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EUCALYPTS SILVICULTURAL SYSTEMS: PLANTATION FORESTRY FOR BIOENERGY AND SOLID-WOOD PRODUCTION

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2009 GOTTSTEIN FELLOWSHIP REPORT

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

The Trust's major forms of activity are:

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

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

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

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His research is focused on the development of tree populations which increase the value of plantation forests using traditional genetic selection as well as developing strategies to efficiently deploy these populations into production forests using a range of propagation systems. Prior to joining CSIRO, Jeremy worked as a geneticist in a variety of roles, which took him from the US to Paraguay and Argentina, Chile, Australia and New Zealand. Jeremy has a Masters of Science and a Bachelors of Forest Resources and Conservation from the University of Florida in the USA.

Executive Summary

This report summarises the findings of visits to the University of Florida and various companies in North America as well as plantations, processing facilities and research laboratories in Paraguay and Argentina. The principal goal of this study was to gain a better understanding of alternative silviculture regimes, processing methods and wood quality evaluation procedures that could be applied in the *Eucalyptus* plantation forest industry in Australia.

The visit to the University of Florida was focused on reviewing economic methodologies that would allow for the comparison of various silvicultural strategies and the identification of variables in the production system that are most likely to alter financial returns due to risk or uncertainty in the future. Discussions covering the growth of the bioenergy industry in the South-eastern United States were linked to visits to eucalypt plantations in southern Florida and a large eucalypt seedling producer, ArborGen. The time in South America focused on 1) evaluating destructive and non-destructive methods for both in-field and mill evaluation of eucalypts managed to produce solid-wood products, 2) comparing the costs and benefits of different silvicultural regimes, and 3) visiting saw and veneer mills to gain experience in evaluating log and timber quality. The final leg of the fellowship was to the Big Island of Hawaii to assess a progeny trial of *E.grandis* (genetically linked to the Florida, Paraguayan and Argentinean breeding populations) and discuss the future of biofuel production in the Pacific islands with bioenergy experts from the University of Florida and Forest Solutions. In the end, the major foci of this report became: 1) assessing silvicultural strategies and wood quality traits impacting solid-wood recovery in eucalypt plantations and 2) understanding the relationships between wood property assessments.

Alternatives to the well tested pulpwood silvicultural regimes commonly applied in Australia could be used to increase the profitability of plantation forest growers and sawlog processors. The use of pruning and thinning to create a plantation resource of eucalypts, which can be converted to higher value timber products, appears to be financially feasible using disparate regimes. Processes for the rapid and efficient

evaluation of wood quality exist and methods require further evaluation to determine the most pathways that can be used to efficiently improve the plantation resource through tree breeding.

Another option for increasing the profitability of the forest industry is increasing the recovery and use of residual biomass from thinning and harvest operations. Including the utilisation of waste wood has the potential to increase returns with existing technologies ranging from simple combustion for co-generation of electricity in existing plant to more scalable and complex pyrolysis production technologies for liquid fuel. Although the pulp and paper industry should be a major player in the development of advanced bio-refineries, the scaling up of cellulosic ethanol technologies to produce significant amounts of fuel will not be trivial. While adopting silvicultural prescriptions that use pruning and thinning to increase the value of sawlogs has the potential to increase the forest industries profitability on its own, the financial impact using residual wood for alternative energy production could provide greater incremental returns to Australian plantation forest managers.

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Introduction

The wide range of material that was investigated for this Fellowship is reflected in the title of this report – "Eucalypts Silvicultural Systems: Plantation Forestry for Bioenergy and Solid-wood Production". A concerted effort was made to reduce the scope of the project from what was identified in the fellowship proposal following a review of the literature, which showed an extremely wide array of topics on forestry for bioenergy production and ample work on solid-wood production systems. The review of the literature focused on those studies investigating the economic impacts of bioenergy production on eucalypt forestry, with most attention devoted to the simultaneous production of solid wood products and biomass for bioenergy. The study of multiple-use forests appears to be widespread. The concept of combining biofuel and solid-wood production in plantations rather than developing specific silvicultural prescriptions for each product was of interest to the range of organisations visited.

Following a period of study on different economic methods available to evaluate the merit of silvicultural systems, a generalised approach of growth modelling with sensitivity analyses of model uncertainties was adopted. A focus on silvicultural options for the production of solid-wood products from eucalypts was used with residuals from thinning and waste allocated to a 'pulp' product that was considered equivalent to biomass for bioenergy generation. Although there are frequent reports in the Southern US of new bioenergy facilities being developed or expanded, prices for pulpwood or biomass have proven to be 'sticky' with little increase in price being realised from the apparent increase in demand (http://www.tmartsouth.com) caused by new entrants (mainly pellet plants) to the market. However, it is becoming increasingly obvious that the amount of forest residues will be nowhere near enough to supply the current and announced bioenergy projects in the Southern US and feedstock demand will soon exceed supply (Gonzalez et al 2009). Therefore, the uncertainty of 'pulp' or biomass price changes into the future became an additional aspect for the financial and economic modelling undertaken during the time spent at the University of Florida.

Revision of wood property sampling methods with Forestal Pomera's Paraguayan and Argentinean plantation estates and research trials was also a valuable experience with assessments of wood quality taken in the field, in the sawmill and in the laboratory. This work will have direct relevance to the CSIRO, Queensland Department of Primary Industries and University of Sunshine Coast collaborative 'Smart Forest Alliance' (SFA) project. Methodologies and strategies for wood quality evaluation have been reviewed and are currently under evaluation in the field sampling stage of SFA.

Silvicultural regimes for eucalypt solid-wood forestry

Over the past few years, managed investment scheme (MIS) forestry companies have been promoting projects that intend to generate wood products with a higher value than wood-chip, which is the principal low-value commodity used domestically and exported from Australia ($1.07bn in 2007/2008, ABARE). The conversion of stands established for pulpwood crops into structural or appearance timber crops is straightforward within the first two to three years following establishment. Thinning to increase individual stem diameter rather than overall stand volume is a key intervention in the production of trees intended for conversion to solid-wood products. Evidence of increased growth stresses from delayed thinning of eucalypts have been documented (Volker 2008, Nolan et al. 2005, Nutto and Touza-Vazquez 2004), with anecdotal findings from South America and other locations indicating that thinning after inter-crown competition has set in will increase the instability of sawn products (E.Shields, pers. comm.). A variety of silvicultural regimes were discussed with forest managers over the course of the fellowship travel, particularly while in South America. The companies that formed in Paraguay and Argentina following the sale of Shell Forestry in 2000 provided a range of log production estimates from pruned and thinned stands. Although limited, processing studies of silvicultural experiments and seed orchards have been instructive in identifying regimes that increase board recovery. As well, evidence that delaying pruning (after branch death) causes serious defects and wood quality degradation was made apparent in many stem dissections; branch stubs are typically not occluded and cause scaring to what should be high-value clear wood outside the knotty core.

