Material evaluation**

**When selecting tonewoods which of the following factors do you take into account ?**
**Please indicate YES or NO**

**Soundboards**

**Tap tone - Do you undertake any basic evaluation of how the wood sounds by tapping or other ?**
**YES ☐ NO ☐**
**If 'yes', what type of evaluation?**

**Stiffness evaluation – Do you do use any form of test to evaluate the woods stiffness; i.e. weights/bending ?**
**YES ☐ NO ☐**
**If 'yes', what type of evaluation?**

**Growth ring width – Do you have a preference for a particular annual growth ring width for the instruments soundboard ?**
**YES ☐ NO ☐**
**If so, for which instrument, and what are the upper & lower limits?**

**Growth ring uniformity – Is growth ring uniformity across the soundboard top something you require when purchasing a soundboard ?**

**YES ☐ NO ☐**

**Grain straightness – Is grain angle relative to the boards edge something you consider when purchasing a soundboard ?**

**YES ☐ NO ☐**

**Color/figure – Does the aesthetic appeal ( and likely market acceptance ) of a soundboard play a part in the selection process ?**

**YES ☐ NO ☐**

**Back & sides**

**Tap tone - Do you undertake any basic evaluation of how the wood sounds by tapping or other ?**

**YES ☐ NO ☐**

**If 'yes', what type of evaluation?**

**Stiffness evaluation – Do you do use any form of test to evaluate the woods stiffness: i.e. weights/bending ?**
**YES ☐ NO ☐**
**If 'yes', what type of evaluation?**

**Grain straightness – Is grain angle relative to the boards edge something you consider when purchasing a 'set' for the back and sides ?**
**YES ☐ NO ☐**

**Color/figure – Does the aesthetic appeal (and likely market acceptance ) of the 'set' play a part in the selection process ?**
**YES ☐ NO ☐**

**Evaluation of the performance of Australian timbers in finished instruments**

Instrument makers are better placed than anyone to compare Australian tonewoods with instruments made from 'traditional' tonewoods. This is a highly subjective territory and perhaps unfair to compare inherently different wood species for there tonal qualities. Wood is highly variable within one tree of one species which is reflected in the finished instrument. Therefore it is important to gather as many opinions on the performance of different woods before dismissing them as unsuitable.
It should also be noted that refinements in the utilization and combination of Australian tonewoods may in time yield further improvements in their utilization and ultimately instrument quality.
However at this point it is useful to benchmark the 'sound' of these instruments against what is familiar to us.
The aim of this section of the survey is to rate (subjectively) the sound produced with instruments using Australian tonewoods with the combinations which dominate the markeplace (i.e.rosewood/spruce/cedar for guitars, and European maple/spruce for violins)

**Using a rating of 1 to 6, categorise the timbers you have used according to the following criteria. Timbers not used leave blank**
**1. Variable (results not consistent, but combination of below)**
**2. Very good T (comparable to the traditional sound)**
**3. Very good U ('high quality' sound, but unique relative to traditional sound)**
**4. Good**
**5. Poor**
**6. Unknown**

| **Soundboards** | **Variable** | **Very good T (traditional)** | **Very good U (unique)** | **Good** | **Poor** |
|---|---|---|---|---|---|
| **King William Pine** | | | | | |
| **Bunya Pine** | | | | | |
| **Hoop Pine** | | | | | |
| **Kauri (Agathis)** | | | | | |
| **Blackwood** | | | | | |
| **Satinwood** | | | | | |
| **Klinki Pine** | | | | | |
| **Other specify** | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| Back & sides (Acacias) | Variable | Very good T (traditional) | Very good U (unique) | Good | Poor |
|---|---|---|---|---|---|
| Blackwood | ☐ | ☐ | ☐ | ☐ | ☐ |
| Black wattle | ☐ | ☐ | ☐ | ☐ | ☐ |
| Silver wattle | ☐ | ☐ | ☐ | ☐ | ☐ |
| Lightwood | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other - specify | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |

| Back & sides (Eucalypts) | Variable | Very good T (traditional) | Very good U (unique) | Good | Poor |
|---|---|---|---|---|---|
| Mountain/Alpine Ash | ☐ | ☐ | ☐ | ☐ | ☐ |
| Messmate | ☐ | ☐ | ☐ | ☐ | ☐ |
| Jarrah | ☐ | ☐ | ☐ | ☐ | ☐ |
| Manna gum | ☐ | ☐ | ☐ | ☐ | ☐ |
| Red stringybark | ☐ | ☐ | ☐ | ☐ | ☐ |
| Apple Box | ☐ | ☐ | ☐ | ☐ | ☐ |
| Shining gum | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other - specify | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |

