REVIEW OF EUCALYPT WOOD PROCESSING ISSUES AUGUST 2016

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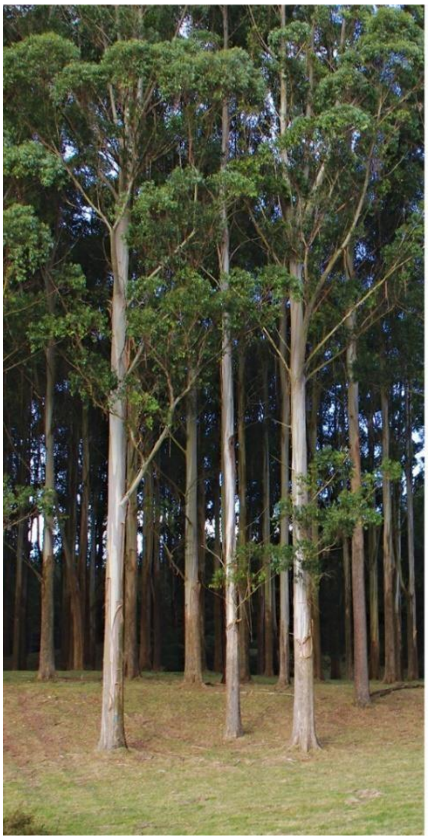

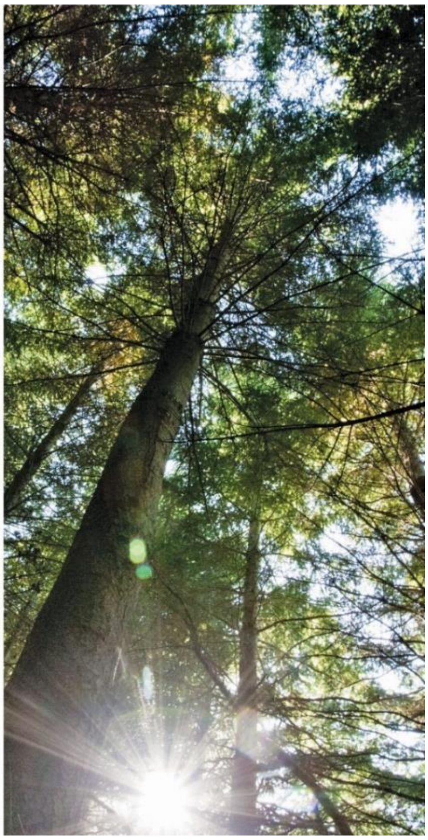

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EXECUTIVE SUMMARY

The vast majority of eucalypt plantations worldwide (at least 20 million ha) have been established as fast-growing exotic biomass forests for pulpwood and energy in tropical and sub-tropical environments and have been a major success in that regard.

The Australian hardwood industry was founded on the utilisation of eucalypts, and has now moved on from a long history of unseasoned utility timber to an industry aiming for higher-value sophisticated solid wood products for appearance and structural uses, since eucalypt forests can achieve high growth rates and the wood is known to potentially have superior performance characteristics for many applications. Almost any conventional sawing system can be applied to eucalypts provided there is an understanding of the material properties of the logs, but eucalyptus logs are undeniably more difficult to process economically, mainly due to the common presence of growth stresses, high wood shrinkage and associated internal defects. Nevertheless, it is possible to produce timber of high appearance and strength quality although economic yields cannot be guaranteed for various reasons.

Prior to about 2000, most conversion research on plantation eucalypts was ad hoc, without carefully considering production issues or market requirements. It has now been accepted that material properties should be carefully considered when planning all processing activities from felling and log-making to primary log breakdown, sawing and drying. Research scientist, Dr Russell Washusen (formerly a CSIRO world expert in eucalypt utilisation), has concluded that one of the biggest remaining challenges in processing young eucalypt plantations is the limitation of the adverse effects of growth stresses and shrinkage in both sawing and drying, and both must be carefully considered in any new enterprise.

Production lines that can be considered consist of frame-saw lines, double-arbor-multiple-circular sawlines, single to quad-band lines or even rotary veneer peeling for the production of laminated veneer lumber. The basic approach to sawing eucalypts in South America (where most eucalypt sawn timber is produced) is a twin saw unit and re-sawing the centre cant with a multi-saw. This basic principle applies over a very wide range of throughputs, from about 3,000 m^3/year to over 100,000 m^3/year. The larger mills use more sophisticated, faster equipment with more saws, such as quad band break-down units and combined optimisation technology. Modern technology may not be particularly well suited to the NZ situation where log supply is erratic at best. According to one of the most comprehensive reports on eucalypt processing, even technological advances such as scanning, sawing and drying methods, can clearly help to improve the efficiency and recovery levels, but cannot in themselves overcome material-related defects such as knots, grain deviation, shrinkage, tension wood and gum veins. To take full advantage of the potential of the eucalypts, it is necessary to understand the specific material characteristics of the species considered.

Conventional wood drying methods need to be altered from softwood schedules to provide greater control over the timber drying conditions, moisture content, and the effectiveness of re-conditioning treatments. Such control, coupled with improvements in sawing accuracy and sawmill efficiency, should improve product recovery and quality and reduce processing costs.

Eucalypts in general have a reputation of superior strength and stiffness and this has been confirmed in NZ studies. The reputation of some species for high in-ground durability, based mainly on testing of old natural forest material, has perhaps been exaggerated for plantation products (in fact treated radiata pine is superior in both above-ground and in-ground situations). Young material from the same species is unlikely to show the same level of heartwood development and resistance to decay as the old-growth on which many of the Australian durability classes are based. Those that have been shown to perform best in this regard are either absent or very scarce in NZ, due mainly inappropriate site conditions.

The eucalypt situation in NZ has been fluid, with several phases where groups of species have been recommended based on the evidence of small experimental plantings – often on farms and in shelterbelts. As elsewhere, NZ research has been heavily focussed on genetics, siting and silvicultural issues rather than wood processing techniques. After many studies in NZ during the 1980‘s, it was concluded that for solid wood products, emphasis should be given to the ash eucalypt group (*E. nitens*) as well as *E. saligna* and *E. botryoides*. Later on, more emphasis was given to the Stringybarks. However, few sawmillers have become thoroughly familiar with the specialised techniques required to successfully process eucalypts. For better success in the future, operators must be trained in these specialised techniques and this will be best achieved in specialist eucalypt processing plants with a consistent log supply. The fact that most of the eucalypt plantation resource is very varied, fragmented and not specifically grown for solid wood products, limits the chance of success.

One of the major current issues for New Zealand is that decisions regarding choice of genetic stock, siting and silviculture are often made by landowners, decades ahead of utilisation considerations without robust information on wood properties, technical behaviour, future market conditions, or appropriate processing technology. Australian researchers have stressed the importance of appropriate silvicultural treatments involving both thinning and pruning. On the other hand, a few small-scale NZ studies have confirmed that favourable results are possible in situations where good silviculture has been applied and sawing methods have been well researched and applied. However, the merchantability of other material unsuitable for sawmilling is likely to be critical to overall financial success. This is linked to silvicultural treatments which produce sufficient high grade pruned sawlogs, the acceptability of knotty timber from unpruned logs and the merchantability of thinnings.

Establishment of plantations aimed at solid wood products involves longer rotations, higher costs and greater biological and market risks than simply growing for pulpwood or energy crops. Several species show outstanding ground-durability properties, and fast growth rates, but there is often a trade-off in terms of susceptibility to pests and diseases. However, the profitable management of young eucalypt resources on an industrial scale has been elusive, and remains a major challenge for the wood processing industry around the world.

Some eucalypt species are reputed to exhibit very high in-ground durability, and this has become a sought-after property in order to limit the use of chemicals in wood processing for agricultural uses. While this sounds attractive, great care must be taken to verify the growth, health and durability of young material from selected species grown under NZ conditions. A robust long-term research strategy must be followed, including the establishment of “graveyard” trials in different environments.

There can be no doubt that eucalypt plantations are potentially capable of producing large stems with DBH to around 60 cm on relatively short rotation under good conditions, and the challenge is to process them profitably into a range of useful products. In some areas, the phenomenal growth rates recorded (e.g. up to 70 m^3/ha/annum) have helped the overall economics. However, eucalypt processing is a specialist skill, not to be taken lightly. Those undertaking it should ensure that the logs used have been well tended (thinned and pruned) and that they have read at least some of the voluminous literature from the more comprehensive research completed in Australia.

Developing a robust eucalypt processing industry requires a range of skills. Growers need to be aware of the best establishment, silviculture and harvesting techniques while processors should be aware of the behaviour characteristics of the species they are dealing with, including defect occurrence, growth stress development (significantly affecting conversion rates), and changing market requirements.

Value-chain R&D similar to past targeted efforts is essential to maintain progress.

EUCALYPT FORESTRY AND PLANTATION ISSUES

Eucalyptus species are endemic to Australia, but are now planted as exotics in many tropical and subtropical regions due to their fast growth rate, short rotation, high productivity and adaptability to a broad range of environments (Eldridge, et al., 1993; Harwood, 2011). The Eucalypt forest type as a whole is dominant across most of Australia's forest area, with a total of 92 million hectares (or 74% of Australia's forest area) - http://www.agriculture.gov.au/abares/forestsaustralia/profiles/eucalypt-forest. Eucalypt species are by far the continent's most common forest type, and occurring in all but the continent's driest regions. The term 'eucalypt' encompasses approximately 800 species in the three genera Eucalyptus, Corymbia and Angophora, with almost all of these species native to Australia.

Current plantations worldwide are dominated by the “big nine” species (*E. camaldulensis*, *E. grandis*, *E. tereticornis*, *E. globulus*, *E. nitens*, *E. urophylla*, *E. saligna*, *E. dunnii*, and *E. pellita*) and their hybrids), which together account for more than 90% of Eucalyptus planted forests.

Despite the success of eucalypts as plantation species (about 20 million ha worldwide, mainly for pulpwood or biomass), crop management is more complicated than with softwoods due to the fact that introduced species require localised management techniques and can succumb to pests and pathogens that may originate from their native or introduced environments (Gonçalves, et al., 2013; Withers, et al., 2015). Notwithstanding their promise, they have yet to prove to be a sustainable and profitable basis for a solid wood industry in Australia, South Africa or New Zealand (Harwood, 2010; Nolan, et al., 2005). In fact, hardwood production in Australasia has declined as softwood plantations have dominated (ANON, 2013). China and Brazil both have large areas of plantations, but volume production rates vary enormously (http://www.fao.org/docrep/005/ac772e/ac772e04.htm).

A large historic industry developed in Australia based on the harvest and processing of “old growth” native forests. This industry has been in transition in recent decades as the harvest of native forests significantly reduced due to land clearance for agriculture, forest protection, and replacement with productive softwood plantations. Eucalypt plantation areas have rapidly expanded since 1995 with the total now estimated at 0.98 M ha (most commonly Blue Gum - *Eucalyptus globulus*, Mountain Ash - *Eucalyptus regnans* and Shining Gum - *Eucalyptus nitens*) http://www.agriculture.gov.au/abares/forestsaustralia/profiles/industrial-plantations. The hardwood industry has moved from unseasoned timber to aiming for higher-value dried products for appearance and structural uses, since eucalypt is known to be capable superior performance characteristics (https://www.daf.qld.gov.au/forestry/using-wood-and-its-benefits/wood-propertiesof-timber-trees).

The subtropical eucalypt plantation estate in eastern Australia has developed over several periods of expansion and has now reached around 4500 ha (http://www.australia.gov.au/about-australia/australian-story/eucalypts). Before 1994, Australian state agencies, particularly Forests NSW, had established about 20,000 ha of mainly *Eucalyptus pilularis* and *E. grandis* on land previously under native forest in coastal areas with precipitation of more than 1,000 mm per annum. Much of this area is now going into second-rotation plantations, mainly of *E.* pilularis. Since 1996, state government agencies, particularly Tasmania (*Eucalyptus globulus* and *Eucalyptus nitens*) have established large areas primarily for solid-wood products, and more recently private companies have established large areas for pulpwood as well as for solid wood (Nichols, et al., 2010).

Some years ago eucalypt plantations were estimated to occupy up to 20 million ha worldwide (Flynn, 2010), with approximately 45% of the plantations in Asia (these figures change rapidly). First introduced in Brazil in the early 1900s as an alternative wood source, (*E. grandis, E. europhylla* and others) it become a prime non-native crop, with plantations taking up 4.7 million hectares, giving the nation the biggest share of world's total of 19.6 million hectares. India comes in second with 4.3 ha, followed by China with 2.6 ha. Currently, planted forests in Brazil total about 6.9million ha, from which 4.9million ha is planted with eucalypt (Gonçalves, et al., 2013).
Eucalyptus plantations in Brazil are among the most productive ecosystems in the world - typically producing more than 40 m3/ha/yr of wood. Brazil now produces just over a third of all the plantation-grown Eucalyptus sawlogs in the world (Acosta, 2008; Angelo, et al., 2015; Bradbury, 2010; Cubbage, et al., 2014). Plans are afoot to introduce genetically modified trees which can be harvested in 5.5 years instead of 7 years, and could well have implications for solid wood if accepted by environmental regulatory bodies (Ledford, 2014; Stape, et al., 2010).

However, according to some commentators these eucalypt plantations are destructive, "monoculture eucalyptus plantations cause a considerable loss of organic matter and increased acidity, associated to the alteration of the normal values, which leads to the spread of fungi that prevents water from penetrating the soil, causing surface runoff and soil erosion (http://www.justmeans.com/blogs/eucalyptus-in-brazil-wooing-investors-ignoring-science).

The total area planted to eucalypts in China alone in recent estimates was 1.8 M ha (Blundell, et al., 2013). South-Central China is expected to become a commercial forest base, but because of the difficulties in producing high quality timber, most will be used for pulpwood. A similar situation exists in Vietnam (Brown, et al., 2008).

Significant areas of fast-growing eucalypt plantations are now present to satisfy an increasing demand for wood - some established with the goal of yielding solid wood products on relatively short rotations (Stanturf, et al., 2013; Stape, et al., 2010). Compared to industrial eucalypt plantations for pulpwood, those managed for solid wood are at an earlier stage of development. This is related not only to current market maturity and size and the need to develop industries based on a "new" resource, but also the requirement to apply recently developed silvicultural and processing technologies (Baker, et al., 2006; Flynn, 2010). These are crucial issues that define economic viability, financial risk and certainty for investment in this sector (Carnegie, et al., 2005). Despite wide-spread planting in parts of Asia and Australia, South America is still expected to produce 55% of the world's Eucalyptus roundwood. Most of the Eucalyptus roundwood produced today is in South America (Acosta, 2008; Angelo, et al., 2015; Bradbury, 2010; Cubbage, et al., 2014).

Growing long-rotation plantation eucalypts for sawlogs is a recent goal in Australia, but is also currently being attempted to some extent in New Zealand, South America, South Africa, Spain and Portugal (Baker, et al., 2006; Carnegie, et al., 2005; Flynn, 2010; Stanturf, et al., 2013; Stape, et al., 2010). However, one Australian company apparently successfully processing young plantation eucalypts on a 14-15 year rotation has recently gone into receivership (2010) (http://renconforestry.com.au/sale-process-underway-for-forest-enterprises-australia-fea-assets/).

While the overwhelming majority of the plantation resource has been managed to produce either pulpwood or fuelwood, a number of companies, including some large multi-national companies, are changing their focus. Rather than targeting pulpwood or biomass as the objective, these companies are extending rotations, and pursuing aggressive management regimes including early thinnings and pruning, to produce higher value sawlogs with a maximum amount of clear wood (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, & Harwood, 2008; Brown, et al., 2008). In this paradigm, the pulpwood produced – in the form of thinnings or conversion residues - is a valuable by-product. Sawlogs make up only a small share of the total Eucalyptus harvest today - approximately 6 million m 3 of sawlogs in total. Of this, just over half are logs from native Eucalyptus forests in Australia, while the balance are from plantations worldwide. By 2015, the volume of sawlogs from native forests in Australia will be substantially smaller, but the total sawlog harvest will be nearly double the current amount. Of the total production in 2015, an estimated 1.4 million m 3 are expected to be pruned sawlogs (Flynn, 2010).

More than 80% of Tasmania's eucalypt plantations were established with the intention of producing pulpwood. At the relatively wide initial tree spacing used in plantations (compared to native forest regeneration), shining gum and blue gum trees develop large branches on the lower stem and retain them after the branches die. Without pruning and thinning, such plantation trees neither produce knot-free wood nor attain sufficient log diameter to produce wide sawn boards (Harwood, 2010; Nolan, et al., 2005). About 40 000 hectares (less than 20%) of Tasmania's eucalypt plantations are being grown under 'sawlog' regimes that include pruning and thinning, with the aim of producing large-diameter pruned, knot-free sawlogs (Wood, et al., 2009). The best 300 or so trees per hectare have their lower branches pruned in three successive lifts to a height of 6.4 m above ground during the first five years of the plantation's life, in order to provide a future sawlog. Pruning requires investment of more than $1000 per hectare early in the life of the plantation. In many species it is not possible to produce knot-free sawlogs by pruning at a later age because once the branches have died, the stem incorporates the dead branch-wood. Thinning the smaller and poorly-formed trees early in the life of a plantation enables the retained, pruned trees to grow more rapidly to produce knot-free 'clearwood' and reach the target sawlog diameter of at least 40 cm in 20–25 years. Solid wood yields of high grade products from unthinned and unpruned plantations have been poor (Nolan, et al., 2005).

Australian researchers have concluded that plantations should generally be established at around 1,000 spha to control weeds, improve early stem form, reduce branch size and allow for some selective thinning. This is particularly important for species such as E. nitens, which do not shed branches naturally (Beadle, et al., 2011). Pruning is also essential for solid wood appearance products, but it must be carried out on small live branches to prevent the introduction of pests and diseases (Montagu, et al., 2003; Wiseman, et al., 2006). Growers should be aware that thinning is one of the contributors to the development of tension wood (Wentzel-Vietheer, et al., 2013). There is a consensus that larger stems distribute growth stresses across a larger area and therefore reduce the impact, but there is as yet no agreement on optimum thinning schedules (Washusen, Harwood, et al., 2009). The economics of the required silviculture must be carefully evaluated (establishment, thinning, pruning, fertilisers, rotation length).

The eucalypts that grow in the cool moist montane forests of southeast Australia include a number of valuable timber species which will grow well in the cooler parts of New Zealand (Fry, 1983) These are mostly ash eucalypts, but *E. nitens*, a gum, is also in this category (Anon, 2001). Currently, there are around 12,000 ha of E. nitens plantation in Southland intended for biomass on a rotation of 15 years, but with some potential for solid wood processing (Suontama, et al., 2016). Overall, more than 100 species have been trialled, (mainly in the Gum, Ash and Stringybark botanical groups) but relatively few have been accepted as plantation prospects (Bunn, 1971, 1981; Kininmonth, et al., 1974b; Shelbourne, Nicholas, Hay, et al., 2003). State policy at one time set targets for specialty products and proposed using *E. delegatensis, E. fastigata*, *E. regnans*, *E. botryoides*, and *E. saligna* (Anon, 1981). This policy was abandoned after Forest Service re-structuring in 1987. In general, the Stringybarks are more amenable to sawing, but the Gums and Ashes present more problems, particularly during drying (Haslett, 1988d, 1988e; Haslett, 1990). An outline of some of the issues was given in an earlier review (Todoroki, 2012).

A great variety of Australian trees have been introduced into New Zealand, where many of them can be grown successfully, and some have become acclimatised and will regenerate naturally under certain conditions. Various Eucalyptus species have been popular, initially for shelterbelts and general farm use (Weston, 1957), and were subsequently planted in plantations, mainly for pulpwood, only to lose favour following serious mortality due to introduced pests (Fry, 1983). They ncluding E. globulus and E. nitens (until a biological control was introduced on Paropsis in 1989). In this genus of over 800 species, probably 50–100 could produce utilisable timber in some part of

New Zealand, but in reality, no more than 12–15 species are worth serious consideration, and in all cases species must be matched to site and vice versa because they are very site specific (Reid, 1957). An interest in short-fibre was revived in the 1960's, mainly by NZ Forest products (Shelbourne, et al., 2006).

Unfortunately, there is a permanent biological threat with eucalypts. Australian insects have had a big impact on the value of eucalypts as plantation and amenity trees in that country, and they have been arriving in New Zealand for approximately 150 years. New Zealand lies 1800 km down-wind to the east of Australia, and trade and travel is frequent between the countries, creating a high biosecurity risk (Kay, 2005). This is also the case in other countries planting eucalypts as exotics (Lorentz, et al., 2015). Early plantings (pre 1900) enjoyed relative freedom from insect pests, but the rate of establishment of new arrivals into New Zealand from Australia increased steadily during the 20th century. At the peak of invasions in the 1990s, one new eucalypt specialist established every 17 months. There are now over 30 specialist eucalypt insect pests in New Zealand, about a third of which have caused serious damage (Withers, 2001). Biological control against eucalypt insects started in 1905 and has been extremely successful, with four out of five targeted species under full control. A number of self-established species have also provided control. Over time, various Symphyomyrtus group eucalypt species have gone out of favour with growers as new pest introductions discover this resource. A number of species have suffered biological setbacks from time to time (e.g. *E. globulus*, *E. nitens*) as introduced pests and diseases discover preferable hosts (Berndt, 2010).

