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Breeding Radiata Pine to Maximise Profit from Solid Wood Production

Summary Report

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Summary Report

Prepared for the

Forest & Wood Products
Research & Development Corporation

by

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INTRODUCTION

Radiata pine (*Pinus radiata* D. Don) is the most important commercial pine species planted in Australia. Current radiata pine planting stock provided by the Southern Tree Breeding Association (STBA) breeding program is the product of two-generations of intensive selection and breeding. The selection criteria for the first two generations have been tree growth rate (diameter and height) and form traits (stem straightness and branch quality). Successful breeding for growth rate and tree form has reduced wood density slightly in radiata pine due to a negative genetic correlation between growth rate and wood density. Index selection is an efficient method for improving several biological traits simultaneously, particularly in dealing with (unfavourable) negative genetic correlation. One of the most difficult issues in developing a selection index is to estimate economic values (weights) for targeted traits of improvement. In recent years, a new approach based on bio-economic modelling has been introduced as a means of deriving optimal economic weights for breeding traits in tree species (developing breeding objectives).

To develop breeding objective for radiata pine solid wood production in Australia, in this project the following six studies were completed:
(1) Defined production system for radiata pine solid wood production.
(2) Defined breeding objective traits through literature review and industry survey.
(3) Developed a bio-economic model and estimated economic weights for four breeding objective traits.
(4) Estimated genetic parameters to link early-selection and breeding-objective traits.
(5) Estimated selection indices for three types of radiata pine enterprises (plantation grower, sawmill and integrated company).
(6) Studied sensitivity of the estimation of economic weights and selection indices to economic, biological, and genetic parameters in the bio-economic model.

The key results from these studies are summarized here.

DEFINING PRODUCTION SYSTEM FOR RADIATA PINE SOLID WOOD PRODUCTION

We have defined radiata pine solid wood production systems, wood-flows and the sources of income and costs for eight radiata pine companies: HVP-Hancock Victorian Plantations, FSA-Forestry South Australia, Auspine Ltd, GTFP-Green Triangle Forest Products Ltd, Norske Skög Paper Mills (Australia) Ltd, Midway Plantations Pty Ltd, Treecorp Pty Ltd, and AKD Softwoods Pty Ltd. An integrated production system includes two major components: growing trees and conversion of trees into end-products.

Plantation growers: The plantation grower has a cost structure including land rental, growing of plantations which include establishment costs and maintenance costs (fertilisation, weed control, etc.), and harvesting and transportation costs. The incomes for the growers were derived from the sale of sawlogs to saw-mills, and pulplogs to pulpmills or chipmills. A higher royalty applies to the larger logs. A range of geographic regions, site qualities, silviculture and thinning regimes and rotation ages were examined in this study.

Sawmill and integrated companies: Sawmill operations include debarking, primary and secondary sawing process, edging, docking, drying and sorting. Primary saws break down debarked logs into large pieces (flitches and cant). Optimal cutting patterns are usually set by computerised systems for different logs to increase recovery rate. Secondary bandsaws further cut the flitches and cants into smaller dimension boards, and edgers remove the outer rounded part of the board. Docking involves cutting the ends of boards to achieve specific lengths or to remove obvious defects. The boards are kiln-dried to improve their strength and are sorted into different quality (MGP) classes. Chemicals may be used to treat the dry wood depending on the end use. For sawmills, the most significant costs are for the delivered sawlog at the mill gate and most income is derived from the sale of structural grade lumber.

DEFINING BREEDING OBJECTIVE AND SELECTION CRITERION TRAITS

It is fundamental in identifying breeding objective traits to determine the economic impact of different biological traits of trees. We have identified four traits as breeding objective traits for solid radiata pine products. They are mean annual increment in m^3/ha/year (MAI), stem sweep (SWE - maximum deviation of log axis from straight line over the log length in mm/m), modulus of elasticity (MoE - stiffness of clearwood in GPa), and branch size index (BIX - maximum diameter of branches in four quadrants of a log in cm).

The following seven traits were chosen as early selection-criterion traits: a growth trait (DBH), wood density (DEN), microfibril angle (MfA), stem straightness (STS - measured by score 1-6, 6 is the best with 5% straightest stems in a trial), branch size (BRS - measured by score 1-6, 6 is the best with 5% smallest branches in a trial, this is different from definition for breeding objective trait BIX), branch angle (BRA - measured by score 1-6, 6 is the best with 5% flattest branches in a trial) and branch cluster frequency (BRC - number of branch clusters (whorls) between 1-6 meter above ground along the stem). These traits were found to be heritable, also genetically correlated with later-age traits, and were relatively easy and inexpensive to measure (except for MfA).