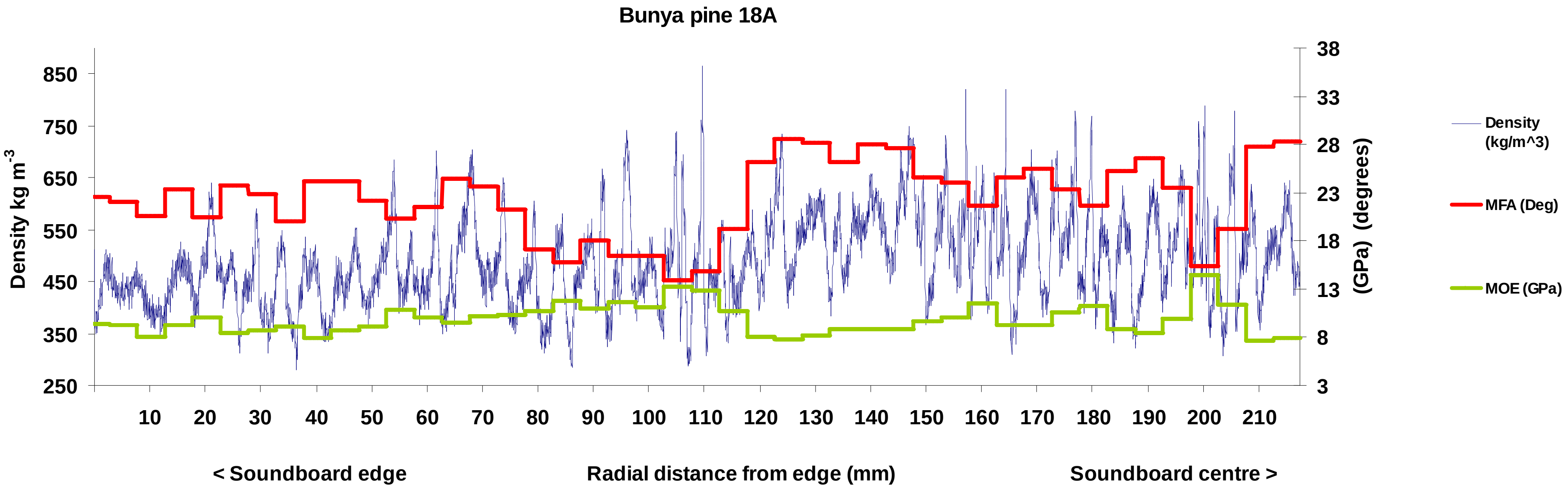
| Back & sides (other) | Variable | Very good T (traditional) | Very good U (unique) | Good | Poor |
|---|---|---|---|---|---|
| Queensland maple | ☐ | ☐ | ☐ | ☐ | ☐ |
| Queensland Walnut | ☐ | ☐ | ☐ | ☐ | ☐ |
| Sassafras | ☐ | ☐ | ☐ | ☐ | ☐ |
| Myrtle | ☐ | ☐ | ☐ | ☐ | ☐ |
| Coachwood | ☐ | ☐ | ☐ | ☐ | ☐ |
| Silky Oak | ☐ | ☐ | ☐ | ☐ | ☐ |
| Beefwood | ☐ | ☐ | ☐ | ☐ | ☐ |
| Celery Top Pine | ☐ | ☐ | ☐ | ☐ | ☐ |
| Kauri (Agathis) | ☐ | ☐ | ☐ | ☐ | ☐ |
| Native Olive | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other -specify | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ |

**Are there any general comments you would like to make regarding the use of Australian timbers based on your personal experiences that have not been specifically addressed in this survey?**