The findings on silvicultural strategies used to increase the recovery of high-value wood in eucalypt plantations were used to develop a pair of regimes that could be applied in Australia. The growth model used to investigate alternative silviculture prescriptions was the ‘TreeTOP’ model developed by MBAC Consulting for the Australian Forest and Wood Products Association[1]. The empirical growth model allows for changes in variables such as species, initial stocking, productivity, thinning intensity (number and residual stocking), pruning intensity (number of lifts and heights), costs, product yields, and log prices. The software facilitates ‘what if’ scenarios in a virtual silviculture environment so forest managers can obtain greater clarity about the market conditions under which thinning and pruning are financially feasible in the production of high-quality sawlogs. Although the software was not found to be conducive to undertaking the stochastic simulation that would allow for more complex frontier analysis, it was well suited for simple sensitivity analyses.

Financial analyses of two contrasting solid-wood silvicultural systems

The initial visit to the University of Florida was undertaken to discuss two econometric methods with Forest Economics Professor Douglas Carter, these were: Risk analysis and Frontier Analysis. Although there are positives and negatives to both methods, the application of frontier analysis required additional data to that which is currently available. These methods will be investigated further following additional work within the Smart Forest Alliance project being undertaken in collaboration with Queensland Primary Industries and Fisheries and the University of the Sunshine Coast. The risk and/or uncertainty analysis was identified as particularly useful for stochastic analysis and was attempted with the TreeTOP growth model in order to identify the importance of variables in a range of silvicultural prescriptions. In its current form, the TreeTOP model was not conducive to undertaking the simulation methods explored with more generic US Southern pine growth models. Therefore, a simple sensitivity analysis approach was undertaken to identify the impact of altering silvicultural variables that drive the TreeTOP growth model. The variables investigated were initial stocking,

[1] http://www.fwpa.com.au/Resources/RD/Reports/PN07.4023%20TreeTOP%20Software%20User%20Guide.pdf?pn=PN07.4023

thinning intensity at non-commercial thin, age of second thinning, intensity of second thinning, management costs, harvesting costs, fixed costs, and log prices (refer Table 4).

Two silvicultural regimes were investigated using this sensitivity analysis: 1) a plantation of spotted gum managed in what could be described as a typical Australian silviculture (high initial stocking and extended rotation age) and 2) a plantation of flooded gum managed in the manner developed out of the Shell Forestry experience (lower initial stocking and shorter rotation age). Similar non-commercial thinning and pruning approaches were applied to both regimes; an age 2 non-commercial thinning and two pruning interventions up to 6 meters at age 2 and 4 were common to both regimes. The 'Australian' silviculture designed for a slower growing spotted gum crop on an average productivity site was simulated to have a higher initial stocking (1000 stems/ha), an age 10 commercial thinning removing 54% of basal area and an age 25 clearfall harvest. Charts describing this silviculture are found in Figure 1 and the financial outcome is detailed in Table 2. This was contrasted with a 'Paraguayan' silviculture designed for a flooded gum crop on an higher productivity site, which was modelled using a low initial stocking (600 stems/ha), an age 2 non-commercial thinning, two pruning interventions up to 6 meters at age 2 and 4, an age 8 commercial thinning removing 50% of basal area and an age 12 clearfall harvest. Charts describing this silviculture are found in Figure 2 and a table detailing the financial outcome is found in Table 3.

Table 1 details the species and site characteristics that are implicit in the TreeTOP growth model for spotted gum and flooded gum with stand basal area asymptotes highlighted for the medium and high growth site respectively. The metric used to compare financial outcomes, Internal Rate of Return (IRR), was very similar for these two silvicultural prescriptions (5.8%).

Table 1 – Species and associated site characteristics used in simulation

Species Characteristics							Site Characteristics Basal Area Asymptotes				
Species	Growth rate	Wood Density	Shade & competition tolerance	Pole suitability	Height growth rapidity	Height growth total	v.low	low	Medium	High	v.high
Flooded Gum	4	480	1		1.1	1	36	43	46	**48**	52
Spotted Gum	3	680	2	2.2	0.8	1	33	40	**42**	44	46