During the late 1970s and 1980s eucalypts grown for sawn timber in NZ were confined mainly to three ash species (*Eucalyptus fastigata*, *E. delegatensis*, *E. regnans*), and two gums species, (*E. botryoides* and *E. saligna*). Except for *E. fastigata*, these species have since proven to be largely unsuitable for solid wood, because they are either difficult to saw, have sub-standard wood properties, or there are serious issues with crop health. Latterly, results indicated that some stringybarks (*E. microcorys* and *E. pilularis*) can grow well in New Zealand across a wide range of sites, although site-species matching is critical (Shelbourne, 2009). Growth rate per se may not be a crucial issue, as stringybarks have better sawing characteristics than species from other eucalypt groups. An upbeat analysis of the future prospects for eucalypts for specialty markets was given by Nicholas, et al., 2007, but it would be dependent on a significant breeding effort to identify "élite" genotypes based on early corewood assessments (Apiolaza, et al., 2009).

In any region, careful species choice is necessary due to the limitations imposed on individual species by frost, differing moisture regimes and complex weather and soil variations. Species-site matching is further complicated by pest and disease problems in the major species that often are first evident where species are not ideally sited. Several pest and disease problems have become evident only after establishment in plantations - even healthy plantations require careful siting and silviculture (including rotation length) to ensure compatibility with prospective markets (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, & Harwood, 2008; De Moraes Gonçalves, et al., 2004; Washusen, Reeves, et al., 2004; Wood, et al., 2009).

While it is agreed that plantation wood differs considerably from that from natural forests (de Fégely, 2001; Volker, 2005), studies have shown that thinning intensity in itself has only a small impact on processing potential (Washusen, Harwood, et al., 2009).

An excerpt from NZ wood (http://www.nzwood.co.nz/forestry-2/eucalypts/) is as follows:
"New Zealand has 28575 hectares planted in eucalypts, with a median age less than 10 years. Approximately 7.5% is of millable age. Eucalypts are exceptionally fast-growing, with timber grown in New Zealand to 30 years age similar to much older material from Australia. Most of the harvestable timber available at present is located in the Central North Island, although small quantities are also available in Northland and Auckland regions. Significant plantings of young

Eucalypt trees have been made in the past five years in the Otago and Southland regions, and also the Central North Island.

The eucalypt species grown in New Zealand are grouped as follows for simplicity because of their wood similarities:
The Eastern Blue Gum group: *E saligna and E. botryoides*
The Stringybark group: *E. muelleriana*, *E. globoidea*, *E. eugenoides*, *E. microcorys*, *E. pilularis*. The Ash group: *E. delegatensis*, *E. fastigata*, *E. regnans*, *E. obliqua*."

To grow these eucalypts in New Zealand with good even diameter growth to a size suitable for milling or veneering, final crop stockings should be around 100/ha, perhaps a few more where sawn timber is the main aim (*E. fastigata, E. obliqua*) and a few less where veneer is the goal (*E. nitens*, *E. regnans*, *E. delegatensis*). Species and provenances with naturally good form require a selection ratio of about 3:1, but others require a selection ratio of at least 4 or 5:1 to get a satisfactory final crop. Bearing in mind that low initial stockings will result in shorter branchy trees, initial planting rates are usually 400 to 1,000sph (Anon, 2001; Cassidy, et al., 2013; Jones, et al., 2010; Revell, 1981).

Although some of these eucalypt species will shed some of their smaller horizontal branches naturally, larger and more steeply angled branches will need to be pruned if the aim is to produce veneer logs or long clear lengths of lumber. For high quality solid wood or veneer, a strict thinning and pruning schedule is vital (Forrester, Collopy, et al., 2013; Gerrand, et al., 1997; Peng, et al., 2015; Reid, et al., 2014; Roper, et al., 2000; Washusen, 2011; Washusen, Northway, et al., 2009). Pruning should be done at the driest time of the year – mid to late summer – and should not exceed half the tree height if growth is not to be too greatly affected. Over-pruning will result in adventitious shoots sprouting later from the pruning wounds. Thinning is critical, and should be carried out before crowns touch if diameter growth is to be maximised. As there is little evidence of a market for thinnings, except as firewood or pulp chips, trees should be removed as soon as it is evident that they will not form part of, or have a beneficial influence on, the final crop.

Establishment of plantations aimed at solid wood products involves longer rotations, higher costs and greater biological risks than growing pulpwood or energy crops (Berndt, 2010; Dungey, et al., 2002; Withers, 2001).

Yields of high-quality logs (those with high recoveries of appearance grade material) in unpruned stands are low (Peng, et al., 2015; Washusen, 2002; Washusen, Menz, et al., 2004; Washusen, 2008b; Washusen, Reeves, et al., 2004), and dependent on good silviculture (Bravo, et al., 2012; Brennan, et al., 2004; Chikumbo, et al., 2011). Silvicultural considerations include:

- Species selection
- Spacing limitations based on planting costs, merchantability and windthrow
- Exposure to pathogens
- Low recovery of appearance grades from unpruned logs
- Variable occlusion of branch stubs
- Development of tension wood due to stem instability
- Kino vein problems
- Brittleheart
- Risk of decay entering from pruning and thinning damage

There is a wealth of evidence for genetic variation in commercial solid timber characteristics of eucalypts
(Apiolaza, et al., 2005; Blackburn, et al., 2012; Blackburn, et al., 2010; De Pádua, et al., 2004;

Hung, et al., 2015; Kennedy, et al., 2012; Raymond, 2002; Shelbourne, et al., 2002; Silva, et al., 2009), all of which indicates that significant improvements can potentially be achieved over time through targeted breeding.

In any plantation estate, several eucalypt species are often required to fully utilise the available land due to the limitations imposed on individual species by frost, differing moisture regimes and complex soil landscapes. Species-site matching is further complicated by pest and disease issues in the major species that often are first evident where species are introduced or not ideally located. Several pest and disease problems have become evident only since the widespread planting of major species in plantations and were apparently present only at low levels in the native populations of these endemic species.

In New Zealand, growers have found that despite the large numbers of eucalypt pest introductions, eucalypts in the Monocalyptus subgenus have remained relatively pest free while thos in the Symphyomyrtus subgenus have been palatable to pest introductions (Health issues with eucalypts, New Zealand Tree Grower November 2006, Denis Hocking)

Some subtropical species can produce trees having excellent wood properties, but the quality of timber from native forest trees and plantation-grown trees differs greatly (Sheild, 2003) and much work remains to be done to define optimum rotation lengths and management regimes.
Localised silvicultural and breeding strategies have been developed to improve performance (Baillères, et al., 2002; Beltrame, de Peres, Delucis, et al., 2015; Blackburn, et al., 2012; Blackburn, et al., 2010; Blackburn, et al., 2013; Candy, et al., 1997; Cassidy, et al., 2013; De Moraes Gonsalves, et al.,
2004; Ferraz Filho, et al., 2014; Malan, et al., 1992; Nichols, et al., 2010; Pelletier, et al., 2008; Raymond, et al., 2004; Raymond, 2002; Revell, 1981; Schönau, et al., 1989; Stovold, et al., 2009; Washusen, Northway, et al., 2009; Wood, et al., 2006; Wu, et al., 2011).

Many countries plant eucalypts as exotics to breech an anticipated wood shortage in the short term, however there are many significant issues involved, such as siting, establishment, species selection (provenance, clone), silviculture, rotation age, monitoring health. However, even if plantations are successfully established and nurtured to maturity, there remains the major issue of utilisation. This is particularly relevant for solid wood uses (sawn timber, veneer and composite products.

Given the potential for both pulpwood and sawlogs, it should be possible to supply both from well-managed plantations (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, Harwood, et al., 2008; Brown, et al., 2008; Nichols, et al., 2010; Wardlaw, et al., 2003).

One of the recurring issues in eucalypt exotic forest management is the frequently shifting species priority, with the result that research tends to be fragmented, subject to changing fashion.
As recently as 1988 a review suggested that hardly any Australian tree species had yet proved to be a significant economic success in New Zealand (Wilcox, et al., 1988) but would very likely be planted by enthusiasts, despite the threat of possible devastating introductions of new insects (Nicholas, et al., 1992). This means that from a solid wood point of view, the material processed has been opportunistic, is based on availability, rather than targeted stands, leading to sub-optimal results (McKenzie, 1999). Australian authors have attributed the lack of success in developing an industry to insufficient volume available, discontinuity of supply, trees too immature, wrong species, lack of targeted silviculture, and unfamiliarity to sawmillers (Candy, et al., 1997).

Solid timber from eucalypt species grown and processed in Northland is marketed throughout New Zealand and exported to Australia. (D. Satchell, pers. Comm). The primary species (*E. pilularis* and *E. saligna*) produce wood of higher density and durability than the cold climate Ash species, however.

With a new era in carbon and bioenergy forestry on the horizon, fast growing eucalypts are gaining favour in some quarters, potentially opening a new resource to Australian pests in New Zealand (Berndt, 2010; Dick, et al., 2004; Withers, et al., 2015). It is also possible that invasive organisms can originate from all over the world due to increased trade (Nahrung, et al., 2016).

EUCALYPTS FOR SOLID WOOD PRODUCTS

In the past many species of eucalypts were planted in New Zealand, initially to provide shelter and for amenity purposes and provision of naturally durable timber (Fry, 1983; Reid, 1957), and later still for pulp, paper and solid wood (https://www.nzgeo.com/stories/eucalypts-trees-of-the-future/). In New Zealand, indigenous and imported hardwoods have been used to meet the demand for clearwood suitable for purposes such as high-quality furniture, joinery, and decorative veneers. However, because of a dramatic reduction in the volume of indigenous forest felled, and significant increases in the price of imported timbers, exotic sources of special-purpose timbers such as eucalypts are now being sought. More recently, the case was often made for a resource of specialty timbers, including furniture, cabinet work, turnery, sliced veneer production, interior joinery and/or exterior joinery and cladding, as well as composite products such as laminated veneer lumber (Dungey, et al., 2013a; Hay, et al., 2005). Early research had identified some of the issues (Barr, 1971; Hay, et al., 1984; Revell, 1976). However, overall, insufficient care and attention was paid to the species choice, site selection and preparation, the provision of good quality nursery stock, and establishment practices, so only a few of these early plantings yielded much saleable timber. This unfortunate experience does not mean that eucalypts cannot be grown well in this country, as selected species, appropriately grown and managed, can produce shortfibred pulp for the manufacture of fine papers and some high-grade clear timber suitable for furniture, interior joinery, and other special end-uses such as those requiring natural durability (Haslett, 1990; Revell, 1982; Satchell, 2015b, 2016; Satchell, et al., 2010a).

<u>However, the establishment of a crop is not itself sufficient to guarantee success and plantation wood differs from wood from natural forests in several important respects:</u>

- Younger and even-aged logs
- Potential of high value from pruned butt logs
- Greater volume of corewood and lower wood density
- Less radial gradient in growth stresses
- More prone to internal checking and collapse

One of the primary commercial uses of eucalypts worldwide is as a source of pulpwood wood (Arnold, et al., 2013; Hamilton, et al., 2015; McGavin, et al., 2015; McGavin, et al., 2014)., but efforts to create industries around solid wood from plantations have had highly variable results (de Fégely, 2004; Harwood, 2010). The reasons for this are related to species characteristics and silvicultural management: many species have high wood density, and good hardness and stiffness as well as even colour and texture. However, they also have high variability in most important properties (Beltrame, de Peres, Delucis, et al., 2015; Eleotério, et al., 2015; Loulidi, et al., 2012; Sharma, et al., 2015; Wu, et al., 2013; Wu, et al., 2012). The FRI/Industry Cooperative "Management of Eucalypts" undertook a large body of work during the 1990's and early 2000's, focusing mainly on breeding, silvicultural and siting issues (Stovold, et al., 2009), but also recognised issues with "corewood" comprising the knotty core – with growth stress, collapse, decay, kino and brittleheart – all of which impact on grade recovery (Ananías, et al., 2014; Blakemore, et al., 2008; Haslett, et al., 1997a; Ilic, et al., 1986; Nicholas, 1992; Pinkard, et al., 2004; Wadlaw, et al., 1999; Warren, et al., 2009). In fact, collapse on drying (Ilic, et al., 1986) is so severe in certain species of the ash group with low wood density that their viability as commercial timber producers has been questioned (Harris, et al., 1987).

Australian researchers in particular have found that untended stands planted for biomass are generally unsuitable for high sawmill recoveries and good appearance timber grades (Blakemore, Morrow, Ngo, et al., 2010; Brown, et al., 2008; de Fégely, 2004; Harwood, 2010; Washusen, 2008a, 2013b).

Eucalypts have been milled from natural forests for a long time by conventional means, and processors have learned by experience how to deal with the characteristics of the particular species (degree of shrinkage, growth stress, collapse, internal checking, gum veins and knots). Eucalypt species come in a great variety of species, most of them with unique crown or log features which necessitate prior knowledge for successful processing (Ananías, et al., 2014; Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, Harwood, et al., 2008; Blakemore, Morrow, Ngo, et al., 2010; Blakemore, Morrow, Washusen, et al., 2010; Blakemore, et al., 2009b; de Fégely, 2004; Nolan, et al., 2005; Rebolledo, et al., 2013; Shelbourne, Nicholas, McKinley, et al., 2003; Washusen & Innes, 2008). Differential shrinkage and collapse are inherent properties of some cold-climate low-density eucalypt timbers and shrinkage varies markedly between eucalypt species (Blakemore, et al., 2009b; Campbell, et al., 1978; Vermaas, 1995). Normal shrinkage is not affected to any great extent by drying conditions, but collapse shrinkage (above the fibre saturation point - FSP) is greatly affected by drying rate and can cause serious degrade in some species (Ananías, et al., 2014; Ilic, et al., 1986; Innes, 1996; Peng, et al., 2015; Rezende, et al., 2015). "Gross shrinkage" describes the combined effect of the combined effect of normal shrinkage and collapse shrinkage. Until recently, many Australian sawmillers considered fast-grown plantation eucalypts to be too hard to process on account of the prevalence of growth stresses (de Fégely, 2004; Wardlaw, et al., 2003; Waugh, et al., 2002). Some of the manifestations and effects on sawing of stresses and other internal defects have been documented in many reports.

As with other species, hardwood wood stiffness is determined by a combination of wood density, microfibril angle (MFA) and spiral grain. Overall, wood density seems to be the predictor of the likely strength performance (Yang & Evans, 2003). The wood density levels shown by the eucalypts in general are significantly higher than most softwoods (http://www.csudh.edu/oliver/chemdata/woods.htm). The potential is therefore for much stiffer and stronger products (Walker, et al., 2011). Values of both density and MFA increase with distance from the pith, so stem age or growth rate/silvicultural regime also is a factor in determining if the inner young wood is adequate to meet requirements. With most eucalypts this is easily the case, (McKinley, et al., 2000) but in NZ, E. nitens is an exception with some very low wood density values close to the pith in the “corewood” or juvenile wood region (350 - 400 kg/m3) showing lower log and stem value than most other species (Haslett, 1988d; McKinley, et al., 2003). Nevertheless, studies have confirmed that laminated lumber from young 15 year old *E. nitens* buttlogs was superior to radiata pine (Gaunt, et al., 2002). Veneer from the heavily branched, unpruned second logs of fifteen-year old *E. nitens* was also successfully manufactured into LVL. Although visual grading indicated that most of the veneer was not suitable for construction plywood, it produced LVL with high stiffness and extremely high strength achieving MGP12 or F17 as limited by stiffness.

One of the unique wood features of hardwoods in general - tension wood - is similar but more insidious than compression wood in softwoods because it can result in non-recoverable collapse (Lausberg, et al., 1996; Washusen, 2002; Washusen, Ades, et al., 2002; Yuniarti, et al., 2015).

Much research has been carried out over the years on specific species and site conditions and it goes without saying that good results are very dependent on species, silviculture and local knowledge (Satchell, 2006; Washusen, 2002). These latter results were in contrast to the issues with 15-year old nitens documented by Scion researchers only a few years earlier, where log end-splitting and variable recoveries were serious drawbacks for both timber and veneer (McKenzie, et al., 2002). It has been suggested that the inclusion of eucalypt veneers alongside radiata pine would significantly enhance product stiffness (Gaunt, et al., 2002). A separate review is being done on eucalypt for veneer and composite products (Gaunt, pers. comm.).

Natural durability of eucalypt wood is highly variable, depending on species, wood age and tree-to-tree variability (McCarthy, et al., 2009). This review does not specifically cover wood durability, but some comments are to be found in Appendix 2 – Wood Durability Issues.

A tremendous amount of research has been done in Australia in particular to examine the solid wood potential of plantation eucalypts (Nolan, et al., 2005; Reid, et al., 2014), but it is only over the past 10 years or so that systematic studies have been undertaken in full knowledge of the technological and of market requirements (Washusen, 2011). Even so, detractors have suggested that a viable industry is unlikely to develop (de Fégely, 2004). It is true to say that most early sawing studies (prior to about 2000) could best be described as exploratory (Washusen, 2013b).

Better understanding of the variability in wood characteristics within and between logs and timber has led to suggestions of segregating material before or during processing to ensure greater uniformity in the production and avoidance of logs below minimum specifications (Dickson, et al., 2003; Garcia, et al., 2010; Meder, et al., 2010; Warren, et al., 2009). It is worth noting that while techniques are being developed to estimate the mechanical properties of logs, they give little indication of stress levels or internal appearance properties (Washusen, Morrow, et al., 2008) – factors that can make or break the economics of processing.

One of the most comprehensive reports on adding value to Eucalypts concludes that Australia still "does not currently have a solid wood products industry that profitably processes plantation eucalypts" (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, & Harwood, 2008). This is a very significant statement, and should be compulsory reading for owners of eucalyptus plantations. Many CSIRO and Co-operative Research Centre reports deal specifically with sawing and drying eucalypts for high value wood products (Redman, 2008; Washusen, 2016; Washusen, Harwood, et al., 2009; Washusen, 2008b; Washusen, Northway, et al., 2009).

A recent Australian study (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, Harwood, et al., 2008) concluded "Since 1988, there has been a major focus in Tasmania on research for the management of temperate eucalypt plantations for solid wood. This coincided with the formal transfer of large areas of native forest that had previously been part of the production forest estate into reserves, a decision that triggered the establishment of eucalypt plantations for solid wood". The study summarised research on several key areas: silvicultural requirements for solid-wood production; wood properties of plantation-grown eucalypts and the influence of silviculture and genetics on these properties; factors influencing stem defect and decay; balancing silvicultural requirements with maintenance of tree vigour; and issues concerning wood processing and products. They concluded that there are still significant operational challenges to be confronted in the production of solid wood from plantations. There is widespread consensus that the single most serious issue is the development of growth stresses in trees and logs and the consequent impact on log handling and processing (Biechele, et al., 2009; Brown, et al., 2008; Chafe, 1979; Omonte, et al., 2015; Severo, et al., 2010; Trugilho, et al., 2008; Yang, et al., 2004; Yang, et al., 2001). If these can be overcome in the medium term, temperate plantation eucalypts have the potential to provide wood products that meet the requirements for appearance-grade material and that can compete in the same markets as wood from native forests. The bigger challenge at the national level will be to provide the log volumes of suitable material to meet the anticipated demand 25 to 30 years from now.

A persuasive argument has been made to encourage the use of eucalypts in NZ on that basis that they can produce useful wood on much shorter rotations (12-18 years) than softwoods without the deleterious effects of corewood (Walker, 2013). However, as pointed out in this review, there are many other issues with tree growth and wood performance which have to be carefully considered when dealing with eucalypts.

The most comprehensive NZ information on handling eucalypts was collated some years ago (Haslett, 1987; Haslett, 1988a; Haslett, 1989; Haslett, 1990; Haslett, Kininmomth, et al., 1984), but tends to concentrate on older material, similar to the Australian old-growth. A more recent approach was take for evaluation of E nitens, well-tended on a productive site at 15 years of age, using best-practice sawing to produce floorboards (Satchell, 2016). Good recoveries were reported, with only about 15% loss due to defect removal, and economic estimates gave moderate financial recovery. This is perhaps the most relevant NZ eucalypt sawing study to date.

The indications are that almost any species in NZ will potentially yield strong veneers (Farrell, et al., 2008; Hague, 2013; Hamilton, et al., 2015). The limiting factors for commercial success are likely to be plantation growth rates and health, recovery losses due to stresses, collapse, shrinkage and defects, rather than the intrinsic stiffness of the wood.

Sawmill equipment

Historically the Australian timber resource has been dominated by larger diameter mature and over-mature trees, which provided the sawmilling industry with high quality feedstock. During processing of large, old-growth logs, sawmills had to deal with some losses from growth stress release, but the timber was largely slowly air-dried, had excellent woodworking properties, dried well with limited degrade, and machined and worked well.

Fig. 1 *Eucalypt Old Growth log (Leech, 2008)*

Large-dimension logs represent a decreasing proportion of current supply, pricing for timber from these logs is not substantially differentiated from pricing for timber from smaller logs (Leech, 2008). Properties of timber from large-dimension logs cannot be distinguished clearly from those of timber from other logs. However, they are purported to include improved stability, hardness, appearance and overall recovery and a higher percentage of wide, thick and long boards. The industry was primarily focussed on producing construction grade material for the local and national building market. Competition from framing grade Pinus radiata kiln-dried timber has seen to drive a refocus of the sawn eucalypt output to kiln-dried appearance grade products.