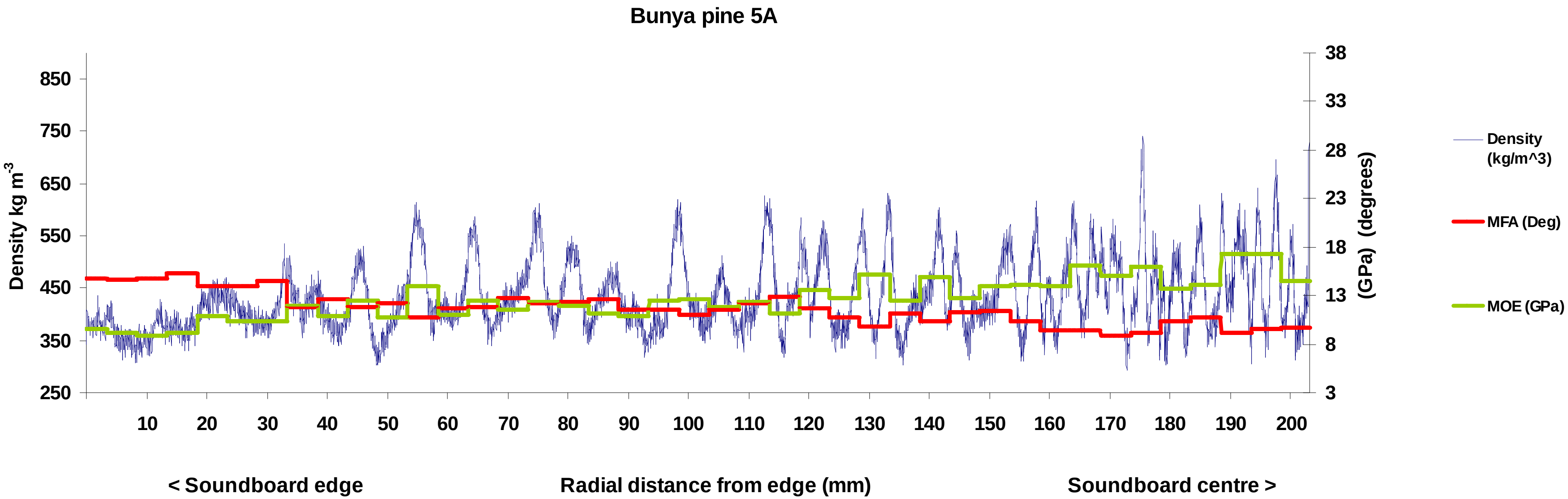
**If you would like to receive an electronic copy of the final report please tick the following box** ☐

**Thank you for the time taken to complete this survey. The information will hopefully assist with improving the utilization of a diverse and unique natural resource.**

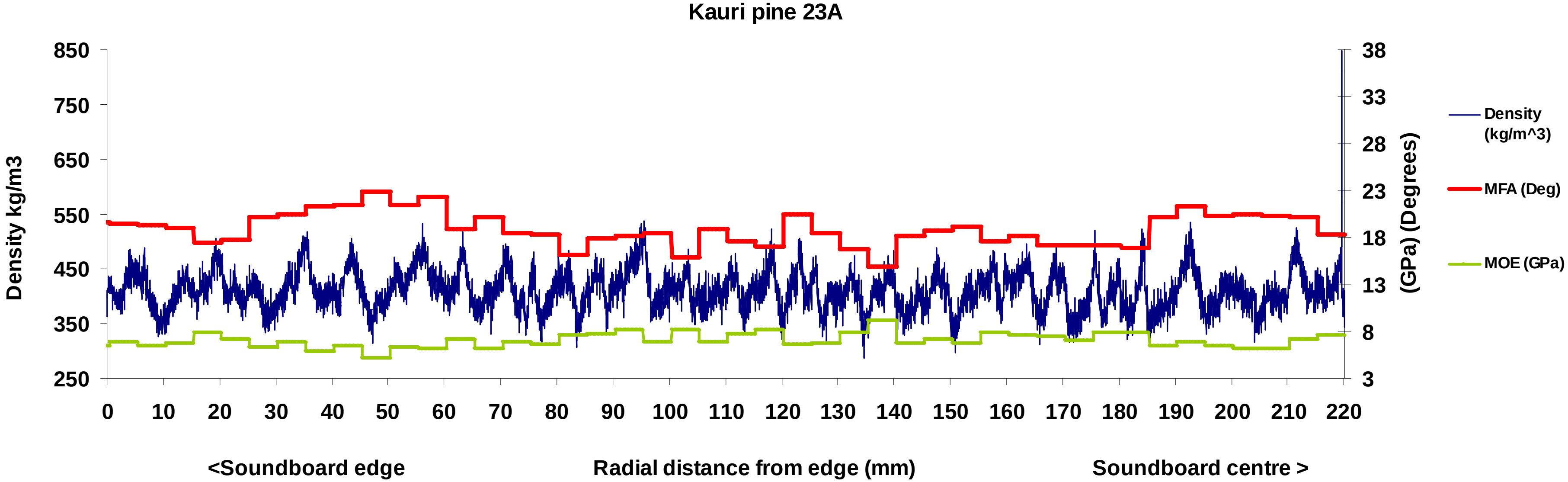
***Appendix 4*** Silviscan-derived wood properties and corresponding strip from soundboard half