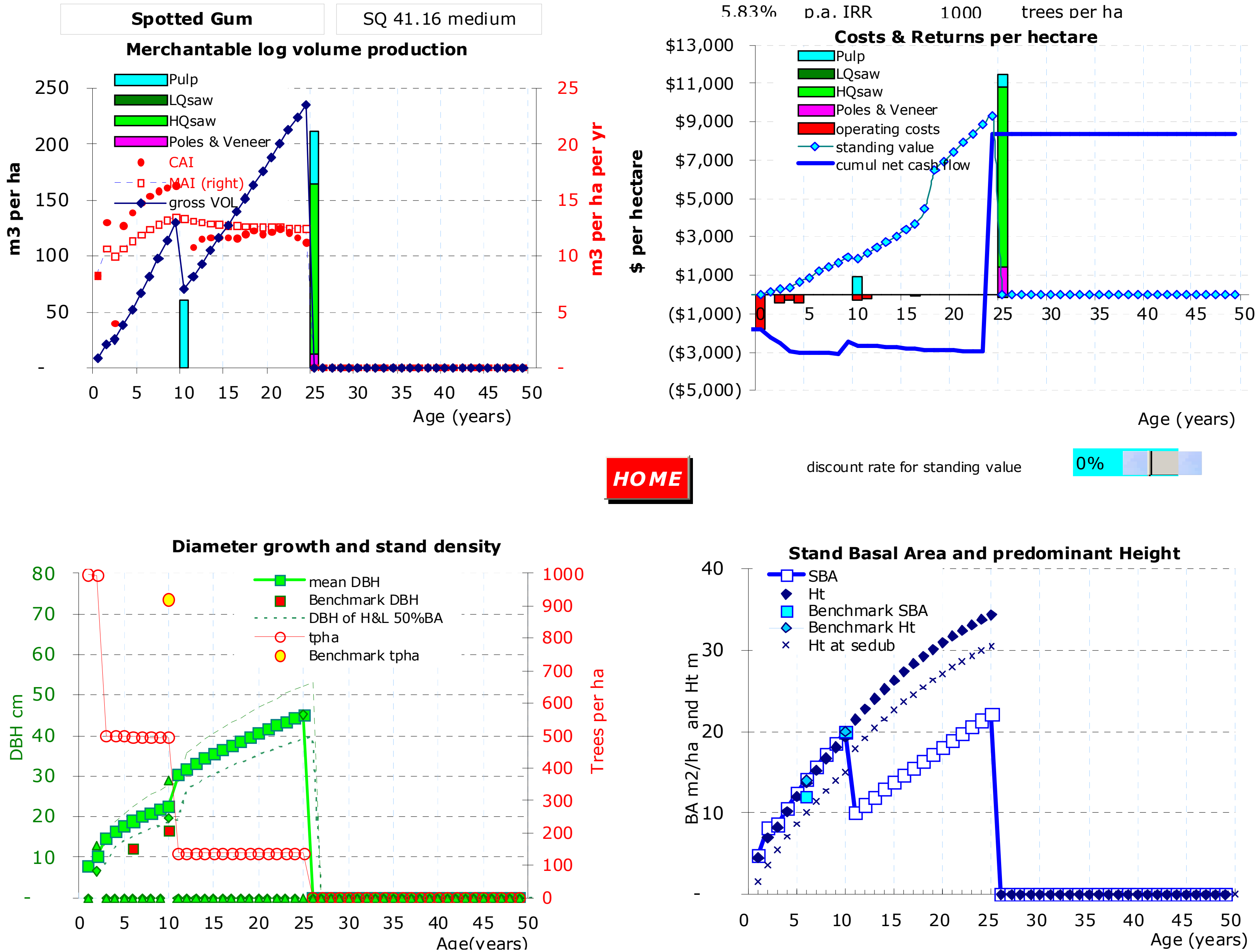


Figure 1 – 'Australian' solid-wood regime for spotted gum grown on average productivity site

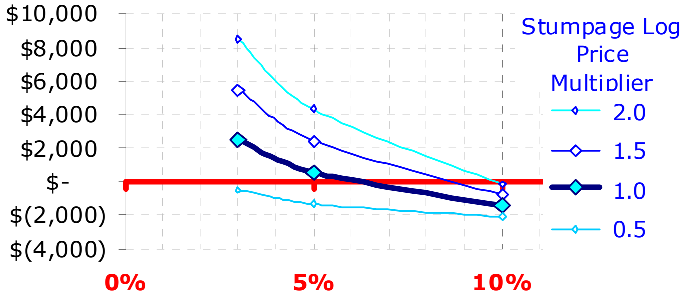
IRR	MAI	SQ 41.16 medium
5.8%	12.5	**Spotted Gum**

HOME

	Volume m3/ha		
	T1	T2	CF
Year	***10***	***16***	***25***
Pulp	61.0	-	47.1
LQsaw	-	-	-
HQsaw	-	-	153.1
Poles & Veneer	-	-	11.8
Total	61.0	-	212.0

	Stumpage Revenue $/ha		
	T1	T2	CF
Year	***10***	***16***	***25***
Pulp	$ 915	$ -	$ 707
LQsaw	$ -	$ -	$ -
HQsaw	$ -	$ -	$ 9,341
Poles & Veneer	$ -	$ -	$ 1,449
Total	$ 915	$ -	$ 11,496

$/ha	***3%***	***5%***	***10%***
NPV	$ 2,491	$ 544	$ (1,454)



IRR = 5.8%

Table 2 – Financial results of solid-wood regime for spotted gum grown on average productivity site

The per hectare net present value of costs and revenues used to derive the financial outcomes were taken directly from the TreeTOP default values and are as follows:

Management costs – Site preparation & planting at year 0 = $1803, Maintenance years 1 to 5 = $375, Maintenance from year 6 = $542

Fixed costs for compartment roads, machinery transport, contractor overheads and planning costs – Non-commercial thin = $20, First commercial thinning = $200, Clear fall harvest = $150

Harvest costs were not included in the sensitivity analysis as IRR calculations were based on stumpage value rather than mill door log value.

Revenues were influenced by stumpage prices of $15, $37, $61, and $123 for pulp, low-quality sawlogs, high-quality sawlogs and veneer/pole log grades respectively