As younger and smaller-diameter resources became available and kiln drying increased the consequences of growth stress release became much more significant. While it is debatable as to whether the stresses are higher in these younger plantations as resource age and diameter declines, the radial gradient in stresses clearly increases in younger trees. Reported recoveries in plantation vary significantly, according to species, the equipment used and to growth stresses and a variety natural defects (Blakemore, Morrow, Ngo, et al., 2010; Blakemore, Morrow, Washusen, et al., 2010; de Fégely, 2004; Haslett, 1988b; Innes, et al., 2008a; Jones, et al., 2010; Washusen, 2013b; Waugh, et al., 1991). Sawmilling equipment has consequently been modified to improve sawing accuracy and to better control growth stress release (Blackwell, et al., 2006). For example, the 'line-bar' carriage and log turning devices, and twin-saw and multi-saw systems, have gradually become more common over recent decades. These modifications no doubt improved sawing accuracy and have assisted in the control of stress release by applying more symmetrical cutting patterns. Sawing methods are still being modified as the characteristics of plantations change (Satchell, et al., 2010b). High longitudinal growth stresses, particularly in small (>30cm) diameter eucalypts lead to end splitting of logs, flitches, slabs and boards, distortion in final products and variable product thickness, all of which reduce product recovery, product value and processing efficiencies (De Lima, et al., 2002; Okuyama, et al., 2004; Peng, et al., 2015; Vega, et al., 2016). In many cases sawmills will cut oversized boards and slabs to ensure acceptable final sizing after drying, but this also reduces recoveries and mill efficiency substantially, particularly in small diameter logs (Blundell, et al., 2013; Washusen & Innes, 2008). Drying from green and kiln drying thicknesses over 20mm have proven uneconomic.

Processing solid wood from young eucalypt resources remains a major challenge for the wood processing industry around the world (de Fégely, 2004; Washusen & Innes, 2008). The largest volume being sawn is in South America (Flynn, 2010), mainly using the twin saw and centre cant multi saw system and works well. Eucalypts are also sawn in many southern African and Mediterranean countries. In Asia, eucalypts are mainly peeled for structural veneer products.

As in Australia, processing plantation eucalypts in New Zealand with conventional saws has given variable results (Haslett, 1987; Haslett, 1988a, 1988c; Haslett, 1988d; Haslett, Kininmomth, et al., 1984; Jones, et al., 2010; Kininmonth, et al., 1974a; McConnochie & Low, 2007; McKenzie, Turner, et al., 2003b; McKenzie, 2000; Revell, 1976; Shelbourne, et al., 2001). Many of the processed logs came from untended stands and were not representative of the potential resource (Revell, 1981). Some years ago it was pointed out that New Zealand, sawmills did not have the most appropriate equipment or training to deal with eucalypts (Haslett, 1988e). This is still largely the case today, despite the intention of converting younger stands to superior products. Few serious attempts have been made to incorporate the knowledge gained by Australian researchers, and both the number of specialist sawmills and well-designed research sawing studies has diminished dramatically (Satchell, 2015b).

The results of surveys indicate that traditional sawmills in general are poorly equipped to handle plantation grown eucalypts and have used much the same equipment as for natural forest logs, albeit with the addition of a line-bar to reduce distortion and variation in sizing (Washusen, 2013b). This situation is probably widespread – for instance (Washusen & Innes, 2008) had pointed out that "in Australia, Vietnam and China most of the existing sawmilling equipment is probably inadequate for this purpose”. Washusen, Morrow, et al., 2008, used contemporary technology (twin bandsaw and twin blade edger) but conventional natural-growth eucalypt drying methods on plantation *E. nitens* which resulted in good sawn timber recoveries but poor dry product grade recoveries. The same situation applies in New Zealand (Haslett, 1988e; Todoroki, 2012) where there have been no speciality eucalypt sawmills built, at least partly on account of the small, varied and unpredictable resource.

The optimum sawing strategy adopted (Fig. 2) will depend on species, log size and the desired product mix, but of course it is often in practice limited by available sawing equipment. For larger logs quarter-sawing seems to be the preferred option for appearance grade products (Nolan, et al., 2005). It should be noted that the choice of sawing strategy affects the principle grain orientation of boards and hence the shrinkage and checking behaviour (Washusen, Morrow, et al., 2008).

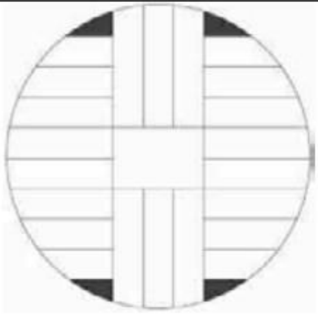
Quarter sawing strategy

Recovery: >40 cm SED moderate-high; <40 cm SED low-moderate.

Advantages: Surface checking and internal checking is minor in collapse prone species. Can produce thicker boards. Low shrinkage across face of the boards.

Disadvantages: Greater losses due to growth stress related distortion in small diameter logs. Drying times longer.

Relative cost: High in small diameter logs.



Back sawing strategy

Recovery: >40 cm SED moderate-high; <40 cm SED moderate-high.

Advantages: Produces wider boards than quarter sawing. Potentially faster log throughput and lower sawing costs.

Disadvantages: Drying degrade can be high in many eucalypt species. High shrinkage across face of board in some species.

Relative cost: Low in all diameter classes, very low in high throughput systems.

Figure shows log breakdown strategy for 45 cm SED log on twin saw equipped with chippers.

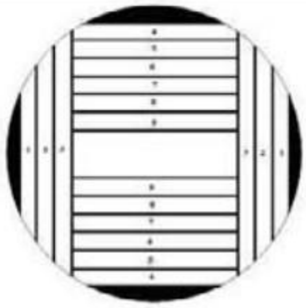


Fig. 2a: *Main Eucalypt Sawing Strategies Nolan (et al.) 2015*

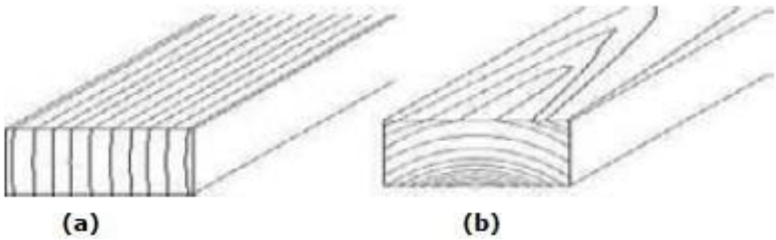


Fig. 2b: *Typical Boards from Sawing Patterns in Fig. 1a*

A relatively new and untested concept is Radial Sawing (Fig. 2c). This produces a wide range in widths of flat-sawn boards, which can be prone to surface checking.

Radial sawing strategy

Recovery: Very high recovery of radial sawn wedges and high recovery of back sawn boards.

Advantages: For back sawn boards evidence suggests higher recoveries of non-conventional bevelled products than conventional sawing.

Disadvantages: Prototype system has slow throughput. However, there is potential for technical improvement. The pattern illustrated produces high volume of narrow boards suitable from a restricted range of applications.

Relative cost: Uncertain.

Figure adapted from Radial Timber Australia brochure

Fig. 2c: *Radial Sawing*

With quarter sawn timber, the growth rings are predominantly parallel to the short face. The long face of every board is close to a radial face so a large number of growth rings can be seen on this face. Quarter-sawing timber is best for hardwood species that are prone to collapse during drying. Quarter sawn timber has the following advantages: Best grain shows on face

- Good wearing surface for floors, furniture
- Radial face preferred for coatings
- Lower width shrinkage on drying Less cupping and warp than other cuts Can be successfully reconditioned.

Back-sawing is the simplest and most common sawing method used for eucalypts in Australia and tends to yield high-grade timber from logs. Most structural timber and many appearance products are backsawn. With backsawn timber, the long face of each board is close to a tangential face, and the short face is close to a radial face. Growth rings are parallel to the long edge and the wide face does not intersect many growth rings. The growth rings on the wide face appear to be appear wide apart. This approach offers more flexibility in that large boards can be backsawn from the centre of the log, where the board width can be around the diameter of the log.

Back sawn timber has the following advantages:

- Seasons more rapidly
- Good figure on face
- Less prone to splitting when nailing Wide sections possible Few knots on edge. Less crook (spring) in boards

The disadvantages of back sawn timber include:

- Shrink more across width when drying
- More likely to warp and cup
- Collapsed timber more difficult to recondition.

Back-sawing vs. quarter-sawing is partly theoretical as log taper and ring patterns ensure a lot of variation in the grain orientation of individual boards.

Radial sawing is not very common, but has an efficiency that the other cuts cannot achieve, and makes optimal use of a log. Because of the cutting pattern, each piece of radially sawn timber is a wedge shape. It has sapwood on the wider edge and pith or corewood at the point. As real logs are not perfectly round and not perfectly straight, each radially sawn board reflects the longitudinal shape of the log. These details can make for interesting architectural use of the timber. Apart from flooring, radial sawn timber is used mainly for external applications such as cladding, decking, poles, wedges and timber screens. Radially sawn timber has the following advantages:

- Dimensional stability
    - Less prone to warping, cupping Less wastage in milling.

The disadvantages of radial sawn timber include:

- Wedge shaped cross section
- More difficult to detail
- More difficult to stack.

The success of sawing strategies is highly dependent on the levels of growth stresses present (Nolan, et al., 2005; Redman, et al., 2016). Slowing the drying rate of logs reduces defects such as internal checking, collapse, case hardening and surface checking. However, if the timber is dried too slowly sapstain and mould growth can discolour the timber. The thicker the timber, the longer the drying time, and the more difficult it is to dry without degrade. Internal checking is much more likely as thickness increases with higher shrinkage hardwoods. Where internal checking takes place ripping the timber to smaller sizes results in significant surface checking degrade (http://www.nzffa.org.nz/specialtyhttp://www.nzffa.org.nz/specialty-timber-market/information-resources/drying/drying-hardwoods/timber-market/information-resources/drying/drying-hardwoods/). This section timber (12mm nominal) has been found to dry with little collapse and checking degrade.

Research scientists, Dr Russell Washusen and Gary Waugh (pers. comm.) maintain that the biggest challenges of processing young eucalypt plantations are trying to limit the adverse effects of growth stress release and internal defects such as log end splits, collapse, knots, and gum veins. Other scientists agree (Yang, et al., 2004; Yuniarti, et al., 2015). The prevalence of grade-reducing defects can vary widely between species, silvicultural regime and processing methods (Satchell, et al., 2010a; Temel, et al., 2000). Reducing controllable effects such as log and board end-splitting, board distortion and poor sizing accuracy, can enhance economic production of sawn timber (Vega, et al., 2016; Washusen, 2016).

To take full advantage of the potential of the eucalypts, it is necessary to understand material properties such as growth stresses in standing trees, logs and cants (and the possible reduction of these stresses), brittle heart, kino rings and knots. Material properties should be carefully considered when planning all processing activities from felling and log-making, to primary log breakdown or sawing. Log diameter and sweep significantly impact overall recovery, but these factors are mainly affected by genotype and silviculture. The most important of these adverse effects is spring and board end-splitting, which may potentially impact on recovery and product value (Blundell, et al., 2013; Crafford, et al., 2016; Sepulveda-Villarroel, et al., 2016). Complicating the remediation of growth stress is the high variability not only between species, but between provenances and even individual stems (McConnochie, et al., 2004; Trugilho, et al., 2005; Yang, et al., 2004; Zhou, et al., 2005).

Production lines that can be considered consist of frame-saw lines, double-arbor-multiple-circular sawlines, single to quad-band lines or even rotary veneer peeling for the production of laminated veneer lumber (Vermaas, 2000). Recent research results generally support the hypothesis that processing systems which release growth stresses symmetrically around the log mitigate the adverse effects of growth stress release.

Plantations tend to produce logs with greater shape uniformity suggesting that modern multi-saw systems combined with chipper canters more commonly associated with softwood sawmills may be applied (Fig. 3). These systems have the potential to produce accurately sawn boards because all saws are operating simultaneously and the chippers operating in front of the saws can remove highly stressed wood uniformly around the log, although care must be taken to ensure accurate centring of the log (Harwood, et al., 2005). They cannot completely eliminate degrade due to board distortion - spring in quartersawn boards - (Blakemore, Morrow, Ngo, et al., 2010). Production rates of well over 100,000 m3/year are possible.

Fig. 3: *Chipper Canter HewSaw 250 (Washusen & Innes, 2008)*

Victoria as gone from about 300 to 30 sawmills in the last 15 years and there is no longer any ‘old growth’ being sawn there. Highly variable results have been obtained by processing plantation eucalypt logs using conventional single circular saws or single bandsaws (Blakemore, Morrow, Ngo, et al., 2010; de Fégely, 2004; Haslett, 1987; Haslett, 1988e; Jones, et al., 2010; Monteiro, et al., 2013; Washusen, 2011, 2013b). With single-saw systems, either back-sawing or quartersawing is effective, particularly if a line-bar is available to counter log movement during sawing. Where a line-bar is not available the only option with single-blade systems is to rotate the log or use face-cutting to straighten the sawn face. These latter options reduce both throughput and recovery (Washusen & Innes, 2008). Preferred log lengths are around 3.5m, otherwise relief of growth stresses can dramatically also reduce recovery due to the resulting sawing variation. Collapse prone species largely have to be quartersawn to permit recovery by reconditioning (Fegely, 2004). Quarter-sawn boards tend to shrink more on the face than flat-sawn because tangential shrinkage is up to twice as high as radial (Ananías, et al., 2009; Yang, Ilic, et al., 2003). BackSawing (https://timbertech.wikispaces.com/file/view/Conversion+of+timber.pdf) can improve results to some extent (Washusen, Harwood, et al., 2008).

Several studies have now been reported which deal with the more modern sawing systems. The capacity of multiple circular saw lines to process logs with a range of growth stress levels was assessed (Haslett, 1987; Haslett, et al., 1997b; Washusen, 2013b; Washusen, Harwood, et al., 2008; Washusen & Innes, 2008; Washusen, Menz, et al., 2004). The overall results indicate that the HewSaw R250 (or similar technology incorporating chippers with multi-saws) is well suited to processing small diameter young eucalypt logs, despite the large range in growth stress levels. "Given the high throughput, good sawing accuracy and its capacity to handle logs with a range of growth stress levels, the HewSaw R250 is capable of considerably reducing sawmilling costs over conventional hardwood mills. It is also more suited to processing eucalypts" (Washusen, 2013b). There is also a theory that chipper/profilers may remove sufficient amounts of high stressed wood prior to sawing to minimize bow (Washusen, et al., 2007). "The Hewsaw" is OK if you have a large volume of small STRAIGHT logs. You need to sort logs on diameter and reset the sawing pattern for each size class (Farrell, et al., 2008; Farrell, et al., 2012). Once you get over about 33 cm SED, there are other options. The most popular unit for sawing regrowth (35 cm upwards) is the line-bar carriage" (Gary Waugh pers. comm.). In fact it has been suggested that logs smaller than 350 mm should be live-sawn to random-width boards and later re-sawn to the required sizes (Waugh, et al., 2002). A comparison of live sawing and Saw-Dry-Rip was undertaken on E. saligna by Portuguese researchers (Franke, et al., 2014) after six months air-drying of the logs. They concluded that SawDry-Rip leads to less distortion both before and after drying by vacuum and kiln (about 2 weeks each). Both drying methods showed significant collapse and internal checks.

Twin-saw and multi-saw systems offer big advantages in throughput and symmetrical growth stress reduction, particularly if combined with chippers and narrow-kerf sawblades (Washusen & Innes, 2008; Washusen, Menz, et al., 2004). Twin bandsaw breakdown into slabs followed by twin-blade edging is the most cost-efficient method of gradesawing for high recoveries and is scaleable (D. Satchell pers. comm)

Most trials of plantation timbers have involved *E. globulus* and *E. Nitens* (Blakemore, Morrow, Ngo, et al., 2010; Innes, et al., 2008b; Washusen, 2013b). Results have been very variable partly due to wood drying behaviour.

Research and data are needed on which to base prediction of likely returns for growers associated with grade-sawing younger, smaller-diameter plantation ash eucalypt logs in New Zealand. Satchell (2011, 2015) has studied this at a pilot scale on smaller-scale operations in New Zealand but further work is required. Sawing logs below 40 cm small end diameter (SED) is difficult primarily because of growth stresses. Some studies suggest keeping log lengths short if using straightening cuts to deal with movement (i.e. quarter-sawing). Quarter-sawn logs had lower total recovery (partly because of a greater tendency to under-sizing) but higher recoveries of select and standard grades, than back-sawn logs (Washusen, Harwood, et al., 2009). Suggested lengths are 3m for diameters up to 45 cm and 4m for larger diameters (Harwood, 2010; Satchell, 2015c). The choice of breakdown strategy in practice is often determined by the existing equipment and log size.

Comparisons of yield and quality indicate that the final result depends on log size and species – particularly in regard to the level of growth stress, degrade and shrinkage (Washusen, 2013b).

As with most plantation hardwoods commercially processed in Australia and NZ, the early trials conducted by CSIRO and Scion used conventional drying strategies typically derived from local experience with native forest timbers. This usually entailed a period of air-drying or pre-drying in a kiln followed by reconditioning and final kiln drying. However, the refractory nature of eucalypt timber (Ananías, et al., 2014), and the more demanding requirements for added-value products encouraged the application of more novel wood drying systems such as pre-drying schedules (Blakemore, et al., 2008; Chafe, et al., 1996; Vermaas, 1995, 2002), vacuum drying (Greaves, 1998; Hansmann, et al., 2008; Redman, et al., 2010; Vermaas, 1995), radio-frequency drying (Rosza, et al., 1996), microwave (Torgovnikov, et al., 2010), steam reconditioning, compression drying, and intermittent drying technologies in an attempt to lessen the effects of growth stresses (Haque, et al., 2005; Weir, et al., 2013; Yiqiang, et al., 2008). While some significant gains have been obtained, it often necessitates very methodical research, particularly for the younger, lower density material (Xu, et al., 2012; Yuniarti, et al., 2015). The major challenge in hardwood drying remains the development of economical ways of drying appearance grade back-sawn timber, free of degrade and in various thickness.

Some eucalypts with their characteristically high shrinkage and low mass diffusivity values are notoriously difficult to season without degrade, and traditionally took months to air-dry especially backsawn boards (Jankowsky, et al., 2005; Vermaas, 1995).

Seasoning of cold-climate eucalypt timber is problematic (Blakemore, 2011; Blakemore, et al., 2009b; Mugabi, et al., 2011), and issues such as collapse, surface and internal checking, cupping, distortion and high shrinkage can significantly lower product recovery and value (Beltrame, De Peres, Lazarotto, et al., 2015; Blakemore, et al., 2008; Chafe, et al., 1996; Washusen, Northway, et al., 2009; Yang, et al., 2004; Yang, 2005). Despite these grade-limiting defects, when correctly sawn and seasoned, eucalypt timber can have attractive appearance, along with high strength and stiffness, although the economics have been questioned (Blakemore, 2011; Innes, et al., 2008a; Satchell, et al., 2010a). Stresses and drying issues can dominate the processing of some species, especially *E. globulus, E. Nitens* (Nolan, et al., 2005). Currently under evaluation at Scion is the Super-Critical method (Dawson, et al., 2014; Franich, et al., 2014). Intermittent drying regime is very likely to be a potential drying method suitable for collapse-prone lower-density plantation-grown eucalypt wood (Wu, et al., 2010).

Drying performance varies considerably between species, with E. nitens in particular showing considerable variability (Haslett, et al., 1992; Washusen & McCormick, 2002; Washusen, et al., 2006). The difficult eucalyptus species are best air-dried first to minimize collapse, and drying must be very slow to control checking as well (Washusen, Menz, et al., 2004). Many of these species also have lots of growth stress, so end splitting can be severe. Collapse and internal checking are two of the most serious defects affecting appearance-grade products, although species vary in their expressions of degrade - distortion vs. collapse and checking - (Innes, et al., 2008b). Fastgrown plantations are expected to show more collapse. While processing variables (log handling, sawmill types saw pattern and drying techniques) are significant factors, but currently they can only be manipulated to minimise the damage rather than eliminate it because of the inherent characteristics of the timber.

A host of drying techniques have been investigated (Rosza, et al., 1996; Rosza, 1994; Severo, et al., 2013) but currently no economic way has been developed for processing wood to avoid collapse altogether (Ananías, et al., 2014; Blakemore, et al., 2009b; Pang, et al., 2004; Yang, et al., 2014). The only technique that has been shown to avoid collapse totally is freeze-drying, and it is expensive and impractical (Blakemore, et al., 2009a). Super critical CO_2 also holds some promise for eliminating collapse, but requires much more research and validation (Franich, et al., 2014). A longer-term solution may be a targeted genetic approach (Hamilton, et al., 2008).