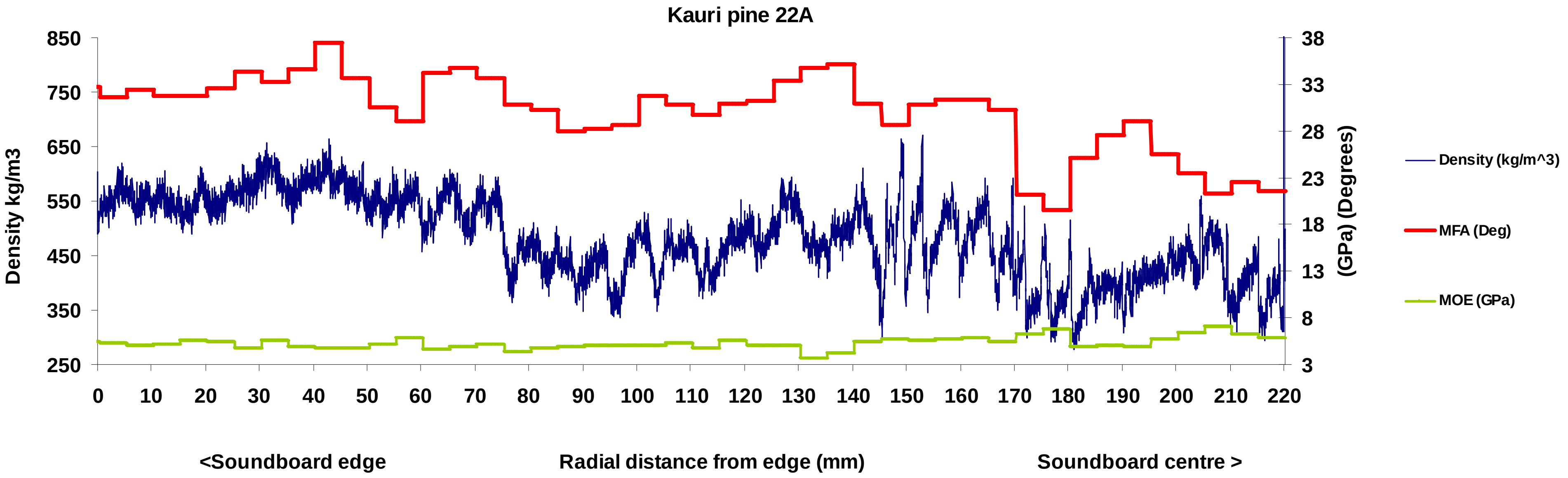
***Appendix 5*** Silviscan-derived wood properties and corresponding strip from soundboard half

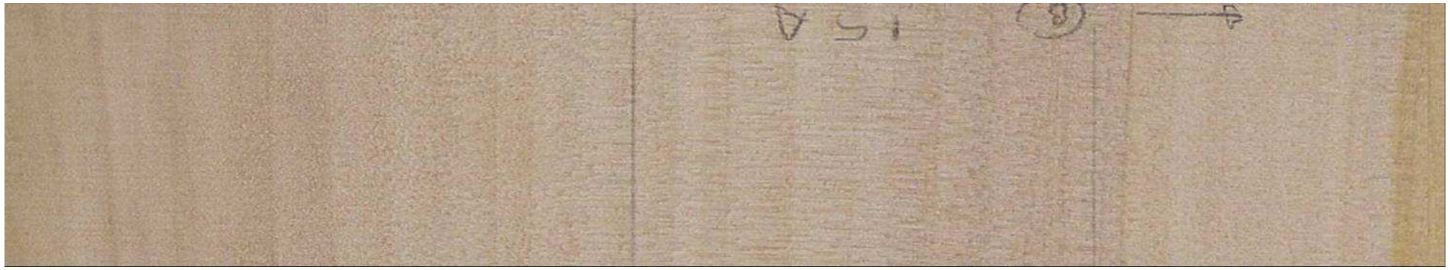
***Appendix 6*** Silviscan-derived wood properties and corresponding strip from soundboard half



***Appendix 7*** Silviscan-derived wood properties and corresponding strip from soundboard half



***Appendix 8*** Silviscan-derived wood properties and corresponding strip from soundboard half



**Kauri pine 15A**