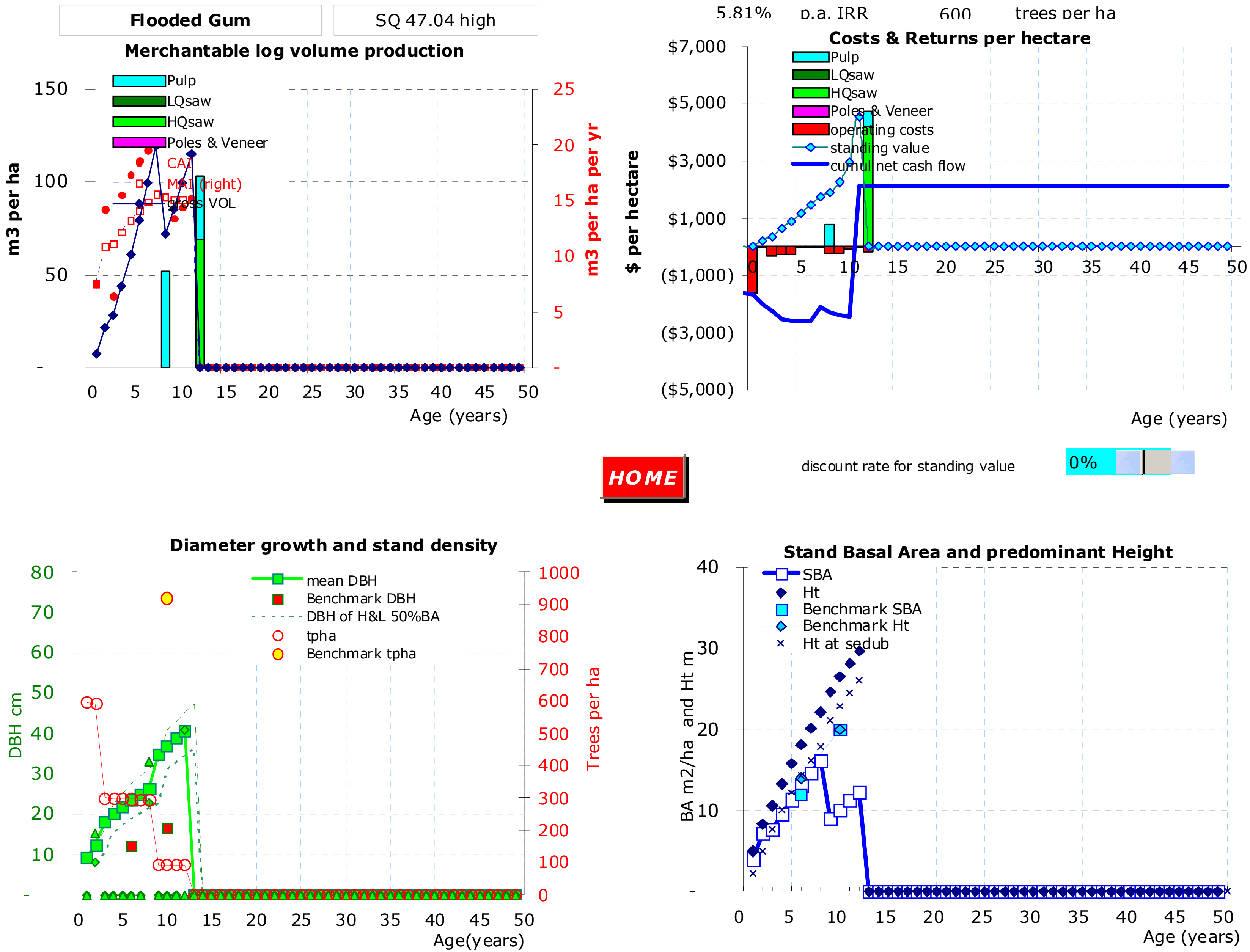


Figure 2 – ‘Paraguayan’ flooded gum solid-wood regime on a high productivity site

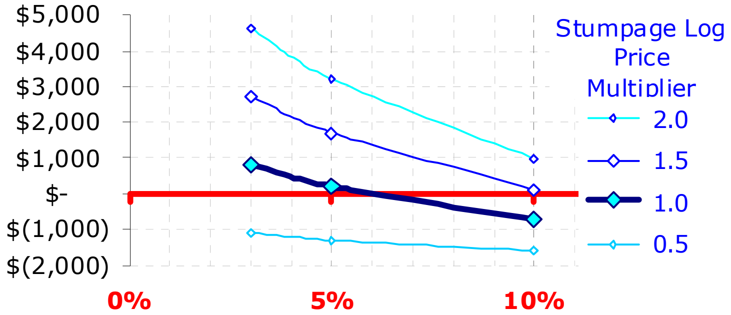
IRR	MAI	SQ 47.04 high		
5.8%	15.1	**Flooded Gum**		

HOME

	Volume m3/ha		
	T1	T2	CF
Year	***8***	***10***	***12***
Pulp	51.7	-	34.5
LQsaw	-	-	-
HQsaw	-	-	69.0
Poles & Veneer	-	-	-
Total	51.7	-	103.6

	Stumpage Revenue $/ha		
	T1	T2	CF
Year	***8***	***10***	***12***
Pulp	$ 776	$ -	$ 518
LQsaw	$ -	$ -	$ -
HQsaw	$ -	$ -	$ 4,211
Poles & Veneer	$ -	$ -	$ -
Total	$ 776	$ -	$ 4,729

$/ha	***3%***	***5%***	***10%***
NPV	$ 814	$ 201	$ (730)



IRR = 5.8%

Table 3 – Financial results of a solid-wood regime for flooded gum grown on a high productivity site

Table 4 – Sensitivity analysis detailing changes in Internal Rate of Return (IRR) caused by altering growth model inputs from initial values for solid-wood regimes of spotted Gum (SG) on average productivity site and flooded Gum (FG) on a high productivity site

Factor altered	**Change**	**SG Initial**	**Spotted Gum IRR Baseline = 5.83%**	**FG Initial**	**Flooded Gum IRR Baseline = 5.81%**
Initial stocking	+10%	1000	**5.11**	600	6.12
	-10%		5.76		5.44
First thinning intensity	+10%	50%	**5.21**	50%	6.25
	-10%		5.65		**5.30**
Age of second thinning	+2 years	10	**5.09**	8	**2.92**
	-2 years		5.78		5.68
Second thinning intensity	+10%	54%	5.66	50%	5.28
	-10%		**5.18**		6.28
Clear-fall age	+2 years	25	5.71	12	**6.87**
	- 2 years		**5.05**		**4.18**
Management costs	+10%	$2326	**5.18**	$2326	**4.34**
	-10%		**6.53**		**7.41**
Fixed costs	+10%	$450	5.80	$450	5.71
	-10%		5.86		5.91
Pulpwood price	+10%	$15	5.94	$15	6.11
	-10%		5.75		5.50
Low quality sawlog price	+10%	$37	5.83	$37	5.81
	-10%		5.83		5.81
High quality sawlog price	+10%	$61	6.18	$61	**6.64**
	-10%		5.45		**4.91**
Pole & veneer price	+10%	$123	5.88	$123	5.81
	-10%		5.77		5.81

Cells in bold denote a change from baseline IRR greater than 0.50%

Results of the sensitivity analysis were used to highlight silvicultural variables that have a large impact on the internal rate of return (IRR) when altered. Large changes in IRR highlighted in bold in Table 4 were assumed to be important when the IRR deviated by one-half percent. While the IRR of spotted gum (SG) regime was impacted negatively by increasing initial stocking and decreasing the intensity of the second thinning, the flooded gum (FG) regime was less sensitive to changes in these variables. Both increasing and decreasing the intensity of the first thinning caused an IRR reduction in SG, while removing more basal area in the initial thinning actually increased the FG IRR. While increasing the age at which the second thinning is scheduled to take place had a negative impact in both cases, the FG regime IRR was severely reduced and the SG IRR was reduced to a lesser extent. Changes to the clear-fall harvest age led to much larger changes in the IRR of the FG regime compared to the SG regime.