ESTIMATION OF ECONOMIC WEIGHTS FOR BREEDING OBJECTIVE TRAITS

Economic weights for the breeding objective traits reflect how the improvement in those traits impact on the overall profitability of a forestry enterprise. An economic weight is formally defined as the expected change in overall profitability of an enterprise as a result of a unit increase in a given breeding objective trait. A bio-economic model was constructed to link breeding objective traits with each component of a production system and used to estimate economic weights for breeding objective traits. Correlations of breeding objectives among enterprises and regions were calculated.

For the integrated production system, a 10% increase in MAI or MoE, or 10% reduction for SWE or BIX will increase net present costs by $1231, $0, $172, and $227 per hectare, respectively, while also increasing net present incomes by $2171, $376, $590, and $1091 per hectare, respectively. Overall net present values (NPV) and internal rates of return (IRR) for the plantation grower, sawmiller, and an integrated production system were computed for before and after a 10% change of MAI, SWE, BIX and MoE on per hectare or on per cubic meter basis (Table 1). All three types of production systems (plantation grower, sawmill, and an integrated company) had positive net present value at 6% discount rate, indicating that all Australian radiata pine enterprises were profitable. For a plantation grower, MAI, SWE, and BIX affect grower profitability and MAI is the main driver of profit. For a sawmill, MoE was the most important trait and MAI had a negligible negative effect. For an integrated production system, MoE is the most profitable trait for improvement and MAI the second most important trait.

Table 1. Average value of a 10 % change in individual breeding objective traits for a plantation grower, sawmill and an integrated enterprise.

		Base	MAI	SWE	BIX	MoE
	Change%	0	10	-10	-10	10
Grower	NPV $/ha	2104	2760	2165	2249	2104
	ΔNPV $/ha		654	61	145	0.0
	ΔNPV %		**31.2**	**2.9**	**6.9**	**0.0**
	IRR %	8.4	9.1	8.5	8.6	8.4
	ΔIRR %		7.6	0.6	1.4	0.0
Sawmill	NPV $/m^3	41	40	42	42	52
	ΔNPV $/m^3		-0.4	1.2	1.1	11
	ΔNPV%		**-1.0**	**3.1**	**2.8**	**28.8**
Integrated	NPV $/ha	4539	5449	4763	4921	5650
	ΔNPV $/ha		940	204	362	1090
	ΔNPV %		**20.6**	**4.5**	**7.9**	**23.9**
	IRR %		10.9	10.4	10.5	10.9
	ΔIRR %		5.6	1.1	1.9	5.7

Plantation growers do not get a premium for stiffer wood in the current Australian market. Several recent wood quality initiatives have influenced forestry companies to use dynamic evaluation of MoE for sawlog sorting (Carter Holt Harvey 2004). It seems that market signals are leading to potentially higher premiums for higher quality logs. This will influence decisions regarding selection of trees for establishing new plantations.

Economic weights were found to be different among the integrated companies examined. MoE had a higher economic weight for the integrated company with a shorter rotation length relative to a company with a longer rotation. The effect of a 10% change in MoE on NPV of the integrated companies ranged from 9.5% to 32.5%. For the plantation grower, profit resulting from an unit change of the breeding objective traits for a hectare can be calculated as $H_G = 291(MAI) - 58(SWE) - 248(BIX)$. For a sawmill, profit per m^3 sawlog resulting from an unit trait change is $H_M = -0.18(MAI) - 1.19(SWE) - 1.97(BIX) + 10.5(MOE)$. For an integrated enterprise, profit resulting from unit trait changes per hectare of plantation is $H_I = 416(MAI) - 194(SWE) - 620(BIX) + 977(MOE)$.

The correlations between breeding objectives for a plantation grower and an integrated enterprise within a region were intermediate ($r_{H_GH_I}$ = 0.648), indicating that tree improvement for a vertically integrated firm would result indirectly in about 65% of the potential gain for a forest grower. The correlation was slightly higher between a sawmill and an integrated enterprise ($r_{H_MH_I}$ = 0.713). The correlation between breeding objectives for two integrated enterprises was higher ($r_{H_IH_I}$ = 0.875). A correlation less than unity may be expected given that the production systems, including silvicultural regimes, rotation ages and wood resources were different between the two enterprises. In contrast, the correlation between plantation growers was on average very high within the Green Triangle region (r_{H1H2} = 0.998). There was also regional difference for breeding objectives with a correlation of 0.73 between Green Triangle region and Ballarat. This suggests that a breeding population selected for one region only can produce about 73% of the potential profit gain for another region.
The accuracy of the estimates of correlations between breeding objectives depends on the accuracy of estimates of economic weights and genetic parameters.

ESTIMATION OF GENETIC VARIANCE AND COVARIANCE FOR BREEDING OBJECTIVE AND SELECTION CRITERIA TRAITS

Genetic parameters used in this project were estimated from genetic analyses of three rotation-aged progeny trials and from the literature review. A total of 1518 cross-sectional wood disks (about 40 mm thick) sampled near breast height (about 1.3 m) were collected after trees were felled at the three sites. One hundred and eighty billets were also sampled after the wood disks were taken at the Flynn and Rennick sites. Billets were cut bark-to-bark through pith about 50mm thick and 600 mm in length. In addition, 360 SilviScan samples (strips) were cut at the top of each billet (two strips from each billet, one from south and the second north from pith).