As in Australia, successful utilisation depends heavily on sawing and drying (Haslett, Kininmonth, et al., 1984). For optimum recovery and value, the sawing strategy depends to an extent on the eucalypt species and intended final product (appearance, structural or industrial). Some species, e.g. *E. pilularis* (a stringybark) can be back-sawn without significant loss of appearance grade, though back-sawn timber can be prone to surface checking. *E. saligna* and other similar density species can also be back-sawn without significant loss in recovery of appearance grade timber. In general, material of high basic density is associated with low levels of internal checking and collapse. However, when quarter-sawn, crook can be a problem (McConnochie & Nicholas, 2007). Quarter-sawing is recommended for collapse-prone and high shrinkage species, such as E. nitens, in order to reduce checking and produce the best recoveries of appearance grade products. Larger log diameters (40 cm +) are preferred for quarter-sawing to produce adequate recoveries and reduce losses due to crook (spring). Quarter-sawing of small diameter logs reduces conversions, although the recovery of check-free appearance grade boards after drying is improved. For structural products, where drying degrade such as checking is not a major grade determinant, logs can either be quarter-, flat- or back-sawn.

Another approach successful for many high value species is Saw-Dry-Rip (SDR). This allows decisions regarding cross-cutting of boards to be delayed until after drying (Franke, et al., 2014) and has been proven for some species of eucalypt (Del Menezzi, et al., 2004; Ratnasingam, et al., 2013).

In the New Zealand situation, it is unlikely that a large commercial industry based on eucalyptus sawn products will develop in the short term because apart from areas of *E. nitens* in the South Island, the resource will remain small and scattered for decades due mainly to siting and ownership issues.

In New Zealand, eucalypt wood processing markets have never reached the volume necessary to warrant the establishment of specialised processing or research facilities, despite apparently strong consumer demand for timbers with some of the quality of eucalypts (mainly strength and appearance characteristics). The continued small-scale processing of the existing eucalypt resource is likely to be quite successful as local knowledge is acquired and knowledge of appropriate siting, silviculture, log handling and sawing develops. However, this has not happened on a sustained basis even in Australia, where Government support for appropriate R&D has been strong but was waned in recent years.

Findings (Sawing):

- The best summary of eucalypt sawing is given by (Washusen & Innes, 2008)
- Processing of plantation eucalypts will be challenging in view of the extensive research already carried out in Australia in particular, which has highlighted that many eucalypt species grown in plantations are not commercially well suited for timber and veneer production, mainly due to the characteristics of the wood when grown in plantations
- Logs should be held in longer log lengths before cross cutting for sawing to reduce losses to end splitting. Fine end cracks on the freshly cross cut ends of eucalyptus logs occur almost immediately. However, if the ends of the log are coated with wax sealants and stored under shed/shade/water, extension of these initial end cracks, which otherwise results in extensive damage, is almost completely eliminated. In some countries they are held under water spray for up to 3 months. An end coating may prevent fast drying and reduce end checking. Cross cutting for product yield should be done as soon as possible before sawing
- Logs should be processed as soon as possible after felling to alleviate the worst effects of growth stress development. Shorter lengths are preferred for sawing.
- Steaming is a common procedure to recondition collapse in boards.
- Some large Australian studies have been undertaken with different sawing strategies and drying regimes, but results vary somewhat according to species, crop age, diameter distribution and

silvicultural treatment. Growth stresses, tension wood, knots and various kinds of checks (surface and internal) were the major causes of downgrade. Reconditioning enables most checks to close superficially (but they are still there in the wood and may re-appear with in service!).

- Sawing efficiency is improved by log batching according to diameter where a hewsaw is used.
- Many of the earlier sawing studies were carried out on out-dated equipment (single band saws or circular saws) where stresses were relieved unevenly, leading to excessive losses due to distortion. More recent studies have focused on the use of more modern saw designs such as twin-saw systems for smaller logs, with better results. Such mill designs allow more even stress relief.
- An in-depth understanding the problems associated with the processing of plantation wood and development of appropriate drying technologies are important for economic exploitation of plantation wood. To take full advantage of the potential of the eucalypts, it is necessary to understand material properties such as growth stresses in standing trees, logs and cants (and the possible reduction of these stresses), brittle heart, kino rings and knots. Material properties should be carefully considered when planning all processing activities from felling and logmaking, to primary log breakdown and sawing. Production lines that can be considered, consist of frame-saw lines, double-arbor-multiple-circular sawlines, single to quad-band lines
- Higher recovery and reduced costs are achieved using linear sawing systems with multiple saws where stresses can be relieved evenly.
- Sawpattern significantly affects volume recovery and board appearance.
- Flat-sawn (sometimes called “backsawn” boards are likely to suffer from significant surface checking; radially-sawn boards much less so but far more prone to spring and internal ring checking.
- Board thickness is strongly related to the incidence of internal checks (thin boards less prone).
- Defects other than end splitting and checking are not a major source of degrade in pruned logs, but multiple knots in unpruned logs result in most boards being assigned to utility grades.
- Reducing the effects of log and board end-splitting, board collapse and distortion and poor sizing accuracy, can enhance economic production of sawn timber (Mackay, 1972; Satchell, et al., 2010a; Satchell, et al., 2010b; Washusen, 2011; Wu, et al., 2010).
- Drying remains a major obstacle to processing of collapse-prone species. Schedules had a relatively minor impact on internal ring checking; internal checking is much more prevalent in unpruned logs; the number of visible checks is dramatically reduced following re-conditioning.
- A huge effort has gone into researching drying schedules in Australia over the past 20, but there remains much work to do.

IMPACT OF GENETICS AND SILVICULTURE ON LOG AND WOOD QUALITY

Processing of eucalypt logs for solid wood products has proven to be a challenging task, and the potential for high value end uses has not yet been realised (Washusen, 2013a). ***One thing that stands out in the literature is that log attributes, particularly dimensions and growth stresses, can determine success at least as much as the actual conversion process, and these develop during the growing of the trees, and these can be greatly influenced by genetics and silviculture. Studies have shown that unmanaged stands are incapable of yielding good solid wood results (Nolan, et al., 2005; Washusen, 2013a).***

There are indications that several aspects of wood performance can be modified through breeding programmes (Apiolaza, et al., 2009; Blackburn, et al., 2012; Blackburn, et al., 2010; Blackburn, et al., 2013; Blackburn, et al., 2011; Botrel, et al., 2007; Chauchan, 2001; Chauhan, et al., 2010; De Pádua, et al., 2004; Hamilton, et al., 2008; Harwood, et al., 2001; Harwood, et al., 2007; Poole, et al., 2013; Raymond, 2002). In the longer term, genetic improvement is the only method that is likely to eliminate the problem completely. However, genetic material with no collapse propensity is still some years away and would require the screening of large populations (Apiolaza, et al., 2009;

Blakemore, et al., 2009b; Hamilton, et al., 2010). Early Australian trials indicated that it should be possible to grow good sawlogs in 30-40 years, but later developments in breeding and silviculture now indicate that shorter rotations should be viable (Volker, 2005; Volker, 2008).

It is outside the scope of this review to discuss breeding strategies for wood characteristics, except to point out that any such undertaking is probably worthwhile, but a huge and on-going commitment is required to focus on end -product characteristics, and preferably a small number of species (involving provenances, hybrids and/or clones). Considerable effort has gone into breeding eucalypts for improved solid wood characteristics already, but as has been pointed out, it requires a multi-disciplinary approach involving genetics, silviculture and processing techniques, and marketing expertise. In Tasmania, the efforts over 30 or more years to develop a viable procedure for growing and processing *E. nitens* have been described as “tortuous” and “not yet completed” (Harwood, 2011). One of the hurdles is that, while growth traits can be quantified at relatively young age (Blackburn, et al., 2013), success of improvements to wood traits can only be assessed after the stems have been processed (Blackburn, et al., 2011).

One of the characteristics of Eucalyptus is the development of several wood defects associated with longitudinal and tangential growth stresses (Clair, et al., 2013; Nolan, et al., 2005). These are not a major issue for pulpwood crops but can present a significant barrier to profitable solid wood processing of plantation material, and include high shrinkage, collapse, internal and surface checking (Ananías, et al., 2014; Beadle, et al., 2011; Harwood, 2010). In Tasmania, the efforts to develop a viable procedure for growing and processing *E. nitens* has been described as “tortuous” and “not yet completed” (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, & Harwood, 2008; Harwood, 2011).

Initial stocking and spacing are crucial for both financial viability and ability to select the desired quantity and quality of sawlogs with small or no branches (Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, & Harwood, 2008; Gerrand, et al., 1997). Initial stocking is normally around 1000 spha to achieve this, bit without pruning and thinning, eucalypt plantation trees neither produce knot-free wood nor attain sufficient log diameter to produce wide sawn boards (Harwood, 2010).

Thinning is deemed necessary both to allow selection of final crop trees and to promote growth on the pruned component (Wood, et al., 2009). However, the effect of thinning on development of tension wood (prone to high shrinkage and non-recoverable collapse on drying) is still somewhat uncertain (Washusen, 2002; Washusen, et al., 2005; Washusen, 2008b).

Pruning is essential in species with poor branch suppression and shedding for production of a significant volume of knot-free clearwood for veneer and high-grade furniture, and reduce the possibility of defects developing around branches. If poorly executed, however, pruning can reduce stem growth and result in stem damage causing gum flow (Barry, et al., 2005; McKimm, et al., 1988). The best 200-300 or so trees per hectare have their lower branches pruned in three successive ‘lifts’ to a height of 6.4 m above ground during the first five years of the plantation’s life, in order to provide a future sawlog (Harwood, 2010). If kept around 50% of the green crown length, there is minimal impact of stem growth. Pruning requires investment of more than $1000 per hectare early in the life of the plantation, but it is not possible to produce knot-free sawlogs by pruning at a later age. Once the branches have died, the stem grows around the dead branchwood.

In a summary of silvicultural trials (Forrester, 2013), is was found that the relative reductions in crop tree growth due to pruning were greater in thinned stands than unthinned stands, because in young unthinned (and closed canopy) eucalypt stands the lower branches are shed rapidly, whether they are pruned or not, but in thinned stands lower branches are well lit, more efficient and contribute more to a trees' growth. Eight studies examined interactions between pruning (or defoliation) and fertiliser application (or site quality) and when the interactions were significant, the negative effects of pruning were greater in unfertilised stands (or low quality sites) than in fertilised stands (or high quality sites). Five studies, including six Eucalyptus species, examined the thinning x fertiliser application (or site quality) interaction. Absolute and relative thinning responses of crop trees usually increased with fertiliser application or increasing site quality in Eucalyptus stands (or interactions were not significant). The absolute and relative thinning responses of crop trees also depended on stand structure and increased as diameter distributions of unthinned stands became more negatively skewed. When available, studies for species other than eucalypts were also included for comparison, but for all species, the interactions between these treatments have received far less attention than the individual treatments. Although each type of interaction, when significant, was consistent across the different eucalyptus studies, there were few studies available and only a few of those examined the mechanisms that influenced the interactions. Therefore more studies will be required to confidently determine when each interaction will occur and what mechanisms are the most important drivers of these interactions.

However, any manipulation of the growth pattern through silvicultural treatment or application of fertiliser will also modify the inherent distribution of wood properties such as growth stresses, wood density and microfibril angle within stems, and subsequently influence processing characteristics. In Australia, regimes have also been developed that delay thinning until tree size allows a commercial pulpwood harvest, both in Tasmania (Beadle, et al., 2011) and sub-tropical Australia (Glencross *et al.* 2011). Whether this practice is truly commercial has been questioned (Volker, 2005).

Thinning, pruning and fertiliser application have been shown to be important silvicultural treatments used to grow solid - wood products from eucalyptus plantations. These silvicultural treatments are sometimes carried out simultaneously and can therefore potentially interact. These interactions as well as those with site quality are important. While site quality is a useful variable for explaining thinning responses, stand structure in terms of the skewness and variability of diameter distributions, appears to describe some of the variability that site quality does not, and may also help to understand mechanisms behind thinning responses. The growth and physiological responses of eucalypts to thinning, pruning and fertiliser application, with a particular focus on Australian plantations have been reviewed (Beadle, et al., 2011; Forrester, Medhurst, et al., 2013).

CONCLUSIONS

The conversion of pulpwood crops to solid wood by thinning has proven unsuccessful in Australia. Nevertheless, the mere fact of establishing eucalypt plantations for solid wood products is not a guarantee of success. There is a huge body of literature available concerning attempts to successfully create solid-wood industries – much of it from Australia, South Africa and South America. Unfortunately, there are few real success stories, due not only to less-than-ideal siting and silviculture, but also to a lack of appreciation of the challenges of processing eucalypt wood. The most successful developments have perhaps been in South America where reported growth rates are phenomenal (http://www.fao.org/docrep/004/ac121e/ac121e04.htm).

Several factors must align to even offer some hope of a financial return. Breeding objectives, pathology, silviculture and processing methods must be appropriate to ensure yields of reasonable harvest volumes and valuable timber. This necessitates minimising the deleterious influences from wood characteristics such as growth stresses. There are several excellent reviews of the impacts of forest practices on the development of growth stresses, for instance, which are the main cause of loss of value (Forrester, Medhurst, et al., 2013; Potts, et al., 2011; Walker, et al., 2011; Wardlaw, et al., 2003; Washusen, 2016; Wingfield, et al., 2008). However, there remains a lack of detailed knowledge of the best climatic, site and silvicultural conditions for the multiplicity of species which have been considered as potential candidates in New Zealand. In particular there is a history of frequent insect and fungal intrusions which have caused significant setbacks, and this is likely to continue into the future with increased international trade and occasional biosecurity lapses. Climate change may also increase the host range for pathogens and extend the period of infestation by pests (Naidoo, et al., 2014).

Planting and processing eucalypts in NZ has had a significant “suck it and see” component, with lots of disappointments along the way. Progress has been dependant on a small number of enthusiasts (such as Neil Barr and Ian Nicholas) who have been dogged in their pursuit of knowledge. The Eucalypt Co-operative in particular generated a huge volume of literature on siting and silviculture (and processing to a lesser extent). The introduction of “new” species and genotypes such as under the Dryland Initiative necessitates that such research must be continued ***across the value chain*** to minimise the risk of further failures. This approach has in the past been heavily supported by research specialists and the Government but the onus is now passing to industry.

By far the most published research has been in Australia, by CSIRO, FWPA and various research cooperatives who have documented the ecology, silviculture, pathology and wood properties of the most common species and supported efforts at commercialisation of plantation wood following the cessation the of old-growth harvest. Even in Australia it has been an ongoing task to try to establish a robust solid wood industry based on plantation eucalypts. An excellent Australian paper asked the question “Can the inherent deficiencies of eucalypt wood be surmounted by applying appropriate silviculture?” (Beadle, et al., 2011). The answers are complex and by no means clear cut (Nolan, et al., 2005). One thing that is fairly certain is that most species are ***capable*** of yielding some attractive, high stiffness timber and veneers which could enhance the variety of material from NZ forests but it will require further targeted value-chain research and technology development.

ADDENDUM 1 - ENGINEERED WOOD PRODUCTS (EWP)

A surprising finding of a recent Australian review on the use of plantation eucalypts for EWP (Hague, 2013) was that local information was scarce and that significantly more research had been conducted overseas (South America and Europe) where such material is more widely used (e.g. laminated veneer lumber (LVL) and plywood, glulam, flake/strand-based products, fibreboard and particleboard). The conclusions of the review indicated that the plantation resource (particularly *E. nitens, globulus, and grandis*, often established for pulpwood or biomass) is perfectly suitable for LVL, strandboard, flakeboard, and MDF). The faster-grown low-density specie create no problems for adhesive systems with wood densities less than about 650 kg/m3. According to the author, further research for solid wood and EWP uses should concentrate on genetic selection and silviculture (spacing and pruning) to ensure raw material average density in the range 500- 500 kg/m3.

This review does not cover EWP, but in the course of a literature search came across many relevant publications, e.g.:
(Acevedo, et al., 2012; Arnold, et al., 2013; Barshaw, et al., 2004; Beadle, Volker, Bird, Mohammed, Barry, Pinkard, Wiseman, Harwood, et al., 2008; Blackburn, et al., 2012; Blakemore, Morrow, Ngo, et al., 2010; Blakemore, Morrow, Washusen, et al., 2010; Blundell, et al., 2013; Chen, et al., 2011; De Carvalho, et al., 2004; Dungey, et al., 2013b; Farrell, et al., 2011; Franke, et al., 2014; Gaunt, et al., 2003; Gaunt, et al., 2002; Guimarães Júnior, et al., 2011; Hamilton, et al., 2015; Harwood, 2010; Kininmonth, et al., 1974b; McKenzie, Shelbourne, et al., 2003; McKenzie, Turner, et al., 2003a; McKenzie, 2001; Müller, et al., 2015; Nolan, et al., 2005; Ozarska, 1999, 2009; Saviana, et al., 2009; Sheild, 2003; Shelbourne, et al., 2001; Simpson, et al., 1999; Suh, et al., 2012; Thomas, et al., 2009; Valencia, et al., 2011; Zubková, et al., 2009).

ADDENDUM 2 - DURABILITY ISSUES

Eucalypts in general have a reputation of superior durability, based mainly on testing of old natural forest material, but in fact treated radiata pine has proven superior in tests of both above-ground and in-ground. Those that perform best are absent or very scarce in NZ, due mainly to poor survival and growth rates. A relatively small number of species have been properly tested in NZ (Page, et al., 2014b), and any candidates for approval from the large number of possibilities in practice need to follow existing test protocols, involving sample numbers, sites tested and time to completion.

The natural durability of wood comes with heartwood development (age-related and species specific) and is attributed to the presence of certain extractives (Da Costa, 1979). Increasing wood density has also often proven to be a useful predictor of increasing natural durability, especially in hardwoods (Cookson, et al., 2013). Timber from young or fast-grown plantation trees can have reduced colour and density, and there is often the perception or finding that these trees also have lower natural durability than mature trees (Scheffer, et al., 1966). On the other hand it has been found in some species (e.g. Teak) that 5-year-old juvenile wood from intensively-managed plantations is less decay resistant than the wood of 13-year-old trees and mature teak wood of forest plantations. However, it is comparable in natural durability to the inner heartwood of even mature trees (Bhat, et al., 2003). Interestingly, Johnson et al. (1996) conducted a 6.8-year inground stake trial in an Accelerated Field Simulator and found that, out of 10 eucalypt/myrtaceae species, timber from regrowth (23-58 years) had lower natural durability than timber from mature trees (100 – 500 years in only three (Cookson, et al., 2013). In Australia, natural durability for a number of hazard types and exposure conditions, including those above ground and in-ground, is described in Australian Standard 5604-2005 (Australia, 2005). Durability is based on the performance of the outer heartwood from "mature" trees. The in-ground natural durability classes, written in the 1950s, were based upon laboratory trials and the experience of foresters and those writing the standard (Tamblyn 1966). Some modifications occurred after a 33–36-year inspection of Australia's longest-running natural durability trial (Cookson, 2004). Timber species with greatest natural durability in the outer heartwood were raspberry jam (*Acacia acuminata*), red box (*Eucalyptus polyanthemos*), wandoo (*E. wandoo*), tallowwood (*E. microcorys*), bull oak (*Allocasuarina luehmannii*), grey ironbark (*E. paniculata*), yellow box (*E. melliodora*), Gympie messmate (*E. cloeziana*), grey box (*E. moluccana*) and white mahogany (*E. acmenoides*). It is worth noting that creosote-treated and CCA-treated *P radiata* out-performed all other species (Cookson, 2004). To date, species ratings for durability are largely based on old-growth native forest timbers (McCarthy, et al., 2006).The durability of the heartwood of many species is not uniform - pine tend to have greater durability in the inner (oldest) heartwood, while Coast Redwood has better durability in the outer (younger) heartwood (Jones, et al., 2014). There is a lack of information on the heartwood development and durability of eucalypt plantation material.

In Australia the traditional hardwood paling fence durable timbers such as *E. camaldulensis* (River Red Gum), and palings and rails cut from timbers of low natural durability such as *E. regnans* and *E. obliqua*. Because the fence is untreated, palings and rails often need replacing after 15–20 years of service, while posts are usually still serviceable after this time. Although of durable timber, plinths also often need replacing due to decay in the lower edge resting on soil, where because of thinner cross-section, decay is more noticeable than in post (Cookson, 2012).

Australian eucalypts are highly regarded for their durability, with the most durable species used for external applications such as posts, poles, general and heavy engineering construction, decking, and wharf and bridge piles. Farm foresters in lower rainfall environments are growing eucalypt species to supply these and other markets for durable wood products (McCarthy, et al., 2006). A consistent feature of durability studies is the high variability encountered.

There is now an initiative in NZ to do similarly, with species choices based largely on the Australian old-growth data. It is important to remind growers that such data must be treated with caution as the environments and pathogens are different may well lead to different results, particularly if the crops are grown significantly faster, as is possible. In fact, it is not unusual to find that the durability classification of some locally grown timbers may be different to that of imported timber of the same species (Page, et al., 2014b). Hardwoods, particularly eucalyptus species, dominate the list of species suitable for use in moderate-high decay hazard situations such as fence posts and decking where a minimum service life of less than 50 years is required. Some results from the Scion Graveyard tests are shown in the table below.