Altering management costs was shown to have a large impact on IRR for both SG and FG; however, the shorter FG regime was much more sensitive to changes in management costs. Altering the high quality sawlog price did not cause major changes to the SG IRR but strongly impacted the IRR of the FG regime as this was the log grade that generated (Table 3) most of the FG revenues. It should be noted that there was no change in IRR when the price of the low-quality log grade was altered, indicating that both regimes were primarily converting logs to a high-quality grade.

Allocation of 'waste' wood to a pulp log grade to simulate increased bioenergy demand and recovery

There is an increasing interest in the utilisation of harvest residuals to improve returns from plantation forest products. Even when the most efficient harvesting systems are used in uniform blue gum pulpwood plantations, it is estimated that 20% of the biomass available is left on site as waste (Quill 2008). To simulate an increase in demand, which would arise from an expansion of a bioenergy market, wood defined as waste in the TreeTOP default log grades was allocated to the pulpwood grade; it was assumed to be useable for bioenergy production rather than allowed to go to waste. This simple modification of the two silvicultural regimes examined above was used to determine the impact of harvesting of all wood on a site and the elimination of what is considered to be 'waste' in the default solid-wood silvicultural regime's log grades. Allocation of all waste to a 'pulp' log grade increased the IRR for both regimes, assuming all wood biomass would be recovered from the site and processed if bioenergy production facilities raised demand. This reallocation of waste to a 'pulp' log grade increased the spotted gum and flooded gum IRR from 5.83 and 5.81 to 6.17 and 6.62, respectively, indicating FG would benefit more greatly from the elimination of waste. Further, when all waste wood was utilised and the price of a pulpwood log grade was increased by 10%, the spotted gum and flooded gum IRR rose to 6.31 and 6.98, respectively. Greater benefits are expected to be achieved from an increase in the utilisation and price of waste wood in the flooded gum regime.

Biofuel production with eucalypts in North America

Bioenergy production from plantation forests has been the subject of many scientific articles and media reports in the recent past. While much of the literature is focused on the technologies of converting cellulose and lignocellulosic materials into second generation biofuels, a large body of work has also developed to try and better understand the challenges of converting forest biomass to bioenergy using existing technologies such as cogeneration or biomass combustion and pyrolysis. A large number of journal articles were compiled and reviewed to gain a better understanding the opportunities and challenges rising from bioenergy production for the forest products sector.

Regular announcements of new or expanding bioenergy facilities in the Southern United States are common, with activities covering a range of technologies such as: wood pellets, cellulosic ethanol, biodiesel, cogeneration and biomass combustion (Gonzalez et al 2009). Currently, the majority of bioenergy used to meet emission reduction targets in the US South come from co-firing biomass with coal (Mayfield et al 2008). The use of black liquor has also gained attention in the media recently. However, the greatest increase in biofuel production appears to be coming from the wood pellet industry, with 16 pellet plants currently operating in the US South (http://www.pelletheat.org/3/residential/fuelAvailability.cfm#south). The assumed increase in demand for wood fibre resulting from the opening of these new pellet plants has had little impact on pulpwood prices in the US South evidenced by little change in the market price for pulpwood to mid-2009 (http://www.tmartsouth.com).

Discussion with several academic staff at the University of Florida around the use of lignocellulosic materials for liquid fuel production assumed the technology would become a reality in the Southeast US and this could likely result from modification of existing pulp industries via conversion to biorefineries. However, conversion of pulp mills will not be quick, large volumes of cellulosic ethanol from the US South via modified pulp mills is not expected to take place for another 5 to 30 years (USDAF EIA Annual Energy Outlook 2007), and this depends on the Federal and State policy frameworks that develop. The major obstacle to greater production of cellulosic ethanol is that current technologically promising pathways are still being scaled up from petri-dish phase into pilot scale plants. The University of Florida has recently commissioned a cellulosic ethanol biofuel pilot-plant and is working with industry to develop scale-up systems to move quickly through the proof of concept phase.

A review by Wear et al (2009) clearly lays out the policy drivers in favour of increased cellulosic ethanol production from production forests; "*The push for ethanol is most visible in the Energy Independence and Security Act, 2007 which calls for replacing 36 billion gallons of gasoline with biofuel by 2022. Out of this total 15 billion gallons is expected to come from starch based ethanol; 21 billion gallons from cellulosic sources. - The Farm Bill, passed in 2008, begins to shift federal emphasis toward cellulosic ethanol production through a variety of programs. Perhaps most important for forest bioenergy, is a production tax credit of $1.01 per gallon for cellulosic biofuels through 2011*." Although the major policy driving expansion of a biofuel industry in the US was passed in 2007, the impacts of the Energy Independence and Security Act shows lignocellulosic biofuel production will not reach significant levels before 2015 (USDAF EIA Annual Energy Outlook 2007). The future of cellulosic ethanol production is greatly impacted by both the price of conventional energy sources (fossil fuels) and the cost of cellulosic ethanol production (Conti et al 2007). The US Forest Service could be an instrumental player in reducing the cost of ethanol production as it has set two goals that should have an impact: 1) Help develop new and expanded markets for bioenergy and bio-based products and 2) Develop and deploy the needed science and technology (Patton-Mallory et al 2008). In Australia, government may play a similar role in facilitating the development of alternative forest products for the industry.

Discussions with Arborgen, a large forest nursery company in the US, indicated that a major plantation resource of eucalypts for bioenergy production is developing in the Southern US. This resource is almost entirely dedicated to bioenergy and pulpwood products as short-fibre species are typically in short supply in the pine dominated regions of the southern US. To date, there is little interest in developing higher value hardwood plantations as the returns on investment from labour intensive pruning and thinning are not clear. Experience with large scale pruning and thinning programs of pine in the US have not led to extensive adoption of silvicultural systems designed to produce higher value pruned logs; it is more common to establish dense pine plantations and undertake a commercial thinning that will remove an early pulpwood crop. Eucalypts have been established in the southern US with a focus on bioenergy production since the early 1960s (Rockwood et al 1989). Recent extensive plantings have focused on frost tolerant selections of *E.grandis* and hybrids. A number of initiatives over the past decades have failed due to frost damage destroying plantations (Rockwood et al 1991). Alternative species native to Australian summer rainfall regions that have higher levels of inherent frost tolerance, such as *E.benthamii* and *E.macarthurii*, have been increasing in importance in the last few years.