Wood density was measured for 1428 samples cut from disks using the WinDENDRO X-ray facility for the Tantanoola and Flynn sites. Stem Straightness (STS) and BRS data were only available from the Rennick site at age 10. Static MoE (MoE_{static}) was measured using Intron or was predicted from dynamic MoE for 180 billets. Ring width, wood density, microfibril angle and dynamic MoE were derived from SilviScan samples. These data were jointly analysed for traits: ring width (diameter growth), wood density, microfibril angle and dynamic MoE at breast height, in order to examine: (1) Age trends of observations; (2) Age trend of heritability; (3) Genetic correlations among the traits and (4) Age-age correlations for each trait.

We constructed matrices for genetic correlation (Table 2), genetic and phenotypic variances and covariances based on the estimates from the three progeny trials and the estimates reported in the literature for radiata pine.

Table 2. Final construction of genetic correlation matrix for breeding objective project

Genetic Correlations		Breeding Objective Traits at Rotation Age			
		Mean annual increment (MAI)	Timber stiffness (MoE)	Stem sweep (SWE)	Branch index (BIX)
Selection Criterion Traits at early age (6/7 years)	DBH	0.69	-0.54	-0.27	0.28
	Wood density (DEN)	-0.49	0.54	0.25	0.05
	Microfibril angle (MFA)	-0.24	-0.77	0.05	-0.04
	Stem straightness (STS)	0.53	-0.74	-1.00	-0.42
	Branch angle (BRA)	-0.02	-0.44	-0.14	-0.46
	Branch size (BRS)	-0.11	0.17	-0.42	-1.00
	Branch cluster (BRC)	0.28	-0.31	-0.39	-0.60

SELECTION INDEX AND SENSITIVITY ANALYSES

Selection indices were developed for three enterprises (plantation grower, sawmill, and integrated) using estimated genetic parameters and economic weights. Expected genetic gains were computed from selection based on these indices (Table 3). By applying the optimal selection index weights developed in this project, substantial improvements in NPV are expected for the plantation grower, sawmill and integrated company.

Table 3. Expected genetic gains for breeding objective traits MAI, SWE (log sweep expressed on metric scale), BIX (maximum branch size expressed on metric scale) and MOE after selection of 1 in 10 parent trees (*i* =1.755).

	Objective Traits				ΔNPV
	MAI	SWE	BIX	MoE	
present mean	24.0	10.3	5.5	11.3	
unit	m^3/ha	mm/m	cm	GPa	%
Grower	8.09	0.37	-0.63	0.02	85.5
SawMill	2.21	-4.40	-0.31	0.32	35.1
Integrated	6.70	-2.07	-0.57	0.15	56.8

To study the reliability of the estimated economic weights, both Monte-Carlo and what-if studies were conducted. Using the Monte-Carlo simulations we examined the distribution and standard errors for the estimated economic weights. The estimated standard errors on economic weight estimates were low (approximately 15% of the mean, Table 4) and similar for three production systems (plantation grower, sawmill and/or integrated company) and two management regimes (rotation lengths).

Table 4. Monte Carlo estimates of economic weights and their standard errors expressed in NPV$/ha per unit trait change, for shorter (S - 30 years) and longer (L - 35 years) generic rotation management regimes.

Production System		MAI	SWE	BRS	MOE
Plantation Growing	S	303.0 ± 32.8	-49.0 ± 7.7	-266.4 ± 33.0	0.0 ± 0.0
	L	264.0 ± 32.2	-34.5 ± 5.8	-183.7 ± 24.4	0.0 ± 0.0
Sawmilling	S	0.341 ± 0.046	-1.74 ± 0.145	-6.46 ± 0.432	10.0 ± 0.61
	L	-0.207 ± 0.059	-2.13 ± 0.180	-6.52 ± 0.407	9.41 ± 0.56
Integrated Company	S	270.2 ± 47.2	-215.1 ± 33.2	-916.2 ± 122.1	738.4 ± 95.2
	L	320.8 ± 47.7	-160.6 ± 27.1	-655.7 ± 95.7	479.2 ± 68.5

Sensitivity analyses also indicated that the three parameters in the production system: discount rate, round wood price and sawn timber price had the most significant impacts on the estimates of economic weights. The most important factors affecting sensitivity of the selection index were the phenotypic variances of early selection traits tree diameter and wood basic density. Economic weights of mean annual increment (MAI) and modulus of wood elasticity (MOE) were also important. The correlation of economic weights and selection index weights diminished rapidly as the standard errors for genetic parameters increased. Thus, minimising estimation errors of both economic weights and genetic parameters is critical when developing a selection index, but reducing estimation errors of genetic parameters may be more important.

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