In-ground stake durability variation for three Class 2 eucalyptus species (Page, et al., 2014b)

Species	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Average
E. pilularis	13.3	6.6	10.9	5.7	10.4	**9.9**
	(5 – 21)	(3 – 13)	(3 – 17)	(1 – 12)	(5 – 12)	
E. muelleriana	10.7	6.2	6.6	8.2	9.4	**9.2**
	(6 – 20)	(2 – 16)	(2 – 15)	(3 – 13)	(4 – 18)	
E. globoidea	12.4	14.3	12.0	9.4	14.3	**9.8**
	(6 – 20)	(5 – 24)	(3 – 32)	(3 – 18)	(5 – 21)	

It should also be pointed out that new indirect methods (e.g. NIR) are being proposed to drastically shorten the time required for durability tests, but the results can only be treated as indicative until supported by authenticated regional in-ground tests.

New Zealand Dryland Forests Initiative (NZDFI)

Durability is highly variable both within and between species (Page, et al., 2015). While natural durability is often associated with tree age and heartwood development, these is evidence that with some eucalypt species, young heartwood can also be reasonably durable (but inside non-durable sapwood) (Bush, 2001; Cookson, 2005).

With CCA (copper chrome arsenic)-treated wood now banned for many uses by the USA and several European countries, there are significant international and domestic markets for naturally durable hardwoods. The wood properties of New Zealand grown durable eucalypts ensure they can replace CCA treated material for many uses and are also ideal for a wide range of agricultural and land-based industrial applications, particularly for posts, poles and utility cross-arms as well as heavy structural timbers.

NZDFI (New Zealand Dryland Forests Initiative) has selected eucalypt species which can be sawn to produce durable hardwoods for farm, vineyard and specialty uses and reduce the use of chemicals in the environment (Walker, et al., 2011). Using these species, NZDFI is committed to developing viable best-practice forest management systems to complement livestock farming. NZDFI wants to encourage planting durable hardwood forests and woodlots to protect steep slopes and waterways, for shade and shelter, and to generate income from carbon credits and sustainable timber harvesting. This industry/research joint effort is an ambitious attempt to identify, grow, and manage a selection of eucalypts known to have superior natural in-ground durability at an early age, mainly for use in a rural environment (farms, vineyards, and engineered structures). Comparatively little breeding work has been done on durable eucalypt species anywhere in the world, in contrast to radiata pine genetic improvement work which has continued for around 70 years. By applying knowledge and techniques developed by tree breeders working with other species, huge gains in the growth, form and wood quality are anticipated (http://nzdfi.org.nz/). A small number of species (not currently planted on a significant scale) have been identified with known or suspected durable heartwood (Cookson, 2004; Nicholas, et al., 2012a, 2012b; Rudman, 1964).

This will be a challenging project since most of the superior properties of eucalypts (including heartwood extractive content and durability) develop with tree age (Cookson, et al., 2013; Miranda, et al., 2007; Miranda, et al., 2009; Moraisa, et al., 2007; Page, et al., 2014a; Santana, et al., 2012). It is encouraging that some Australian studies have been able to demonstrate good early durability. *E. agrophloia*, for instance has been assessed at age 10 years in a low rainfall area of Queensland, albeit with relatively low growth rates (Armstrong, et al., 2003; Lee, et al., 2001).

Timber - Natural Durability Ratings (AS5604 2005)

1	2	3	4		5
Standard common name and scientific/botanical name	Lyctid Susceptibility of sapwood	Termite resistance of heartwood (inside above ground applicable to H2 in AS 1604 series)	Natural durability class of heartwood		Marine borer resistance of heartwood
			In-ground contact, Dig	Outside above ground, Dag	
blackbutt *Eucalyptus pilularis*	NS	R	2	1	3
box, grey, coast *Eucalyptus bosistoana*	S	R	1	1	3
box, white-topped *Eucalyptus quadrangulata*	NS	R	2	2	-
box, yellow *Eucalyptus melliodora*	NS	R	1	1	-
gum, blue, Sydney *Eucalyptus saligna*	S	NR	3	2	3
gum. red, river *Eucalyptus camaldulensis*	S	R	2	1	2
gum, spotted *Corymbia maculata*	S	R	2	1	4
gum, sugar *Eucalyptus cladocalyx*	S	R	1	1	-
ironbark, red *Eucalyptus tricarpa*	S	R	1	1	2
mahogany, southern *Eucalyptus botryoides*	NS	R	3	2	-
stringybark, yellow *Eucalyptus muelleriana*	NS	R	3	2	3
tallowwood *Eucalyptus microcorys*	S	R	1	1	3

Notes:

Dig = in-ground natural durability class
S = Susceptible
R = Resistant to termite

Dag = above-ground natural durability class
NS = Not susceptible
NR = Not resistant to termite

Natural Durability – Probable Life Expectancy (AS5604 2005)

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

N.B. These data were often determined in the 1950's, often using small numbers of samples from trees of unknown age, and thus may not apply reliably to plantation-grown timber.

Marine Borer Resistance – Probable Life Expectancy (AS5604 2005)

Class	Probable marine-borer-resistance life expectancy in southern waters (years)
1	Greater than 60
2	41 – 60

3	21 - 40
4	0 to 20, usually less than 5

There is plenty of scope for genetic improvement of eucalypt durability, should it be given research priority (Apiolaza, et al., 2001).

REFERENCES

Acevedo, A., Bustos, C., Lasserre, J. P., & Gacitúa, W. (2012). Nose bar pressure effect in the lathe check morphology to Eucalyptus nitens veneers. *Maderas: Ciencia y Tecnologia, 14*(3), 289-301. doi:10.4067/S0718-221X2012005000004

Acosta, M. S. (2008). Wood technologies and uses of eucalyptus wood from fast grown plantations for solid products. *Proceedings of the 51st International Convention of Society of Wood Science and Technology, November 10-12, 2008 Concepción, CHILE*, 12pp.

Ananías, R. A., Díaz, C., & Leandro, L. (2009). Preliminary study of shrinkage and collapse in eucalyptus nitens. *Maderas: Ciencia y Tecnologia, 11*(3), 251-262.

Ananías, R. A., Sepúlveda-Villarroel, V., Pérez-Peña, N., Leandro-Zuñiga, L., Salvo-Sepúlveda, L., Salinas-Lira, C., Cloutier, A., & Elustondo, D. M. (2014). Collapse of Eucalyptus nitens Wood After Drying Depending on the Radial Location Within the Stem. *Drying Technology, 32*(14), 1699-1705. doi:10.1080/07373937.2014.924132

Angelo, H., Paulucio, F. F., de Almeida, A. N., Matricardi, E. A. T., & Soares, P. R. C. (2015). Evolution of eucalyptus plantations in the Goiás State. *Floresta, 45*(2), 223-228. doi:10.5380/rf.v45i2.33301

Anon. (1981). NZ Forest Service Policy on exotic special purpose species. *NZ Forest Service, Wellington*.

Anon. (2001). Growing cold-climate eucalypts for high quality timber. *NZFFA Information Leaflet No 17, http://www.nzffa.org.nz/farm-forestry-model/resource-centre/farm-forestry*http://www.nzffa.org.nz/farm-forestry-model/resource-centre/farm-forestry-association-leaflet-series/no-17-growing-cold-climate-eucalypts/*association-leaflet-series/no-17-growing-cold-climate-eucalypts/*.

ANON. (2013). Australia's State of the Forest Report, Criterion 2 Maintenance of productive capacity of forest ecosystems. *Australia Government Department of Agriculture Report*, 56.

Apiolaza, L. A., Chauhan, S., & Walker, J. C. F. (2009). Revisiting eucalypts—a strategic assessment *In: Apiolaza, L.A., Chauhan, S. and Walker, J.C.F. (Editors) 2009. Revisiting Eucalypts Workshop, Wood Technology Research Centre. 155 p. ISBN 978 0 473 14703.*, 7pp.

Apiolaza, L. A., McConnochie, R. M., Millen, P., van Bellekon, S., & Walker, J. C. F. (2001). Introdicing durable species to New Zealand drylands: Genetics of early adaption of Eucalyptus Bosistoana. *In: Walker (Ed), "Developing a Eucalypt Resource: Learning From Australia and Elsewhere"*, 137-146.

Apiolaza, L. A., Raymond, C. A., & Yeo, B. J. (2005). Genetic variation of physical and chemical wood properties of Eucalyptus globulus. *Silvae Genetica, 54*(4-5), 160-166.

Armstrong, M., Redman, A., & Hopewell, G. (2003). *Eucalyptus agrophloia* processing study. *Queensland DPI Report (unpublished). Cited in Walker et al, 2011)*.

Arnold, R. J., Xie, Y. J., Midgley, S. J., Luo, J. Z., & Chen, X. F. (2013). Emergence and rise of eucalypt veneer production in China. *International Forestry Review, 15*(1), 33-47. doi:10.1505/146554813805927200

Australia, S. (2005). Timber–Natural Durability Ratings. AS 5604-2005. . Standards Australia, Homebush, New South Wales.

Baillères, H., Davrieux, F., & Ham-Pichavant, F. (2002). Near infrared analysis as a tool for rapid screening of some major wood characteristics in a eucalyptus breeding program. *Annals of Forest Science, 59*(5-6), 479-490.

Baker, T., & Volker, P. (2006). Silviculture of eucalypt plantations in southern Australia for highvalue solid wood products. *The Second Latin American IUFRO Congress, La Serena, Chile*

Barr, N. A. (1971). Some selected eucalypts, their silviculture and utilisation in New Zealand. *New Zealand Forest Service, Forest Research Institute, Symposium No. 15, No. 10*(172-180).

Barry, K. M., Hall, M. F., & Mohammed, C. L. (2005). The effect of time and site on incidence and spread of pruning-related decay in plantation-grown Eucalyptus nitens. *Canadian Journal of Forest Research, 35*(3), 495-502. doi:10.1139/x04-190

Barshaw, B. K., Wang, X., Ross, R. J., & Pellerin, R. F. (2004). Relationship between stress wave velocities of green and dry veneer. *Forest Products Journal, 54*(6), 85-89.

Beadle, C., Smedhurst, J., & Forrester, D. (2011). Linking silvicultural management to solid wood values. *In: Walker et al (20011) "Developing a Eucalypt Rersourcs: Learning from Australia and Elsewhere"*, 77-92.

Beadle, C., Volker, P., Bird, T., Mohammed, C., Barry, K., Pinkard, L., Wiseman, D., & Harwood, C. (2008). Solid-wood production from temperate eucalypt plantations: A Tasmanian case study. *Southern Forests, 70*(45-70).

Beadle, C., Volker, P., Bird, T., Mohammed, C., Barry, K., Pinkard, L., Wiseman, D., Harwood, C., Washusen, R., Wardlaw, T., & Nolan, G. (2008). Solid-wood production from temperate eucalypt plantations: A Tasmanian case study. *Southern Forests, 70*(1), 45-57. doi:10.2989/SOUTH.FOR.2008.70.1.6.516

Beltrame, R., de Peres, M. L., Delucis, R. A., de Freitas, D. L., Gatto, D. A., & Haselein, C. R. (2015). Longitudinal growth stress and mechanical properties of wood from Eucalyptus spp. clones. *Revista Materia, 20*(4), 1061-1074. doi:10.1590/S1517-707620150004.0108

Beltrame, R., De Peres, M. L., Lazarotto, M., Gatto, D. A., Schneid, E., & Haselein, C. R. (2015). Growth stress and its relationship with end splits in logs of Eucalyptus spp. *Scientia Forestalis/Forest Sciences, 43*(105), 63-74.

Berndt, L. A., Withers, T M, Bain, J. (2010). Down wind from the source: 150 years of insect pests of eucalypts in New Zealand. *International Forestry Review 12*(5).

Bhat, K. M., & Florence, E. J. M. (2003). Natural decay resistance of juvenile teak wood grown in high input plantations. *Holzforschung, 57*(5), 453-455. doi:10.1515/HF.2003.067

Biechele, T., Nutto, L., & Becker, G. (2009). Growth strain in Eucalyptus nitens at different stages of development. *Silva Fennica, 43*(4), 669-679.

Blackburn, D., Farrell, R., Hamilton, M., Volker, P., Harwood, C., Williams, D., & Potts, B. (2012). Genetic improvement for pulpwood and peeled veneer in Eucalyptus nitens. *Canadian Journal of Forest Research, 42*(9), 1724-1732. doi:10.1139/X2012-105

Blackburn, D., Hamilton, M., Harwood, C., Innes, T., Potts, B., & Williams, D. (2010). Stiffness and checking of Eucalyptus nitens sawn boards: Genetic variation and potential for genetic improvement. *Tree Genetics and Genomes, 6*(5), 757-765. doi:10.1007/s11295-010-02897

Blackburn, D. P., Hamilton, M. G., Harwood, C. E., Baker, T. G., & Potts, B. M. (2013). Assessing genetic variation to improve stem straightness in Eucalyptus globulus. *Annals of Forest Science, 70*(5), 461-470. doi:10.1007/s13595-013-0277-9

Blackburn, D. P., Hamilton, M. G., Harwood, C. E., Innes, T. C., Potts, B. M., & Williams, D. (2011). Genetic variation in traits affecting sawn timber recovery in plantation-grown Eucalyptus nitens. *Annals of Forest Science, 68*(7), 1187-1195. doi:10.1007/s13595-011-0130-y

Blackwell, P., & Walker, J. C. F. (2006). Sawmilling *Primary Wood Processing: Principles and Practice* (pp. 203-250).

Blakemore, P. (2011). Internal checking during eucalypt processing *In: Delamination in Wood, Wood Products and Wood-Based Composites* (pp. 237-254). DOI: 10.1007/978-90-4819550-3_12.

Blakemore, P., & Langrish, T. A. G. (2008). Effect of pre-drying schedule ramping on collapse recovery and internal checking with Victorian Ash eucalypts. *Wood Science and Technology, 42*(6), 473-492. doi:10.1007/s00226-008-0185-6

Blakemore, P., Morrow, A., Ngo, D., Washusen, R., Harwood, C., Northway, R., M., W., Volker, P., & Porada, H. (2010). Plantation-grown Eucalyptus nitens: Solid wood quality and processing performance on linear sawing systems with a range of commercial and experimental drying schedules. *CRC for Forestry Technical Report No. 200* (http://www.crcforestry.com.au/publications/downloads/TR200-Harwood.pdf), 48pp.

Blakemore, P., Morrow, A., Washusen, R., Harwood, C., Wood, M., & Ngo, D. (2010). Evaluation of thin-section quarter-sawn boards and rotary veneer from plantation-grown Eucalyptus nitens. *CRC for Forestry Technical Report No. 202.* (http://www.crcforestry.com.au/publications/downloads/CRC-TR-202-final.pdf), 24pp.

Blakemore, P., & Northway, R. (2009a). Preliminary report: Review of, and recommendations for, internal and surface check research. *Forest & Wood Products Australia, Report*

CMSE20090203 *http://www.fwpa.com.au/rd-and-e/processing/174-processing-methods-for*http://www.fwpa.com.au/rd-and-e/processing/174-processing-methods-for-production-of-solid-wood-products-from-plantation-grown-eucalyptus-species-of-importance-to-australia.html*production-of-solid-wood-products-from-plantation-grown-eucalyptus-species-of*http://www.fwpa.com.au/rd-and-e/processing/174-processing-methods-for-production-of-solid-wood-products-from-plantation-grown-eucalyptus-species-of-importance-to-australia.html*importance-to-australia.html*, 62pp.

Blakemore, P., & Northway, R. (2009b). Review of, and recommendations for, research into preventing or ameliorating drying related internal and surface checking in commercially important hardwood species in south-eastern Australia *FWPA Report, Project No: PNB0470809* (ISBN: 978-1-920883-92-), 84pp.

Blundell, R., & Washusen, R. (2013). Improving the value chain for plantation-grown eucalypt sawn wood in China, Vietnam and Australia: sawing and drying. *Australian Centre for International Agricultural Research, FR2013-11*, 43pp.

Botrel, M. C. G., Da Silva, J. R. M., Trugilho, P. F., Da Silva Rosado, S. C., & Fernandes, B. R. (2007). Genetic gain in physical and mechanical properties of Eucalyptus clones. *Ganho genÃ©tico em propriedades fÃ-sicas e mecÃ¢nicas de clones de Eucalyptus*(76), 13-19.

Bradbury, P. (2010). Plantation forestry - Argentina. *New Zealand Journal of Forestry, 55*(1), 10.

Bravo, S. D., Espinosa, M., Valenzuela, L., Cancino, J., & Lasserre, J. P. (2012). Effect of thinning on growth and some properties of wood of Eucalyptus nitens in a plantation of 15 years old. *Maderas: Ciencia y Tecnologia, 14*(3), 373-388. doi:10.4067/S0718-221X2012005000009

Brennan, G. K., Hingston, R. A., & Moore, R. W. (2004). Processing 17-year-old Tasmanian blue gum sawlogs grown at wide spacing. *Australian Forestry, 67*(4), 240-246.

Brown, A. G., & Beadle, C. L. (2008). Plantation Eucalypts for High-Value Timber. *Rural Industries Research and Development Corporation Report, RIRDC Publication No 08/113*(ISBN 1 74151 701 X), 182pp.

Bunn, E. H. (1971). Eucalypts for New Zealand: why, what, how and where? *Farm Forestry 13(2): 39-48, 13*(2), 39-48.

Bunn, E. H. (1981). The nature of the resource *New Zealand Journal of Forestry Science, 26*, 162– 199.

Bush, D. (2001). Selecting and breeding eucalypts for natural durability. *In Walker (Ed) "Developing a Eucalypt Resource: Learning from Australia and New Zealand*, 123.

Campbell, G. S., & Hartley, J. (1978). Drying and dried wood. *Chapter 16 in "Eucalypts for Wood Production", Hillis, W.E. and Brown, A.G. (ed.). CSIRO, Australia.*

Candy, S. G., & Gerrand, A. (1997). Comparison of financial returns from sawlog regimes for *Eucalyptus nitens* plantations in Tasmania. *Tasforests, 9*, 35-50.

Carnegie, A. J., Stone, C., Lawson, S., & Matsuki, M. (2005). Can we grow certified eucalypt plantations in subtropical Australia? An insect pest management perspective. *New Zealand Journal of Forestry Science, 35*(2-3), 223-245.

Cassidy, M., Palmer, G., & Smith, R. G. B. (2013). The effect of wide initial spacing on wood properties in plantation grown Eucalyptus pilularis. *New Forests, 44*(6), 919-936. doi:10.1007/s11056-013-9385-5

Chafe, S. C. (1979). Growth stress in trees. *Australian Forest Research 9*, 203-223.

Chafe, S. C., & Ananias, R. A. (1996). Effect of presteaming on moisture loss and internal checking in high-temperature-dried boards of Eucalyptus globulus and Eucalyptus regnans. *Journal of the Institute of Wood Science, 14*(2), 72-77.

Chauchan, S. (2001). Segregation of Eucalyptus tereticornis Sm. clones for properties relevant to solid wood products. *Annals of Forest Science, 68*(3), 511-521.

Chauhan, S., & Entwistle, K. (2010). Measurement of surface growth stress in Eucalyptus nitens maiden by splitting a log along its axis. *Holzforschung, 64*(2), 267-272. doi:10.1515/HF.2010.022

Chen, S., & Wood, M. (2011). The potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opportunities for this resource: Part B *Forest & Wood Products Australia Report, PNB 139-0809*, 17pp.

Chikumbo, O., & Nicholas, I. (2011). Efficient thinning regimes for Eucalyptus fastigata: Multiobjective stand-level optimisation using the island model genetic algorithm. *Ecological*

Modelling, 222(10), 1683-1695. doi:10.1016/j.ecolmodel.2011.03.004

Clair, B., Alteyrac, J., Gronvold, A., Espejo, J., Chanson, B., & Alméras, T. (2013). Patterns of longitudinal and tangential maturation stresses in Eucalyptus nitens plantation trees. *Annals of Forest Science, 70*(8), 801-811. doi:10.1007/s13595-013-0318-4

Cookson, L. J. (2004). The in-ground Natural Durability of Australian Timbers *Forest & Wood Products Research & Development Corporation Project No. PN04.1004*, 12pp.

Cookson, L. J. (2005). The in-ground natural durability of Australian timbers. *FWPRDC, Melbourne, PN04.1004, 14 pp. http://www.fwprdc.org.au/content/pdfs/PN04.1004.pdf*, 75pp.