Flooded gum breeding populations assessed for genotype by site interaction studies

Flooded gum (*Eucalyptus grandis)* is thought to represent more than 10% of the world's plantations and, if restricted to the tropics and subtropics, that species constitutes more than 25% of the planted area (Kellison 2001). *E. grandis* has been widely planted for pulp or fuel wood production and more recently plantations are being managed for solid wood production (Evans and Turnbull 2003, Marco and Shield 2004, Shield 2004). There are many reports describing breeding programs of *E.grandis* developed across the tropics and sub-tropics (van Wyk 1976, Campinhos and Ikemori 1989, van Wyk 1990, Rockwood and Meskimen 1991, Eldridge et al. 1993, Bouvet and Vigneron 1995, Marco and Lopez 1995, Osorio et al. 1995, White 1995, Lee et al. 1999, Balmelli 2000, Verryn 2002, Brawner et al 2009). Most of these breeding populations were developed to improve pulpwood production in unthinned plantations, which makes the direct evaluation of clear-wood properties difficult. Given the unique history of a series of progeny trials managed with intensive pruning and thinning, the Pomera trials visited in South America as part of the Gottstein Fellowship (described above) presented an excellent opportunity to explore the interrelationships of wood quality, growth and form traits in trials mimicking pulpwood silviculture (Florida and Hawaii) and solid-wood silviculture (Paraguay and Argentina) (Brawner and Elizaul 2007). These populations are largely derived from a University of Florida frost challenged breeding program focused on reducing frost damage and plantation loss. Pedigree connections are extensive in these trials, although different coding conventions across organisations have complicated initial attempts at concurrent analysis.

Eucalyptus grandis progeny trials, managed with pruning and thinning to produce solid wood, are rare for a variety of reasons: 1) the species is primarily grown for pulp yield, 2) there are difficulties in maintaining consistency across treatments when pruning and thinning are used, 3) higher trial maintenance costs, and 4) there is an increased land requirement due to thinning. The wide range of germplasm in South American trials managed to maximise clear veneer production and material established in Floridian and Hawaiian progeny trials managed to maximise biomass production are all linked via pedigree. Data collected from these populations can be interrogated to determine whether genetic parameters can assist in assessing the suitability of families for use in either a biomass or solid-wood silvicultural system. Although the confounding of environment and management interactions between the individual trials will not allow for direct inferences to be made without many assumptions being made, several hypotheses will be tested. This data has been compiled and is to be written up for publication once climatic and soil data is collated. Special attention will be given to the changes in ranking of families across the range of sites.

Eucalypt wood property assessments for solid-wood forestry

The time spent in South America primarily focused on gaining an understanding of procedures used to evaluate the wood quality of logs from intensively managed eucalypt plantations. Forestal Pomera purchased the Shell Forestry projects in Paraguay and Argentina, which included extensive genetic improvement and silviculture field trials designed to inform the company about the production of knot-free eucalypt veneer. The tree improvement program, briefly described above, included a wide range of third-party improved germplasm in clonal and progeny trials as well as native range *E.grandis* families. Over the past five years, many selections have been made in these trials (Brawner and Elizaul, 2007) and a large investment has been made in the assessment of these selections wood quality. A set of these selected clones is currently being propagated via cuttings in a hydroponic system (Photo 1) and they are being deployed in commercial plantations in Paraguay and Argentina (Photo 2). All selections were chosen on a basis of either trial results or visual superiority in the field initially. In 2007 50 trees were felled, sawn into boards and seasoned; assessments of wood properties were taken at all stages of the selection process. The visit to Forestal Pomera's Paraguayan and Argentinean plantation estates and research trials was used to gain experience with assessments of wood quality in the field, in the sawmill and in the laboratory. This work will have direct relevance to the CSIRO, Queensland Department of Primary Industries and University of Sunshine Coast collaborative 'Smart Forest Alliance' project, which has set as an objective to develop a population of spotted gum with improved wood quality.

For the in-field wood quality assessments, particular emphasis was placed on assessing end-splitting in clonally replicated eucalypts identified as high-splitting and low-splitting varieties; end splitting has been shown to have major impacts on sawn timber recovery (Shield 2004, Yang 2005, Volker 2008, Washusen and Innes 2008). In Paraguay, examples of high-splitting and low-splitting clones were felled and in-field end-splitting was assessed prior to sawing to examine the impact of end-splitting on board characteristics (Photo 3, 4). A dramatic difference in end-splitting of the a-priori selected clones was noted immediately following felling of the trees with rather loud

Photo 1 - Propagation of clonal selections via rooted cuttings

Photo 2 – Clonal plantation pruned to 2.4 m 20 months from planting cracking sounds coming from high-split clone (Photo 4). When visually compared to the low split clone (Photo 3 and 4), major differences in log end splitting are apparent. When multiple ramets of each clone were felled and bucked into logs, the repeatability of end splitting was visually clear. Additionally, an individual from a progeny trial of *Corymbia citriodora* var *variagata* established nearby was felled for end-splitting assessment and sawing. The system used to develop an end-splitting score for each end of the bucked logs was adapted from the process developed for CSIR tree breeding course (CSIR short-course notes, 2005). These trees were assessed for the following variables: height, diameter at breast height (DBH), log volume of 8.5m pruned bole, stem excentricity (ratio of maximum to minimum diameter at DBH) and bark thickness (Table 5). Derived traits included percent of total tree volume in the 8.5m clear bole and percent of bark in the 8.5m bole (Table 5). One to two logs from each of these trees was sawn in a nearby mill to provide samples for board evaluation. Examination of boards for splitting, surface checking and the process for bow, sweep and crook measurements were discussed following sawing.

Photo 3 – Face of a low-split clone 72 hours from felling

Photo 4 – Face of a high-split clone 72 hours from felling

The laboratory within the Universidad de El Dorado, which undertook the wood quality assessment, was visited to discuss board drying and evaluation processes. The methodology and equipment used for the assessment variables (listed in Table 5) were discussed for the following traits: surface checking, board end splitting, density, hardness, radial shrinkage, tangential shrinkage and longitudinal shrinkage. Additionally, moisture content reduction curves and methods for homogenizing the environment for various drying schedules were discussed. In an attempt to briefly

	Height	*DBH*	*8.5m log volume*	*Tree volume*	*Excentricity*	*% tree vol in 8.5m log*	*% bark in 8.5m log*	*Length of surface check*	*Length of end split*	*Density*	*Hardness*	*Radial shrinkage*	*Tangential shrinkage*	*Longitudinal shrinkage*
Height	**1.00**													
DBH	**0.49**	**1.00**												
8.5m log volume	**0.54**	**0.99**	**1.00**											
Tree volume	**0.68**	**0.95**	**0.97**	**1.00**										
Excentricity	0.19	0.03	0.08	0.12	**1.00**									
% tree vol in 8.5m log	**-0.86**	**-0.27**	**-0.32**	**-0.52**	**-0.29**	**1.00**								
% bark in 8.5m log	**-0.40**	-0.04	-0.02	-0.16	-0.20	**0.63**	**1.00**							
Length of surface check	**-0.32**	-0.24	-0.22	-0.24	0.14	**0.27**	0.23	**1.00**						
Length of end split	**0.30**	0.19	0.21	0.23	-0.07	-0.19	-0.11	**-0.56**	**1.00**					
Density	0.00	-0.07	-0.11	-0.08	-0.21	0.01	0.03	0.13	0.04	**1.00**				
Hardness	-0.14	-0.05	-0.08	-0.08	**-0.34**	0.12	0.17	0.04	0.03	**0.84**	**1.00**			
Radial shrinkage	**-0.40**	**-0.47**	**-0.43**	**-0.39**	0.04	0.17	0.11	**0.34**	**-0.32**	**0.43**	**0.39**	**1.00**		
Tangential shrinkage	-0.13	-0.07	-0.05	-0.06	-0.19	0.16	0.25	**0.28**	-0.08	**0.52**	**0.51**	**0.50**	**1.00**	
Longitudinal shrinkage	0.08	-0.10	-0.10	-0.03	0.03	-0.13	-0.11	0.04	-0.09	0.10	-0.05	0.06	-0.09	**1.00**

summarise the relationships between this set of assessment traits, a correlation matrix was developed and is presented in Table 5.

Table 5 – Correlations between in-field and wood quality laboratory assessments in eucalypts managed with a solid wood regime

Correlations greater 0.25 or less than -0.25 are highlighted in bold, while blue shading of correlations greater 0.50 or less than -0.50 Although data was not taken from a single designed experiment, the trees selected for wood quality screening were managed in a similar manner and were taken from plantations and a region with relatively homogenous climatic conditions and soils. Most of the associations between growth characteristics presented below depict well known relationships and are as expected. However, the relatively low correlation between DBH and height in this sample was of interest, as it is typically very high in younger plantations. This possibly reflects the impact of differential competition found in stands with irregular thinning patterns leading to deviations in taper.

Although data is not presented in the table above, the correlation between end splitting scores taken from log faces and the length of end-splits in boards was very high. This and various other findings have led to a large reduction in the amount of work undertaken in the laboratory phase of wood quality evaluation for clonal selections.

Of particular interest, and the subject of intense discussion, was the negative correlation between the length of internal checks and the length of end-splits in boards; the initial assumption that there would be a clearly positive correlation was not found. Further examination of scatter plots between the length of checks and end splits showed a frontier in the length of end splits which appeared to control the level of surface checking. While boards with a greater number and total length of internal checks showed very little end splitting, boards with few checks could be either high or low splitting. It appears that surface checks release internal growth stresses in eucalypt sawn timber, which steadily decreases the severity of splitting in boards. It should also be noted that the number of boards with both end-splits and surface checks was low compared to the high number of boards that were split (Figure 6).

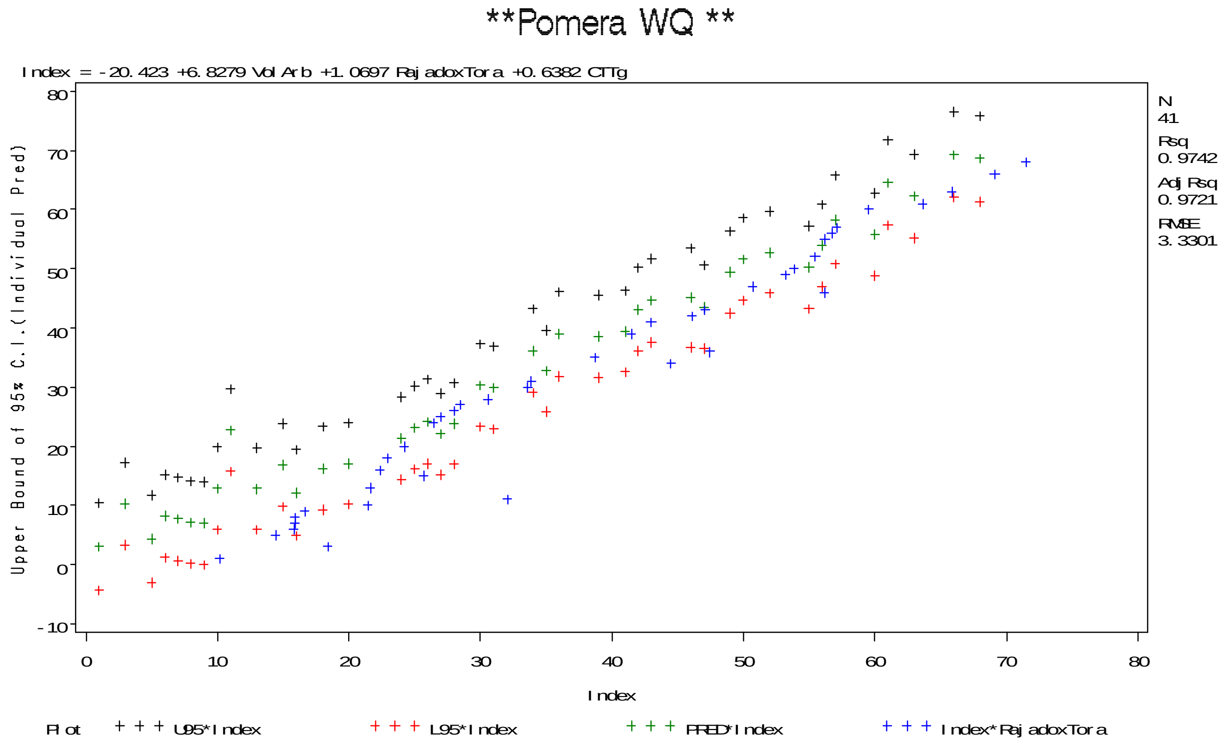
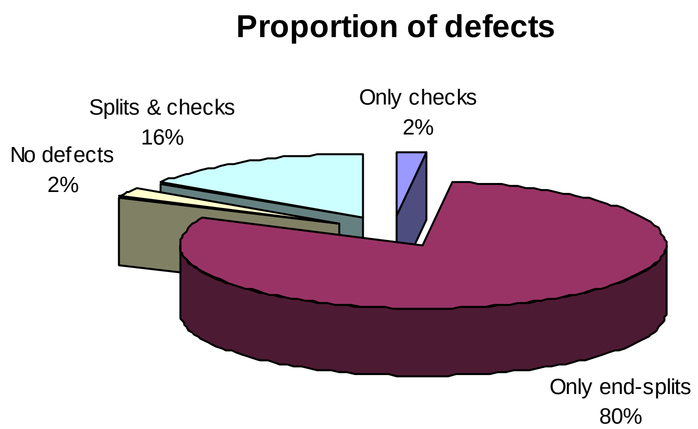