Cookson, L. J. (2012). Preservation of eucalypt paling fences, a test of sub-standard treatments. *International Wood Products Journal, 3*(2), 83-88. doi:10.1179/2042645311Y.0000000024
Cookson, L. J., & McCarthy, K. J. (2013). Influence of tree age and density on the above-ground natural durability of eucalypt species at Innisfail. *Australian Forestry, 76*(3-4), 113-120. doi:10.1080/00049158.2013.817939
Crafford, P. L., & Wessels, C. B. (2016). The potential of young, green finger-jointed Eucalyptus grandis lumber for roof truss manufacturing. *Southern Forests, 78*(1), 61-71. doi:10.2989/20702620.2015.1108618
Cubbage, F., Donagh, P. M., Balmelli, G., Olmos, V. M., Bussoni, A., Rubilar, R., Torre, R. D. L., Lord, R., Huang, J., Hoeflich, V. A., Murara, M., Kanieski, B., Hall, P., Yao, R., Adams, P., Kotze, H., Monges, E., Pérez, C. H., Wikle, J., Abt, R., Gonzalez, R., & Carrero, O. (2014). Global timber investments and trends, 2005-2011. *New Zealand Journal of Forestry Science, 44*. doi:10.1186/1179-5395-44-S1-S7
Da Costa, E. W. B. (1979). Comparative decay resistance of Australian timbers in accelerated laboratory tests. *Australian Forest Research, 9*, 119–135.
Dawson, B. S. W., Pearson, H., Kroese, H., & Sargent, R. (2014). Effect of specimen dimension and pre-heating temperature on supercritical CO_2 dewatering of radiata pine sapwood *Holzforschung, 69*(4), 421-430.
De Carvalho, A. M., Lahr, F. A. R., & Bortoletto Jr, G. (2004). Use of Brazilian eucalyptus to produce LVL panels. *Forest Products Journal, 54*(11), 61-64. de Fégely, R. (2001). Where are we now? *Leading Edge, Forests & Wood Products Research and Development Corporation, Melbourne, December, 1*(4), 4.
de Fégely, R. (2004). Sawing regrowth and plantation hardwoods with particular reference to growth stresses Part A literature review *Foret & Wood Products Research and Development Corporation Report, No. PN02.1308*, 44pp.
De Lima, I. L., Garcia, J. N., & De Stefano Piedade, S. M. (2002). Log end splitting and their implications on lumber end splitting. *Scientia Forestalis/Forest Sciences*(61), 13-24. De Moraes Gonçalves, J. L., Stape, J. L., Laclau, J. P., Smethurst, P., & Gava, J. L. (2004). Silvicultural effects on the productivity and wood quality of eucalypt plantations. *Forest Ecology and Management, 193*(1-2), 45-61. doi:10.1016/j.foreco.2004.01.022
De Moraes Gonsalves, J. L., Stape, J. L., Laclau, J. P., Smethurst, P., & Gava, J. L. (2004). Silvicultural effects on the productivity and wood quality of eucalypt plantations. *Forest Ecology and Management, 193*(1-2), 45-61.
De Pádua, F. A., Trugilho, P. F., Rosado, S. C. D. S., Lima, J. T., Cardoso Jr, A. A., & Oliveira, A. C. (2004). Estimate of the genetic parameters of growth stresses in Eucalyptus clones. *Scientia Forestalis/Forest Sciences*(66), 152-160.
Del Menezzi, C. H. S., & Teixeira, D. E. (2004). Species effect on the quality of Eucalyptus sawnwood obtained by two processing methods. *Journal of the Institute of Wood Science, 16*(4), 215-222.
Dick, M. A., Withers, T. M., Bulman, L. S., & Hood, I. A. (2004). Relative forest health risks of Eucalyptus nitens and Eucalyptus fastigata. *Scion Lecture to Waiariki*.
Dickson, R. L., Raymond, C. A., Joe, W., & Wilkinson, C. A. (2003). Segregation of Eucalyptus dunnii logs using acoustics. *Forest Ecology and Management, 179*(1-3), 243-251.
Dungey, H. S., Gaunt, D. J., Dunningham, E. A., Shearer, J., Lowe, S., Burton, R. J., & Richardson, B. (2013a). Emerging specialty wood industries. *Scion Confidential Report, Sydney Report* (51503), 111.
Dungey, H. S., Gaunt, D. J., Dunningham, E. A., Shearer, J., Lowe, S., Burton, R. J., & Richardson, B. (2013b). Emerging specialty wood industries *Scion Unpublished Report - Research Proposal*, 111pp.
Dungey, H. S., & Potts, B. M. (2002). Susceptibility of some Eucalyptus species and their hybrids to possum damage. *Australian Forestry, 65*(1), 23-30.
Eldridge, K., Davidson, J., Harwood, C., & van Wyk, G. (1993). Eucalypt domestication and breeding. *Oxford Univ. Press*, 288pp.
Eleotério, J. R., Reichert, D., Hornburg, K. F., & Meneguelli, I. (2015). Specific gravity and shrinkage coefficients of wood of six species of eucalypts cultivated on the coast of Santa

Catarina. *Floresta, 45*(2), 329-336. doi:10.5380/rf.v45i2.34699

30

Farrell, R., Blum, S., Williams, D., & Blackburn, D. (2011). The potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opportunities for this resource: Part A *FWPA Report PNB139-09 ISBN: 978-1-921763-47-2* 82pp.
Farrell, R., Innes, T., & G., N. (2008). Sorting plantation Eucalyptus nitens logs with acoustic wave velocity. *Forest and Wood Products Australia, Project number: PN 07.3018*, 32p.
Farrell, R., Innes, T. C., & C.E, H. (2012). Sorting Eucalyptus nitens plantation logs using acoustic wave velocity. *Australian Forestry, 75*(1), 22-30.
Fegely, d. (2004). Sawing Regrowth and Plantation Hardwoods with Particular Reference to Growth Stresses Part B Survey Results. *FWPRDC Report, Report No. PNO2.1308*, 35pp.
Ferraz Filho, A. C., Scolforo, J. R. S., & Mola-Yudego, B. (2014). The coppice-with-standards silvicultural system as applied to Eucalyptus plantations - a review. *Journal of Forestry Research, 25*(2), 237-248. doi:10.1007/s11676-014-0455-0
Flynn, R. (2010). Eucalyptus: Having an Impact on the Global Solidwood Industry *Wood Rersources International*, 1pp.
Forrester, D. I. (2013). Growth responses to thinning, pruning and fertiliser application in Eucalyptus plantations: A review of their production ecology and interactions. *Forest Ecology and Management, 310*, 336-347.
Forrester, D. I., Collopy, J. J., Beadle, C. L., & Baker, T. G. (2013). Effect of thinning, pruning and nitrogen fertiliser application on light interception and light-use efficiency in a young Eucalyptus nitens plantation. *Forest Ecology and Management, 288*, 21-30. doi:10.1016/j.foreco.2011.11.024
Forrester, D. I., Medhurst, J. L., Wood, m., Beadle, c. l., Valencia, J. C., & Harwood, C. (2013). The effect of solid-wood silviculture on growth, form and wood properties in Eucalyptus plantations: an Australian perspective. *FWPA Report* (PNB291-1112B), 99pp.
Franich, R. A., Gallagher, S., & Kroese, H. (2014). Dewatering green sapwood using carbon dioxide cycled between supercritical fluid and gas phase. *Journal of Supercritical Fluids, 89*, 113-118. doi:10.1016/j.supflu.2014.02.019
Franke, S., & Marto, J. (2014). Investigation of Eucalyptus globulus wood for the use as an engineered material, *WCTE 2014 - World Conference on Timber Engineering, Proceedings*.
Fry, G. (1983). Eucalypts in New Zealand: A position report. *New Zealand Journal of Forestry, 28*(3), 394-411.
Garcia, R. A., de Carvalho, A. M., de Figueiredo Latorraca, J. V., de Matos, J. L. M., Santos, W. A., & de Medeiros Silva, R. F. (2010). Nondestructive evaluation of heat-treated Eucalyptus grandis Hill ex Maiden wood using stress wave method. *Wood Science and Technology*, 112.
Gaunt, D., Penellum, B., & McKenzie, H. M. (2003). Eucalyptus nitens laminated veneer lumber structural properties. *New Zealand Journal of Forestry Science, 33*(1), 114-125.
Gaunt, D. J., Penellum, B. S., & McKenzie, H. M. (2002). Eucalyptus nitens Laminated Veneer Lumber (LVL) structural properties. *New Zealand Journal of Forestry Science 33*(1), 114125.
Gerrand, A., Medhurst, J., & Neilsen, W. (1997). Thinning and pruning eucalypt plantations for sawlog production in Tasmania. *Tasforests, 9*, 15-34.
Gonçalves, J. L. D. M., Alvares, C. A., Higa, A. R., Silva, L. D., Alfenas, A. C., Stahl, J., Ferraz, S. F. D. B., Lima, W. D. P., Brancalion, P. H. S., Hubner, A., Bouillet, J. P. D., Laclau, J. P., Nouvellon, Y., & Epron, D. (2013). Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. *Forest Ecology and Management, 301*, 6-27. doi:10.1016/j.foreco.2012.12.030
10.1016/j.foreco.2012.07.045; Vigneron, P., Bouvet, J., (2000) Eucalypt hybrid breeding in Congo, pp. 14-26. , Dungey, H.S., Dieters, M.J., Nikles, D.G. (Eds.), Hybrid Breeding and Genetics of Forest Trees. Proceedings of QFRI/CRC-SPF Symposium, 9-14th April 2000 Noosa,

Queensland, Australia. Department of Primary Industries, Brisbane; Wilcken, C.F., (2011) Breeding Eucalyptus for insect resistance, , IUFRO Working Group 2.08.03 - Improvement and Culture of Eucalyptus. 2011: Porto Seguro, Bahia State, Brazil. Proceedings... Piracicaba: Vitor's Design, 2011. v. 1; Wilcken, C.F., Sanchez-Bezerra, N., Oliveira, R.J.R., Orlato, C., Ferreira Filho, P.J., (2008), pp. 129-134. , Manejo Integrado de Pragas em povoamentos florestais. In: Encontro Brasileiro de Silvicultura, 1. Curitiba, Parana State, Brazil. Proceedings... Piracicaba: PTSM/IPEF/ESALQ/FUPEF, 2008Wilcken, C.F., Barbosa, L.R., Sa, L.A.N., Soliman, E.P., Lima, A.C.V., Dal Pogetto, M.H.F.A., Dias, T.C.R., (2011) Manejo de pragas exóticas em florestas de eucalipto, pp. 129-134. , Encontro Brasileiro de Silvicultura, 2. Campinas, São Paulo State, Brazil. Proceedings... Piracicaba: PTSM/IPEF/ESALQ/FUPEF, 2011; Xu, D.P., Dell, B., (2002) Nutrient management of eucalypt plantations in South China, pp. 139-159. , International Symposium on Eucalypt Plantations. Presentation Papers & Abstracts, September 2002, Guangdong, P.R. China, 1-6. RITF, Guangdong; Xu, D.P., Yang, Z.J., Dell, B., Gong, M., Effects of site management in Eucalyptus urophylla plantations in Guangdong province, China (2000) Site Management and Productivity in Tropical Plantation Forests: Workshop Proceedings 31-40 December 1999, Kerala, India, pp. 11-20. , CIFOR, Bogor, E.K.S. Nambiar, C. Cossalter, A. Tiarks, J. Ranger (Eds.); Zen, S., Influência da matocompetição em plantas de Eucalyptus grandis (1987) IPEF Série Téc., 12, pp. 25-35; Zen, S., Yonezawa, J.T., Feldeberg, J.E., (1995), pp. 65-72. , Implantação de florestas no sistema de cultivo mínimo. In: Seminário Sobre Cultivo Mínimo do Solo em Florestas, 1, CuritibaBrasil, 1995. Proceedings. Curitiba-Brasil, CNPFloresta/IPEF/UNESP/SIF/FUPEFZobel, B., Campinhos, E., Ikemori, Y.K., Selection and breeding for wood uniformity (1982) TAPPI Research and Development Division Conference, pp. 159-168 2009.1.15637.1.8^USP^ 2009.1.15637.1.8^COFECUB^

Greaves, H. (1998). Trends in wood research and utilisation - a view from the Institute of Wood Science, Australian Branch. *Journal of the Institute of Wood Science, 14*(6), 293-300.

Guimarães Júnior, J. B., Mendes, L. M., Mendes, R. F., & Mori, F. A. (2011). Wood paticleboards made from residues obtained in the veneer production of eucalypt species and provenances. *Cerne, 17*(4), 443-452.

Hague, J. R. B. (2013). Utilisation of plantation eucalypts in engineered wood products. *FWPA Report, PNB290-1112* 16pp.

Hamilton, M., Joyce, K., Williams, D., Dutkowski, G., & Potts, B. (2008). Achievements in forest tree improvement in Australia and New Zealand -9. Genetic improvement of Eucalyptus nitens in Australia. . *Australian Forestry, 71*, 82-93.

Hamilton, M., & Potts, B. (2008). Review of Eucalyptus nitens genetic parameters. *New Zealand Journal of Forestry Science, 38*, 102-119.

Hamilton, M. G., Blackburn, D. P., McGavin, R. L., Baillères, H., Vega, M., & Potts, B. M. (2015). Factors affecting log traits and green rotary-peeled veneer recovery from temperate eucalypt plantations. *Annals of Forest Science, 72*(3), 357-365. doi:10.1007/s13595-0140430-0

Hamilton, M. G., Greaves, B. M., & Dutkowski, G. W. (2010). Genetic correlations between pulpwood and solid-wood selection and objective traits in *Eucalyptus globulus*. *Annals of Forestry Science, 67*, 511-521.

Hansmann, C., Stingl, R., Prieto, O. G., Lopez, C. B., & Resch, H. (2008). High-frequency energyasisted vacuum drying of fresh eucalyptus globulus. *Drying Technology, 26*(5), 611-616. doi:10.1080/07373930801946759

Haque, M. N., & Langrish, T. A. G. (2005). Assessment of the actual performance of an industrial solar kiln for drying timber. *Drying Technology, 23*(7), 1541-1553. doi:10.1081/DRT200063544

Harris, J. M., & Young, G. D. (1987). Wood properties of eucalypts and blackwood grown in New Zealand. *Proceedings of the AFDI International Forestry Conference for the Australian Bicentenary, 1988, Albury, NSW.*

Harwood, C. (2010). Sawn timber from native forests and plantations in Tasmania. *CRC for Forestry Bulletin 13*, 6pp.
Harwood, C., Bandara, K., Washusen, R., Northway, R., Henson, M., & Boyton, S. (2005). Variation in Wood Properties of Plantation-Grown Eucalyptus dunnii Relevant to SolidWood Products. *Forest and Wood Products Research and Development CorporationMelbourne, Report PN04.3003, FWPRDC,* , 37 pp.
Harwood, C., Bulman, P., Bush, D., Stackpole, D., & Mazanec, R. (2001). Australian Low Rainfall Tree Improvement Group: Compendium of Hardwood Breeding Strategies. *RIRDC Publication 01/100. Rural Industries Research and Development Corporation, Canberra.*, 148pp.
Harwood, C. E. (2011). New introductions - do it right. *In: Walker (Ed), "Developing a Eucalypt Resource: Learning From Australia and Elsewhere"*, 43 - 53.
Harwood, C. E., Bush, D. J., Butcher, T., Bird, R., Henson, M., Lott, R., & Shaw, S. (2007). Achievements in forest tree genetic improvement in Australia and New Zealand 4: Tree improvement for low-rainfall farm forestry. *Australian Forestry, 70*(1), 23-27.
Haslett, A. N. (1987). Guide to handling and grade-sawing plantation-grown eucalypts. *New Zealand Forest Research Institute Bulletin 142*, 74pp.
Haslett, A. N. (1988a). Handling and grade-sawing plantation-grown eucalypts. . *Forest Research Institute Bulletin,. New Zealand Forest Research Institute, Rotorua., No. 142*, 72pp.
Haslett, A. N. (1988b). Properties and processing of New Zealand-grown eucalypts. *Proceedings of the AFDI International Forestry Confor the Australian Bicentenary, 1988, 3*.
Haslett, A. N. (1988c). Properties and processing of New Zealand-grown eucalypts. *Proceedings of the AFDI International Forestry Confor the Australian Bicentenary 1988. Volume III*.
Haslett, A. N. (1988d). Properties and utilisation of exotic speciality timbers grown in New Zealand. Part V: Ash eucalypts and Eucalyptus nitens. *Forest Research Institute Bulletin No. 119: Part V*, 20pp.
Haslett, A. N. (1988e). Sawing eucalypts: techniques are more important than equipment. *NZ Forest Industries, March 1988* 37, 39, 44.
Haslett, A. N. (1989). Properties and utilisation of exotic speciality timbers grown in New Zealand. Part VI: Eastern blue gums and stringy barks. *NZ FRI Bulletin 119 Part VI*, 18pp.
Haslett, A. N. (1990). Properties and utilisation of exotic speciality timbers grown in New Zealand: Part VI: Eastern blue gums and stringybarks: E. botryoides, E. saligna, E. globoidea, E. muellerana, E. pilularis. *FRI Bulletin, Ministry of Forestry, Forest Research Institute, Rotorua, NZ., No. 119*.
Haslett, A. N., Kininmomth, J. A. K., & Revell, D. (1984). Utilisation of New Zealand grown eucalypts. *NZ FRI What's New in Forest Research 122*, 4.
Haslett, A. N., Kininmonth, J. A., & Revell, D. H. (1984). Utilisation of New Zealand grown eucalypts. *What's New in Forest Research No. 122*, 4pp.
Haslett, A. N., Simpson, I., & Sole, J. A. (1997a). Drying of plantation-grown Eucalypts. *FRI Unpublished Report, Sydney Output*(No. 52198), 34pp.
Haslett, A. N., Simpson, I. G., & Sole, J. A. (1997b). Drying of plantation-grown Eucalypts. *Scion Unpublished Report, Sydney Output No. 07718*, 7pp.
Haslett, A. N., & Young, G. D. (1992). Nitens for sawn timber? *New Zealand Tree Grower 13*(2), 8-9.
Hay, A. E., Franklin, D. A., & Revell, D. H. (1984). Eucalypts: species choice and site requirements. *What's New in Forest Research No. 124*, 4pp.
Hay, A. E., Nicholas, I., & Shelbourne, A. (2005). Alternative species to radiata pine. *Section 5.4 in: Forestry Handbook, editor M Colley, New Zealand Institute of Forestry Inc, Christchurch, 2005*, 83-86.
Hung, T. D., Brawner, J. T., Meder, R., Lee, D. J., Southerton, S., Thinh, H. H., & Dieters, M. J. (2015). Estimates of genetic parameters for growth and wood properties in Eucalyptus pellita F. Muell. to support tree breeding in Vietnam. *Annals of Forest Science, 72*(2), 205217. doi:10.1007/s13595-014-0426-9
Ilic, J., & Hillis, W. E. (1986). Prediction of Collapse in Dried Eucalypt Wood. *Holzforschung, 40*(2), 109-112. doi:10.1515/hfsg.1986.40.2.109

Innes, T., Greaves, B., Nolan, G., & Washusen, R. (2008a). Determining the economics of processing plantation eucalypts for solid wood products. *FWPA Project No: PN04.3007*, 90pp.

Innes, T. C. (1996). Pre-drying of collapse prone wood free of surface and internal checking. *Holz als Roh - und Werkstoff, 54*(3), 195-199.

Innes, T. C., Greaves, B. M., Nolan, G., & Washusen, R. (2008b). Determining the economics of processing plantation eucalypts for solid timber products *Forest & Wood Products Research & Development Corporation Rerport, PN04.3007* 90pp.

Jankowsky, I. P., & dos Santos, G. R. (2005). Drying behaviour and permeability of*Eucalyptus grandis* lumber. *Maderas ciencia y Technologia, 7*(1), 17-21.

Jones, T. G., McConnochie, R. M., Shelbourne, T., & Low, C. B. (2010). Sawing and grade recovery of 25-year-old Eucalyptus fastigata, E. globoidea, E. muelleriana and E. pilularis. *New Zealand Journal of Forestry Science, 40*, 19-31.

Jones, T. J., Low, C. B., O'Callahan, D. R., & Chittenden, C. M. (2014). Variation in the wood properties of coast redwood trees in New Zealand. *New Zealand Journal of Forestry Science 44*(http://www.nzjforestryscience.com/content/44/1/11).

Kay, M. K. (2005). The risk of growing eucalypts in New Zealand. *In F. Lieutier & D. Ghaioule (Eds.), Entomological Research in Mediterranean Forest Ecosystems, France.*, 229-236.

Kennedy, S. G., Dungey, H. S., Yanchuk, A., & Low, C. B. (2012). Eucalyptus fastigata: Its current status in New Zealand and breeding objectives for the future. *Silvae Genetica, 60*(6), 259266.

Kininmonth, J. A., Revell, D. H., & Williams, D. (1974a). The drying of eucalypt species in New Zealand. 4. The sawing, seasoning and grading of E.delegatensis and E.saligna sawn timber in commercial-scale studies. *FRI Unpublished Report, Sydney Output* (No. 04640), 24pp.

Kininmonth, J. A., Revell, D. H., & Williams, D. H. (1974b). Utilisation of New Zealand grown eucalypts for sawn timber and veneer. *New Zealand Journal of Forestry, 19*(2), 246-263.

Lausberg, M. J. F., Gilchrist, K. F., & Skipwith, J. H. (1996). Wood properties of *Eucalyptus nitens* grown in New Zealand. *NZ Journal of Forestry Science, 25*(2), 147-163.

Ledford, H. (2014). Brazil considers transgenic trees: Genetically modified eucalyptus could be a global test case. *Nature, 512*(7515), 357.

Lee, D. J., Zbonak, A., & McGavin, R. L. (2001). Development of *E. agrophloia* in Queenslend: Lessons learnt. *In: Walker et al (2011) "Developing a Euicalypt Rersource: Learning From Australia and elsewhere"* 55-66.

Leech, M. D. (2008). Researching high-value markets for eucalypt timber from old-growth forests in Tasmania. *Australian Goveernment, Dept. Agriculture, Gisheries, Forestry, http://www.forestrytas.com.au/assets/0000/0562/Leech_report_to_TCFA_Research_Implementation_Committee.pdf*, 19pp.

Lorentz, K. A., & Minogue, P. J. (2015). Exotic Eucalyptus plantations in the southeastern US: risk assessment, management and policy approaches. *Biological Invasions, 17*(6), 1581-1593.

Loulidi, I., Famiri, A., Chergui, M., & Ellghorba, M. (2012). The physical and mechanical properties of Eucalyptus hybrid *E. camaldulensis x E. grandis*: Comparison with its parental species. *International Journal of Engineering and Science, 1*(1), 1-7

Mackay, J. H. G. (1972). Recovery of collapse in *Eucalyptus delegatensis* by use of anhydrous ammonia and steam. *Wood and Fiber, 4*(3), 126-129.

Malan, F. S., & Hoon, M. (1992). Effect of initial spacing and thinning on some wood properties of Eucalyptus grandis. *South African Forestry Journal 163*, 13-20.

McCarthy, K., Cookson, L., & D, S. (2009). Natural durability of six eucalypt species from farm forestry and low rainfall areas. *Report Rural Industries Research and Development Corporation, Canberra, 08-161*, 63pp.

McCarthy, K., & Cookson, L. J. (2006). Natural Durability of Five Eucalypt Species Suitable for Low Rainfall Areas. *RIRDC Publication No 08/162, RIRDC Project No CSF-61A*, 16pp.

McConnochie, R. M., & Low, C. B. (2007). Eucalypt Species Wood Properties and Sawing Study. *In: Eucalypts For High Value Timber Conference, Melbourne, October 2007*.

McConnochie, R. M., & Nicholas, I. D. (2007). Eucalypts For High Value Timber - Poster. *Conference, 9-12 October 2007*.
McConnochie, R. M., Shelbourne, C. J. A., Kimberley, M. O., & McKenzie, H. M. (2004). Development of non-destructive methods for the prediction of growth stress and internal checking in the sawing and drying of Eucalyptus nitens lumber. *In: Abstracts of IUFRO conference, Eucalypts in a changing world, Aveiro, Portugal, 11-15 October 2004*, 23pp.
McGavin, R. L., Bailleres, H., Hamilton, M., Blackburn, D., Vega, M., & Ozarska, B. (2015). Variation in rotary veneer recovery from australian plantation Eucalyptus globulus and Eucalyptus nitens. *BioResources, 10*(1), 313-329.
McGavin, R. L., Bailleres, H., Lane, F., Blackburn, D., Vega, M., & Ozarska, B. (2014). Veneer recovery analysis of plantation eucalypt species using spindleless lathe technology. *BioResources, 9*(1), 613-627.
McKenzie, H. M. (1999). Eucalyptus fastigata: a research update. *In: Proceedings of the 43rd National Conference of the NZ Farm Forestry Association, 12-16 March 1999, New Plymouth*, 80-81.
McKenzie, H. M., Britton, R. A. J., Kimberley, M. O., McKinley, R. B., & Shelbourne, C. J. A. (2002). Sawing, sawn-timber, veneer and wood properties and their inter-relationships in 15-year-old Eucalyptus nitens. *Scion Unpublished Report, Sydney Output 33065*.
McKenzie, H. M., Shelbourne, C. J. A., Kimberley, M. O., McKinley, R. B., & Britton, R. A. J. (2003). Processing young plantation-grown Eucalyptus nitens for solid-wood products. 2: Predicting product quality from tree, increment core, disc, and 1-M billet properties. *New Zealand Journal of Forestry Science, 33*(1), 79-113.
McKenzie, H. M., Turner, J. C. P., & Shelbourne, C. J. A. (2003a). Processing young plantationgrown Eucalyptus nitens (Dean et Maiden) for solid-wood products : 1. Individual-tree variation in quality and recovery of appearance-grade lumber and veneer. *New Zealand Journal of Forestry Science 33*(1), 62-78.
McKenzie, H. M., Turner, J. C. P., & Shelbourne, C. J. A. (2003b). Processing young plantationgrown Eucalyptus nitens for solid-wood products. 1: Individual-tree variation in quality and recovery of appearance-grade lumber and veneer. *New Zealand Journal of Forestry Science, 33*(1), 62-78.
McKenzie, H. M. B., R D; Roper, J G;. (2000). Quality of timber sawn from pruned plantation-grown Eucalyptus fastigata in New Zealand. *In Proceedings of the International Union of Forest Research Organisations conference "The Future of Eucalypts for Wood Products", March 2000, Launceston, Tasmania, Australia In Proceedings of the International Union of Forest Research Organisations conference "The Future of Eucalypts for Wood Products", March 2000, Launceston, Tasmania, Australia*, 184-191.
McKenzie, H. M. G., D J;. (2001). Eucalyptus nitens laminated veneer lumber. *Forest Research Wood Processing Newsletter`` May 2001, 29*, 499.
McKimm, R. J., Waugh, G., & Northway, L. (1988). Utilisation potential of plantation-grown Eucalyptus nitens. *Australian Forestry, 51*(1), 63-71.
McKinley, R. B., Shelbourne, A., Low, C., Penellum, B., & Kimberley, M. O. (2003). Wood properties of young Eucalyptus nitens, E. globulus and E. maidenii in Northland, New Zealand. *New Zealand Journal of Forestry Science, 32*(3), 334-356.
McKinley, R. B., Shelbourne, C. J. A., Harris, J. M., & Young, G. D. (2000). Variation in whole-tree basic wood density for a range of plantation species grown in New Zealand. *New Zealand Journal of Forestry Science, 30*(3), 436-446.
Meder, A. R., Yang, J., Blakemore, P., Morrow, A., Ngo, D., Ebdon, N. J., Josh, M., & Muruganathan, M. (2010). Investigation of NDE technologies for drying quality segregation to aim for optimal kiln schedules to reduce drying degrade and accelerate kiln throughput in the hardwood sawmilling industry. *FWPA Project No. PNB126-0809*, 102.
Miranda, I., Gominho, J., Lourenço, A., & Pereira, H. (2007). Heartwood, extractives and pulp yield of three Eucalyptus globulus clones grown in two sites. *Appita Journal, 60*(6), 485488+500.
Miranda, I., Gominho, J., & Pereira, H. (2009). Variation of heartwood and sapwood in 18-year-old Eucalyptus globulus trees grown with different spacings. *Trees - Structure and Function, 23*(2), 367-372. doi:10.1007/s00468-008-0285-9

Montagu, K. D., Kearney, D. E., & Smith, R. G. B. (2003). The biology and silviculture of pruning planted eucalypts for clear wood production - A review. *Forest Ecology and Management, 179*(1-3), 1-13.
Monteiro, T. C., Lima, J. T., da Silva, J. R. M., Trugilho, P. F., & de Andrade, B. C. L. (2013). Evaluation of Eucalyptus sawmill log to obtain structural parts. *Cerne, 19*(3), 357-364. doi:10.1590/S0104-77602013000300001
Moraisa, M. C., & Pereira, H. (2007). Heartwood and sapwood variation in Eucalyptus globulus Labill. trees at the end of rotation for pulpwood production. *Annals of Forest Science, 64*(6), 665-671. doi:10.1051/forest:2007045
Mugabi, P., Rypstra, T., Vermaas, H. F., & Nel, D. G. (2011). Effect of kiln drying schedule on the quality of South African grown Eucalyptus grandis poles. *European Journal of Wood and Wood Products, 69*(1), 19-26. doi:10.1007/s00107-009-0392-3
Müller, M. T., Haselein, C. R., De Melo, R. R., & Stangerlin, D. M. (2015). The influence of different combinations of Eucalyptus saligna and Pinus taeda veneers in LVL panels. *Ciencia Florestal, 25*(1), 153-164.
Nahrung, H. F., Loch, A. D., & Matsuki, M. (2016). Invasive insects in mediterranean forest systems: Australia *Insects and Diseases of Mediterranean Forest Systems* (pp. 475-498). Naidoo, S., Külheim, C., Zwart, L., Mangwanda, R., Oates, C. N., Visser, E. A., Wilken, F. E., Mamni, T. B., & Myburg, A. A. (2014). Uncovering the defence responses of eucalyptus to pests and pathogens in the genomics age. *Tree Physiology, 34*(9), 931-943.
doi:10.1093/treephys/tpu075
Nicholas, D. D., & Millen, P. (2012a). Durable Eucalypt Leaflet Series - Eucalyptus bosistoana. *New Zealand Drylands Forests Leaflet, http://nzdfi.org.nz/wp-content/uploads/2015/01/E*http://nzdfi.org.nz/wp-content/uploads/2015/01/E-bosistoana-information-leaflet.pdf*bosistoana-information-leaflet.pdf*, 9pp.
Nicholas, D. D., & Millen, P. (2012b). *Eucalyptus globoidea* - a durable hardwood for planting in the Bay of Plenty Region. *A report prepared for the Bay of Plenty Regional Council http://nzdfi.org.nz/wp-content/uploads/2015/04/Eucalyptus-globoidea-a-durable-hardwood*http://nzdfi.org.nz/wp-content/uploads/2015/04/Eucalyptus-globoidea-a-durable-hardwood-for-planting-in-the-BoP-region.pdf*for-planting-in-the-BoP-region.pdf*.
Nicholas, I. (1992). Pruning eucalypts. *Tree Grower, August 1992*, 18-20.
Nicholas, I. D., & Garner, S. A. (2007). A survey of alternative species markets. *New Zealand Journal of Forestry, 52*(1), 10-13.
Nicholas, I. D., & Hay, A. E. (1992). Selection of special purpose species: effect of pests and diseases. *NZ Journal of Forestry Science, 20*(3), 279-289.
Nichols, J. D., Geoff, R., Smith, B., Grant, J., & Glencross, K. (2010). Subtropical eucalypt plantations in eastern Australia. *Australian Forestry, 73*(1), 53-62.
Nolan, G., Greaves, B., Washusen, R., Parsons, M., & Jennings, S. (2005). Eucalypt Plantations for Solid Wood Products in Australia - A Review - 'If you don't prune it, we can't use it'. *Forest & Wood Products Research & Development Corporation Rerport, Project No. PN04.3002 ISBN 1920883096*, 130pp.
Nolan, G., Innes, T., Redman, A., & McGavin, R. L. (2003a). Australian Drying Best Practice Manual Part 1. *FWPRDC Report No. PN01.1307*, 180.
Nolan, G., Innes, T., Redman, A., & McGavin, R. L. (2003b). Australian Drying Best Practice Manual Part 2. *FWPRDC, Report No. PN01.1307*, 324.
Okuyama, T., Doldán, J., Yamamoto, H., & Ona, T. (2004). Heart splitting at crosscutting of eucalypt logs. *Journal of Wood Science, 50*(1), 1-6. doi:10.1007/s10086-003-0533-y
Omonte, M., & Valenzuela, L. (2015). Longitudinal growth stresses in eucalyptus nitens trees with sawable dimensions. *Maderas: Ciencia y Tecnologia, 17*(3), 673-684. doi:10.4067/S0718221X2015005000059
Ozarska, B. (1999). A review of the utilisation of hardwoods for LVL. *Wood Science and Technology, 33*(4), 341-351.
Ozarska, B. (2009). Engineering properties of selected young plantation-grown Australian hardwoods for furniture. *Forest Products Journal, 59*(7-8), 27-30.

Page, D., & Singh, T. (2014a). Drability of New Zealand grown timbers. *New Zeaand Journal of Forestry, 58*(4), 26-30.
Page, D. R., & Singh, T. (2014b). Durability of New Zealand grown timbers. *New Zealand Journal of Forestry 58*(4), 26-30.
Page, D. R., & Singh, T. (2015). An update on durability of New Zealand grown timber. *IRG/WP 15-1085110-14 May 2015 Vina Del Mar, Chile*.
Pang, S., & Pearson, H. (2004). Experimental investigation and practical application of superheated steam drying technology of softwood timber. *Drying Technology, 22*(9), 20792094. doi:10.1081/LDRT-200034252
Pelletier, M. C., Henson, M., Boyton, S., Thomas, D., & Vanclay, J. (2008). Genetic variation on shrinkage properties of Eucalyptus pilularis assessed using increment cores and test blocks. *New Zealand Journal of Forestry Science, 38*(1), 194-210.
Peng, Y., Arnold, R., Washusen, R., Xiang, D., Wu, G., & Chen, S. (2015). Processing sawn wood from thinned, unpruned 17-year-old Eucalyptus dunnii in southern China. *Australian Forestry, 78*(2), 73-85. doi:10.1080/00049158.2015.1039953
Pinkard, E. A., Mohammed, C., Beadle, C. L., Hall, M. F., Worledge, D., & Mollon, A. (2004). Growth responses, physiology and decay associated with pruning plantation-grown

Eucalyptus globulus Labill. and E. nitens (Deane and Maiden) Maiden. *Forest Ecology and Management, 200*(1-3), 263-277. doi:10.1016/j.foreco.2004.07.004

Poole, B., Waugh, G., & Yang, J. L. (2013). Potential for growing and processing durable eucalypts in New Zealand. *Confidential Report for SWI, Report No.th*(119), 63.

Potts, B., Hamilton, M., & Blackburn, D. (2011). Genetics of Eucalypts: Traps and opportunities. *In University of Canterbury Seminar, Developing a Eucalypt Resource:Learning From Australia And Elsewere, Ed. John Walker*, 1-26.

Ratnasingam, J., Abdullah, A. M., Ramasamy, G., & Seng, C. Y. (2013). A review of different sawing and drying techniques used in processing small-diameter logs. *Journal of Applied Sciences, 13*(3), 341-347. doi:10.3923/jas.2013.341.347

Raymond, C., & Apiolaza, L. A. (2004). Incorporating wood quality and deployment traits in Eucalyptus globulus and Eucalyptus nitens. *In: Plantation Forest Biotechnology for the 21st Century, 2004 (Editors: Christian Walter and Mike Carson), ISBN: 81-7736-228-3* 8799.

Raymond, C. A. (2002). Genetics of Eucalyptus wood properties. *Annals of Forest Science, 59*(56), 525-531.

Rebolledo, P., Salvo, L., Contreras, H., Cloutier, A., & Ananias, R. A. (2013). Variation of internal checks related to anatomical structure and density in eucalyptus nitens wood. *Wood and Fiber Science, 45*(3), 279-286.

Redman, A. L. (2008). Evaluation of super-heated steam vacuum drying viability and development of a predictive drying model for four Australian hardwood species. *FPWA Project No: PNB045-0809*, 127pp.

Redman, A. L., Bailleres, H., Turner, I., & Perré, P. (2016). Characterisation of wood–water relationships and transverse anatomy and their relationship to drying degrade. *Wood Science and Technology*, 1-19. doi:10.1007/s00226-016-0818-0

Redman, A. L., & McGavin, R. L. (2010). Accelerated drying of plantation grown Eucalyptus cloeziana and Eucalyptus pellita sawn timber. *Forest Products Journal, 60*(4), 339-345.

Reid, J. S. (1957). The use of New Zealand-grown eucalypts. *Paper presented at ANZAAS Meeting, Dunedin*, 58-67.

Reid, R. W., & Washusen, R. (2014). Sawn timber from 10-year-old pruned Eucalyptus nitens (Deane & Maiden) grown in an agricultural riparian buffer *In: Rutherfurd et al (Eds) Conference Proceedings Third Australian Stream Management Conference, Brisbane 2729 August 2001 2*, 545- 550

Revell, D. H. (1976). Growing Eucalypts. *What's New in Forest Research No. 37*, 4pp.

Revell, D. H. (1981). Silviculture of eucalypts; New Zealand experience. *Proceedings of Workshop, Wood: Future Growth and Conversion, Canberra, May 1981*, 116-122.

Revell, D. H. (1982). Establishing eucalypts. *What's New in Forest Research No. 107*, 4pp.

Rezende, R. N., Lima, J. T., de Ramos E Paula, L. E., & da Silva, J. R. M. (2015). Effect of the steaming on the drying of eucalyptus grandis boards. *Cerne, 21*(1), 37-43. doi:10.1590/01047760201521011546

Roper, J. G., & Hay, A. E. (2000). Sliced veneer production from pruned plantation grown Eucalyptus in New Zealand. *In Proceedings of the International Union of Forest Research Organisations Conference "The future of Eucalypts for Wood Products", 19-24 March 2000, Launceston, Tasmania, Australia*, 106-112

Rosza, A., & Avramidis, S. (1996). Radio frequency vacuum drying of eucalypt timbers. *In: Proceedings of 5th International Wood Drying Conference, Quebec, Canada,*, 135-138.

Rosza, A. W. (1994). Dielectric vacuum drying of hardwoods. *In: Proceedings of 4th I.U.F.R.O. International Wood Drying Conference, Rotorua, New Zealand, 9-13 August: 271-278*.

Rudman, P. (1964). Durability in the genus eucalyptus. *Australian Forestry, 28*(4), 242-257. doi:10.1080/00049158.1964.10675949

Santana, W. M. S., Calegario, N., Arantes, M. D. C., & Trugilho, P. F. (2012). Effect of age and diameter class on the properties of wood from clonal Eucalyptus. *Cerne, 18*(1), 1-8.

Satchell, D. (2006). Pruning and thinning eucalyptus - Stringybark eucalypt silviculture. *New Zealand Tree Grower,* http://www.nzffa.org.nz/farm-forestry-model/resource-

[centre/tree](http://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/tree-grower-november-2006/stringybark-eucalypt-silviculture/)http://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/tree-grower-november-2006/stringybark-eucalypt-silviculture/*grower-articles/tree-grower-november-2006/stringybark-eucalypt-silviculture/*.

37

Satchell, D. (2015a). Eucalyptus nitens, recovery and economics of processing 15 year old trees for solid timber. *New Zealand Farm Forestry website* *http://www.nzffa.org.nz/special*http://www.nzffa.org.nz/special-interest-groups/eucalypt-action-group/report-eucalyptus-nitens-for-solid-timber/*interest-groups/eucalypt-action-group/report-eucalyptus-nitens-for-solid-timber/*.

Satchell, D. (2015b). Evaluating profitability of solid timber production from 15 year old pruned and thinned Eucalyptus nitens (Deane & Maiden) in Canterbury. *MSc Thesis, Canterbury University, Christchurch, NZ*, 181pp.

Satchell, D. (2015c). Sawing eucalypt. *New Zealand Farm Forestry website* *http://www.nzffa.org.nz/specialty-timber-market/information*http://www.nzffa.org.nz/specialty-timber-market/information-resources/sawmilling/hardwoods/sawing-eucalypt/*resources/sawmilling/hardwoods/sawing-eucalypt/*.

Satchell, D. (2016). *Eucalyptus nitens* for solid timber - silk purse or sow's ear? *New Zealand Journal of Forestry, 60*(4), 33-36.

Satchell, D., & Turner, J. (2010a). Solid timber recovery and economics of short-rotation smalldiameter eucalypt forestry using novel sawmilling strategy applied to eucalyptus regnans *FFR Diversified Species Report, FFR-DS028* 36pp.

Satchell, D., & Turner, J. A. (2010b). Short-rotation cold-climate eucalypt forestry for solid timber production: Prospects and possibilities. *New Zealand Journal of Forestry, 55*(2), 28-31.

Saviana, J., Sosa zitto, M. A., & Piter, J. C. (2009). Bending strength and stiffness of structural laminated veneer lumber manufactured from fast-growing argentinean eucalyptus grandis. *Maderas: Ciencia y Tecnologia, 11*(3), 183-190. doi:10.4067/S0718-221X2009000300002

Scheffer, T. C., & Cowling, E. B. (1966). Natural resistance of wood to microbial deterioration. *Annual Review of Phytopathology, 4*, 147 - 170.

Schönau, A. P. G., & Coetzee, J. (1989). Initial spacing, stand density and thinning in eucalypt plantations. *Forest Ecology and Management, 29*(4), 245-266. doi:10.1016/03781127(89)90097-2

Sepulveda-Villarroel, V., Perez-Peña, N., Salinas-Lira, C., Salvo-Sepulveda, L., Elustondo, D., & Ananias, R. A. (2016). The development of moisture and strain profiles during predrying of Eucalyptus nitens. *Drying Technology, 34*(4), 428-436. doi:10.1080/07373937.2015.1060490

Severo, E. T. D., Calonego, F. W., & de Matos, C. A. O. (2010). Lumber quality of Eucalyptus grandis as a function of diametrical position and log steaming. *Bioresource Technology, 101*(7), 2545-2548. doi:10.1016/j.biortech.2009.11.083

Severo, E. T. D., Tomaselli, I., Calonego, F. W., Ferreira, A. L., & Mendes, L. M. (2013). Effect of steam thermal treatment on the drying process of *Eucalyptus dunnii* variables. *Cerne, Lavras, v. 19, n. 4, p.c, 19*(4), 637-645.

Sharma, S. K., Shukla, S. R., Shashikala, S., & Poornima, V. S. (2015). Axial variations in anatomical properties and basic density of Eucalypt urograndis hybrid (Eucalyptus grandis × E. urophylla) clones. *Journal of Forestry Research, 26*(3), 739-744. doi:10.1007/s11676-015-0080-6

Sheild, E. D. (2003). Utilization of plantation-grown eucalypts: New resource new approaches. *IN Eucalyptus Plantations: Research, Management and Development, EDS, Wei, Run-Peng and Xu Daping,* *https://books.google.co.nz/books?id=qtjcvNSMupUC&pg=PA385&lpg=PA385&dq=added+value+products+from+eucalyptus&source=bl&ots=ZahVTa6bsY&sig=_KBQZBI0LbIPEQYBg*

*wdyxkg037Q&hl=en&sa=X&ved=0CCoQ6AEwATgKahUKEwijqLvK*https://books.google.co.nz/books?id=qtjcvNSMupUC&pg=PA385&lpg=PA385&dq=added+value+products+from+eucalyptus&source=bl&ots=ZahVTa6bsY&sig=_KBQZBI0LbIPEQYBgwdyxkg037Q&hl=en&sa=X&ved=0CCoQ6AEwATgKahUKEwijqLvK-ejGAhWDe6YKHc6KDXI - v=onepage&q=added%20value%20products%20from%20eucalyptus&f=false*ejGAhWDe6YKHc6KDXI#v=onepage&q=added%20value%20products%20from%20eucaly ptus&f=false*, 375-390.