Figure 6 - Model indicating tree Volume, length of board split and tangential shrinkage were the primary drivers for index selection of clones

Figure 7 – Proportion of board defects in wood quality study



While the density-hardness correlation was high and favourable, both traits were unexpectedly correlated positively with radial and tangential shrinkage. Other correlations of interest were: 1) negative correlations between growth variables and radial shrinkage, 2) a positive correlation between shrinkage (radial & tangential) and internal checking, 3) negative correlation between bark percentage and height growth. Although a wide range of hypotheses and conjectures were devised in attempts to explain these phenotypic correlations, further discussions with experts in the field of wood quality assessment are required to clearly interpret this information. Wood samples from clonal selections within these populations have been prepared further investigation of the ability of Near InfraRed spectroscopy to assist in selection of low-split germplasm with acceptable density and hardness profiles for solid wood production.

Photo 5 – Board from a high-split clone left and a low-split clone right 96 hours from felling

During the visit to Paraguay one veneer mill and one sawmill were visited and a tour of a more technologically advanced sawmill with remanufacturing capacity was undertaken in Argentina. While the majority of inventory in the Argentinean mill's shipping yard was pine, a large quantity of eucalypt timber was drying and/or packed for sale both domestically and internationally. The market for eucalypt timber from managed plantations is clearly developing.

Conclusions

Alternatives to the well tested pulpwood silvicultural regimes commonly applied in Australia could be used to increase the profitability of plantation forest growers and sawlog processors. The use of pruning and thinning to create a plantation resource of eucalypts, which can be converted to higher value timber products, appears to be financially feasible using disparate regimes. Processes for the rapid and efficient evaluation of wood quality exist and methods will be evaluated to determine if they can be used to improve the plantation resource through tree breeding.

Another option for increasing the profitability of the forest industry is increasing the recovery and use of residual biomass from thinning and harvest operations. Including the utilisation of waste wood has the potential to increase returns with existing technologies ranging from simple combustion for co-generation of electricity in existing plant to more scalable and complex pyrolysis production technologies for liquid fuel. Although the pulp and paper industry should be a major player in the development of advanced bio-refineries, the scaling up of cellulosic ethanol technologies to produce significant amounts of fuel will not be trivial. While adopting silvicultural prescriptions that use pruning and thinning to increase the value of sawlogs has the potential to increase the forest industries profitability on its own, understanding the financial impact using residual wood for alternative energy production should be better understood across the range of species and sites in Australia.

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APPENDIX A – Contacts and organisations visited during the course of the Gottstein Fellowship

The University of Florida (16-18 June and 3 July 2009)

Timothy White, Douglas Carter, Dudley Huber and Luis Osorio

Forestal Pomera (21-27 June 2009)

Jose Elizaul and Ricardo Kiriluk, Reuben Kolh & Obdulio Pereyra (Univ.El Dorado)

Arborgen (30 June - 2 July 2009)

Victor Steele, Jeff Wright, and Wayne Barfield

U.Florida and Forest Solutions (14 – 17 July 2009)

Donald Rockwood, Nicholas Koch, Marius Ellis

APPENDIX B – Itinerary

Date	Activity
14 June 2009	QF15 Depart BNE 1105 - Arrive MCO 2120 AA 1682
16-18 June 2009	Travel Gainesville, University of Florida School of Forestry
20 June 2009	AA1606 Depart MCO 1800 -
21 June 2009	Arrive FOZ JJ3196 0910 22/6/09
22 June 2009	Saubraz clonal felling protocols
23 June 2009	Drive Posadas – University of El Dorado wood quality lab
24 June 2009	Visit field trials - CIEF cooperative discussions
25 June 2009	Return Saubraz - Eucalypt molecular genetics project planning
26 June 2009	Assess felled clones for wood quality, sawing and peeling trials
27 June 2009	JJ3356 Depart FOZ 0600 - Arrive MCO 2140 AA2190
29 June 2009	Greencircle biofuel plant Travel Pensacola
30 June 2009	Arborgen cold tolerant eucalypt domestication for bioenergy in SE USA
1-2 July 2009	Travel South Carolina Arborgen transgenic laboratory
3 July 2009	University of Florida School of Forest Resources and Conservation
13 July 2009	AA297 Depart BNE 1105 - Arrive Kona 2223 HA 368
14 July 2009	Assess E.grandis cold tolerant trial
15 July 2009	Assess E.grandis cold tolerant trial
16 July 2009	Assess E.grandis cold tolerant trial
17 July 2009	Meet SunFuel Technology and Forest Solutions International
18 July 2009	HA217 Depart Kona 0700
19 July 2009	Arrive BNE QF548 2035

Appendix C – Literature cited

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