Shelbourne, A., Nicholas, I. D., McKinley, R. M., Low, C., MacConochie, R. M., & Lausberg, M. J. F. (2003). Wood density and internal checking of young Eucalyptus nitens in New Zealand as affected by site and height up the tree *New Zealand Journal of Forestry Science 32*(3), 357-385.

Shelbourne, C. J. A. (2009). Domestication of stringybark eucalypts - A literature review. *Scion Unpublished Report, Sydney Output 53641*, 31pp.

Shelbourne, C. J. A., Britton, R. A. J., Kimberley, M. O., McKenzie, H. M., & McKinley, R. B. (2001). Evaluating Eucalyptus nitens for appearance-grade lumber and veneers, and predicting "sawability" and timber quality from tree, disc and short-billet data. *Forest Research Wood Processing Newsletter Issue No. 30, November 2001*, 4pp.

Shelbourne, C. J. A., & Nicholas, I. D. (2006). Carter Holt Harvey Hardwood Review: Tree Growing, Wood Properties and Tree Improvement Aspects. *Scion Confidential Client Report (unpublished) for Carter Holt Harvey*, 28pp.

Shelbourne, C. J. A., Nicholas, I. D., Hay, A. E., & McConnochie, R. M. (2003). Stringybark eucalypts for a future hardwood industry in New Zealand. *NZ Tree Grower 24*(3), 34-35.

Shelbourne, C. J. A., Nicholas, I. D., McKinley, R. B., Low, C. B., McConnochie, R. M., & Lausberg, M. J. F. (2002). Wood density and internal checking of young Eucalyptus nitens in New Zealand as affected by site and height up the tree. *New Zealand Journal of Forestry Science, 32*(3), 357-385.

Silva, J. C., Borralho, N. M. G., Araújo, J. A., Vaillancourt, R. E., & Potts, B. M. (2009). Genetic parameters for growth, wood density and pulp yield in Eucalyptus globulus. *Tree Genetics and Genomes, 5*(2), 291-305.

Simpson, I. G., & Sole, J. A. (1999). *Eucalyptus nitens* pilot veneer peeling and drying study. *Scion Unpublished Report, Syndey Ouktput No. 21525*, 5pp.

Stanturf, J. A., Vance, E. D., Fox, T. R., & Kirst, M. (2013). Eucalyptus beyond Its Native Range: Environmental Issues in Exotic Bioenergy Plantations. *International Journal of Forestry Research*

Volume 2013, 2013 Article ID 463030(http://dx.doi.org/10.1155/2013/463030), 5pp.

Stape, J. L., Binkley, D., Ryan, M. G., Fonseca, S., Loos, R. A., Takahashi, E. N., Silva, C. R., Silva, S. R., Hakamada, R. E., Ferreira, J. M. d. A., Lima, A. M. N., Gava, J. L., Leite, F. P., Andrade, H. B., Alves, J. M., Silva, G. G. C., & Azevedo, M. R. (2010). The Brazil Eucalyptus Potential Productivity Project: Influence of water, nutrients and stand uniformity on wood production. *Forest Ecology and Management, 259*(9), 1684-1694. doi:10.1016/j.foreco.2010.01.012

Stovold, G. T., Low, C. B., & Dungey, H. S. (2009). Status of the New Zealand Eucalyptus nitens breeding programme as at December 2008 and plan to 2014. *Contract Report to FFR*.

Suh, J.-S., Kim, J.-I., Hwang, S.-W., & Park, S.-B. (2012). Bonding Quality of Cylindrical LVL and Surface Durability by Its Painting. 목재공학*, 40*(6), 418-423.

Suontama, M., Klapste, J., Stovold, G. T., Telfer, E. J., Graham, N. J., McKinley, R. B., Low, C. B., & Dungey, H. S. (2016). Towards genomic selection for wood properties in Eucalyptus nitens. *In: Forest Genetics for Productivity, 14-18 March 2016*.

Temel, F., & W.T., A. (2000). Persistence and age-age genetic correlations of stem defects in coastal Douglas-Fir (Pseudotsuga menziesii var. menziesii (Mirb.) Franco. *For. Genet. 145–153, 7*, 145–153.

Thomas, D., Henson, M., Joe, B., Boyton, S., & Dickson, R. (2009). Review of growth and wood quality of plantation-grown Eucalyptus dunnii Maiden. *Australian Forestry, 72*(1), 3-11.

Todoroki, C. L. (2012). Review of sawing technologies for eucalypts. *Scion Sydney Output, 46985 (unpublished)*, 24pp.

Torgovnikov, G., & Vinden, P. (2010). Microwave wood modification technology and its applications. *Forest Products Journal, 60*(2), 173-182.
Trugilho, P. F., & Da Silva Oliveira, J. T. (2008). Relationships and estimates of longitudinal growth stress in Eucalyptus dunnii at different ages. *Revista Arvore, 32*(4), 723-729.
Trugilho, P. F., Lima, J. T., & Rosado, S. C. D. S. (2005). Assessment of growth stresses in *Eucalyptus* trees and their reationship with the characrteristics of growth and some wood properties. *In: Plantation Eucalyptus: Challenge in Product Development, Science Press Beijing*, 59-67.
Valencia, J., Harwood, C., Washusen, R., Morrow, A., Wood, M., & Volker, P. (2011). Longitudinal growth strain as a log and wood quality predictor for plantation-grown Eucalyptus nitens sawlogs. *Wood Science and Technology, 45*(1), 15-34. doi:10.1007/s00226-010-0302-1
Vega, M., Hamilton, M. G., Blackburn, D. P., McGavin, R. L., Baillères, H., & Potts, B. M. (2016). Influence of site, storage and steaming on Eucalyptus nitens log-end splitting. *Annals of Forest Science, 73*(2), 257-266. doi:10.1007/s13595-015-0496-3
Vermaas, H. F. (1995). Drying eucalypts for quality: Material characteristics, pre-drying treatments, drying methods, schedules and optimisation of drying quality. *South African Forestry Journal, 174*(1), 41-49. doi:10.1080/00382167.1995.9629877
Vermaas, H. F. (2000). Primary processing of eucalypts and factors affecting it. *Southern African Forestry Journal*(187), 37-44.
Vermaas, H. F. (2002). State of the Art and Latest Technological Advances in the Drying of Fastgrown Eucalypts. *Proceedings of 4th Cost E15 Workshop, 30th and 31st May 2002, Santiago de Compostela, Spain.* .
Volker, P. W. (2005). Silvicultural management of eucalypt plantations for solid wood and engineered wood products - experience from Tasmania. *In Xiamei J. et al. (Eds.) Plantation Eucalyptus: challenge in product development, Science Press, Beijing*, pp 1-9. .
Volker, P. W. (2008). Manaement of hardwood sawog species. *In "Plantation Eucalypts for Highvalue Timber", Eds Beadle and Brown* 69-80.
Wadlaw, T. J., & Nielson, W. A. (1999). Decay and other defects associated with pruned branches of Eucalyptus nitens. *Tasforests 11*, 49-57.
Walker, J. C. F. (2013). Wood quality: a perspective from New Zealand. *Forests, 4*, 234-250.
Walker, J. C. F., Chauchan, S., & Apiolaza, L. A. (2011). Developing a eucalypt resource: Learning from Australia and elsewere. *University of Canterbury, Wood Technology Research Centre, Workshop Proceedings*, 158pp http://nzdfi.org.nz/wphttp://nzdfi.org.nz/wp-content/uploads/2014/2012/Developing-a-Eucalypt-Resource-Workshop-Proceedings-November2011.pdfcontent/uploads/2014/2012/Developing-a-Eucalypt-Resource-Workshop-Proceedingshttp://nzdfi.org.nz/wp-content/uploads/2014/2012/Developing-a-Eucalypt-Resource-Workshop-Proceedings-November2011.pdfNovember2011.pdf.
Wardlaw, T., Mohammed, C., Barry, K., Eyles, A., Wiseman, D., Beadle, C., Battaglia, M., Pinkard, E., & Kube, P. (2003). Interdisciplinary approach to the study and management of stem defect in eucalypts. *New Zealand Journal of Forestry Science, 33*(3), 385-398.
Warren, E., Smith, R. G. B., Apiolaza, L. A., & Walker, J. C. F. (2009). Effect of stocking on juvenile wood stiffness for three Eucalyptus species. *New Forests, 37*(3), 241-250.
Washusen, R. (2002). Tension wood occurrence in Eucalyptus globulus Labill. II. The spatial distribution of tension wood and its association with stem form. *Australian Forestry, 65*(2), 127-134.
Washusen, R. (2008a). Sawmilling of eucalypts in Australia. *Australian Forestry, 71*(2), 79-81.
Washusen, R. (2011). Processing plantation-grown Eucalyptus globulus and E. nitens for solidwood products— Is it viable? *Cooperative research c entre for forestry, Hobart Tasmania, Technical Report 209*, 34pp.
Washusen, R. (2013a). Improving the value chain for plantation- grown eucalypt-sawn wood in China, Vietnam and Australia: sawing and drying. *Austarlian Centre for International Agricultural Research , July 2013, FST/2001/021*, 43pp.
Washusen, R. (2013b). Processing methods for production of solid wood products from plantationgrown Eucalyptus species of importance to Australia. *Forest & Wood Products*

Australia, Project No. PNB291-1112A, April 2013 *http://www.fwpa.com.au/images/processing/PNB291-1112A_processing_methods_for_SW_products_euc_plantations.pdf*, 55pp.

Washusen, R. (2016). Advances in processing young eucalypts, April, 2016. *Friday Offcuts, http://fridayoffcuts.com/dsp_article.cfm?id=209&aid=1353*.

Washusen, R., Ades, P., & Vinden, P. (2002). Tension wood occurrence in Eucalyptus globulus Labill. I. The spatial distribution of tension wood in one 11-year-old tree. *Australian Forestry, 65*(2), 120-126.

Washusen, R., Baker, T., Menz, D., & Morrow, A. (2005). Effect of thinning and fertilizer on the cellulose crystallite width of Eucalyptus globulus. *Wood Science and Technology, 39*(7), 569-578.

Washusen, R., Harwood, C., Morrow, A., Northway, R., Valencia, J. C., Volker, P., Wood, M., & Farrell, R. (2009). Pruned plantation-grown Eucalyptus nitens: Effect of thinning and conventional processing practices on sawn board quality and recovery. *New Zealand Journal of Forestry Science, 39*(1), 39-55.

Washusen, R., Harwood, C., Morrow, A., Valencia, J., Volker, P., Wood, M., Innes, T., Ngo, D., Northway, R., & Bojadzic, M. (2008). Gould's Country Eucalyptus nitens thinning trial: Solid wood quality and processing performance using conventional processing strategies. *CRC for Forestry Technical Report No. 168*(http://www.crcforestry.com.au/publications/downloads/TR168-Washusen-et-alhttp://www.crcforestry.com.au/publications/downloads/TR168-Washusen-et-al-FORPRINT.pdfFORPRINT.pdf), 47pp.

Washusen, R., & Innes, T. (2008). Processing Plantation Eucalypts for High-Value Timber. In: Brown, A.G. and Beadle, C.L. (eds) Plantation Eucalypts for High-Value Timber: Enhancing investment through research and developmentand development. *Rural Industries Research and Development Corporation. Kingston, ACT, Australia7*, 92-109.

Washusen, R., & McCormick, M. (2002). Recovery potential of quarter-sawn solid wood products from regrowth and plantation-grown *Eucalyptus nitens*. *CSIRO-FFP Client Report, , No. 1227*, 15pp.

Washusen, R., Menz, M., Morrow, A., Reeves, K., Hingston, R. A., & Davis, S. (2004). Processing pruned and unpruned eucalyptus globulus managed for sawlog product 27pp.

Washusen, R., Morrow, A., Ngo, D., Bojadzic, M., Henson, M., Porada, H., Boynton, B. L., Northway, L., Shaoxiong, C., Peng, Y., & B.C., K. (2007). Improving the value chain for plantation-grown Eucalypts in China, Vietnam, and Australia: Sawing and drying.

Genetic variation in growth stress-related wood behaviour of small diameter *Eucalyptus nitens* logs processed with a HewSaw R250 sawmill. *Scion Client Report, No. 1799*, 38pp.

Washusen, R., Morrow, A., Ngo, D., Northway, R., Bojadzic, A., Harwood, C., Volker, P., Wood, M., Valencia, J. C., & Innes, T. (2008). Eucalyptus nitens thinning trial: solid wood quality and processing performance using conventional processing strategies. *Forest & Wood Products Australia, PROJECT NUMBER: PN07.3019* (http://www.fwpa.com.au/images/resources/PN07.3019.pdf), 49pp.

Washusen, R., Morrow, A., Dung Ngo, Northway, R., Boynton, S. and Henson, M. . (2008b). Processing air and kiln dried sawn wood from unthinned and unpruned 9-year old Eucalyptus pilularis from northern New South Wales with a HewSaw R200. *Report for ACIAR project FST/2001/021: Improving the value chain for plantation-grown eucalypts in China, Vietnam and Australia: sawing and drying. CSIRO Material Science & Engineering Client Report, No CMSE(C)-2008-300*, 50 pp.

Washusen, R., Morrow, A., Dung Ngo, Northway, R., Boynton, S. and Henson, M., Reeves, K., Hingston, R., Davis, S., Menz, D., & Morrow, A. (2004). Processing Pruned and Unpruned Eucalyptus globulus Managed for Sawlog Production to Produce High Value Products. *FWPRDC Client, PN03.1315*, 30pp.

Washusen, R., Northway, L., Harwood, C. E., Valencia, J. C., Morrow, A., & Volker, P. (2009). Pruned Plantation-Grown Eucalyptus nitens: Effect of Thinning and Conventional Processing Practices on Sawn Board Quality and Recovery. *New Zealand Journal of Forestry Science, 39*, 39-65.

Washusen, R., Reeves, K., Reid, R., Morrow, A., & Bojadzic, M. (2006). A comparison of wood quality and product value of 16-year-old pruned E. nitens and 65-year-old native forest regrowth E. nitens. *Ensis Client Report No. 1687*, 12pp.

Waugh, G., & Northway, L. (2002). Best practice for sawing and dryingplantation eucalypts forappearance grade products. *In: IUFRO Conference "The Future of Eucalypts for Wood Products", Launceston, Australia"*.

Waugh, G., & Rosza, A. (1991). Sawn products from regrowth Eucalyptus regnans. *In: The Young Eucalypt Report - some management options for Australia's regrowth forest CSIRO, Melbourne, Australia*, 178-209.

Weir, G., & Waugh, G. (2013). Improved drying of eucalypt wood usng new generation solar systems. *Presentation to Wood E xpo, Albury 2013*.

Wentzel-Vietheer, M., Washusen, R., Downes, G. M., Harwood, C., Ebdon, N., Ozarska, B., & Baker, T. (2013). Prediction of non-recoverable collapse in Eucalyptus globulus from near infrared scanning of radial wood samples. *European Journal of Wood and Wood Products, 71*(6), 755-768. doi:10.1007/s00107-013-0735-y

Weston, G. C. (1957). Exotic forest trees in new Zealand. *New Zealand Forest Service Bulletin, 13*.

Wilcox, M. D., & Hathaway, R. L. (1988). Use of Australian trees in New Zealand. *Proceedings of the AFDI International Forestry Confor the Australian Bicentenary 1988, Albury, NSW.*

Wingfield, M. J., Slippers, B., Hurley, B. P., Coutinho, T. A., Wingfield, B. D., & Roux, J. (2008). Eucalypt pests and diseases: Growing threats to plantation productivity. *Southern Forests, 70*(2), 139-144. doi:10.2989/SOUTH.FOR.2008.70.2.9.537

Wiseman, D., Smethurst, P., Pinkard, L., Wardlaw, T., Beadle, C., Hall, M., Baillie, C., & Mohammed, C. (2006). Pruning and fertiliser effects on branch size and decay in two Eucalyptus nitens plantations. *Forest Ecology and Management, 225*(1-3), 123-133.

Withers, T. M. (2001). Colonization of eucalypts in New Zealand by Australian insects. *Australian Ecology, 26*(5), 467-476.

Withers, T. M., & Hood, I. A. (2015). Managing the pests and diseases of Eucalypts. *Presentation at NZ Farm Forestry Association Cofnerence Field Trip, Parakau, Northland*, 2pp.

Wood, M. J., McLarin, M. L., Volker, P. W., & Syme, M. (2009). Management of eucalypt plantations for profitable sawlog production in Tasmania, Australia. *Tasforests, 18*, 117130.

Wood, M. J., Volker, P. W., & Syme, M. (2006). Eucalyptus plantations for sawlog production in Tasmania, Australia: optimising thinning regimes *Report: Forestry Tasmania, Division of Forest Research and Development, Hobart, Tasmania, Australia* *http://www.forestry.org.au/pdf/pdf*http://www.forestry.org.au/pdf/pdf-public/conference2007/papers/Wood Volker and Syme.pdf*public/conference2007/papers/Wood%20Volker%20and%20Syme.pdf*, 17pp.

Wu, S., Xu, J., Li, G., Lu, Z., Han, C., Hu, Y., & Hu, X. (2013). Genetic variation and genetic gain in growth traits, stem-branch characteristics and wood properties and their relationships to Eucalyptus urophylla clones. *Silvae Genetica, 62*(4-5), 218-231.

Wu, S., Xu, J., Li, G., Risto, V., Du, Z., Lu, Z., Li, B., & Wang, W. (2011). Genotypic variation in wood properties and growth traits of Eucalyptus hybrid clones in southern China. *New Forests, 42*(1), 35-50.

Wu, S. j., Xu, J. m., Li, G. y., Du, Z. h., Lu, Z. h., & Li, B. q. (2012). Age trends and correlations of growth and wood properties in clone of Eucalyptus urophylla × E. grandis in Guangdong, China. *Journal of Forestry Research, 23*(3), 467-472. doi:10.1007/s11676-012-0286-9

Wu, Y. Q., Hayashi, K., & Cai, Y. C. (2010). Study on collapse-shrinkage characteristics in plantation-grown eucalyptus wood under continuous and intermittent drying regimes, *Defect and Diffusion Forum* (Vol. 297-301, pp. 1022-1026).

Xu, K., Tu, D., Peng, P., Guo, Q., & Yun, H. (2012). The air-kiln drying technology research on Australian Eucalyptus regnans board. *393-395*.

Yang, J., & Pongracic, S. (2004). The impact of growth stress on sawn distortion and log end splitting on 32-year-old plantation Blue Gum. *Forest and Wood Products Australila, Project No: PN07.3019*, 27pp.

Yang, J. L. (2005). The impact of log-end splits and spring on sawn recovery of 32-year-old plantation Eucalyptus globulus Labill. *Holz als Roh - und Werkstoff, 63*(6), 442-448. doi:10.1007/s00107-005-0035-2

Yang, J. L., & Evans, R. (2003). Prediction of MOE of eucalypt wood from microfibril angle and density. *Holz als Roh - und Werkstoff, 61*(6), 449-452.
Yang, J. L., Ilic, J., Evans, R., & Fife, D. (2003). Interrelationships between shrinkage properties, microfibril angle, and cellulose crystallite width in 10-year-old Eucalyptus globulus. *New Zealand Journal of Forestry Science, 33*(1), 47-61.
Yang, J. L., & Waugh, G. (2001). Growth stress, its measurement and effects. *Australian Forestry, 64*(2), 127-135.
Yang, L., Liu, H., Cai, Y., Hayashi, K., & Wu, Z. (2014). Effect of drying conditions on the collapseprone wood of Eucalyptus urophylla. *BioResources, 9*(4), 7288-7298.
Yiqiang, W., Kazuo, H., Yuan, L., Jianju, L., & Masatoshi, S. (2008). Intermittent drying technologies suitable for plantation-grown timbers. *In: Plantation Eucalypts for High-Value Timber Enhancing investment through research and development, Rural Industries Research and Development Corporation Report, RIRDC Publication No 08/113*(ISBN 1 74151 701 X), 110-119.
Yuniarti, K., Ozarska, B., Brodie, G., Harris, G., & Waugh, G. (2015). Collapse development of *Eucalyptus saligna* under different drying temperatures. *Journal of Tropical Forest Science 27*(4), 462–471
Zhou, Y., Jiang, X., Piao, C., Gao, R. Q., & X., L. (2005). Experimanatal study on sawing of plantation eucalypts in China. *In: Plantation Eucalyptus: Challenge in Product Development, Science Press Beijing*, 125-132.
Zubková, G., Bléron, L., & Zemiar, J. (2009). Selected physical and mechanical properties of laminated veneer lumber of eucalypt. *Acta Facultatis Xylologiae, 51*(2), 17-26.