Evaluation of Investment in Pine Breeding Projects

Introduction

In Australia, there are approximately 985,000 hectares of pine plantations, including 740,000 hectares of radiata pine (Bureau of Rural Sciences 2006). The Southern Tree Breeding Association (STBA) is responsible for the breeding of radiata pine and the Queensland Forestry Research Institute (QFRI) (now Horticulture and Forestry Science of the Queensland Department of Primary Industries and Fisheries) for slash and caribbean Pines.

Previous investment in these breeding programs has been estimated to generate considerable economic benefits. The first crop of genetically improved trees in Australian radiata pine plantations yielded a 30% improvement in growth rate and productivity improvements of this order were calculated to generate $141 million per annum by the year 2025 (Sultech 1999). Breeding for radiata growth rate and tree form has, however, marginally reduced wood density due to the negative genetic correlation between growth rate and timber density (Dean 1990, Cotterill and Dean 1990).

A key issue emerging from faster-growing pines is the higher proportion of juvenile wood in the harvested logs. Juvenile wood has poorer grade recovery, lower strength, and more distortion. These quality issues may increase the proportion of lower stiffness timber from sawn softwoods and lower the overall strength of softwood products. Given the success of improving productivity during early phases of Australia's pine breeding programs, the focus of the program has shifted toward improving the quality of harvested products.

The suite of projects outlined in this report is evaluated in terms of outputs and the principal outcome of delivering quality of improved planting stock with enhanced quality characteristics.

Investment Description

Details of the principal FWPRDC projects that have contributed to the development of the pine breeding program are listed in Table 1.

Table 1: FWPRDC Projects Contributing to the Pine Breeding Program

Project (Total Cost in nominal $)	Title	Period	Personnel and Organisation
1. PN03.1916 ($4,134,950)	Improving Juvenile Wood of Radiata Pine and Slash/Caribbean Hybrid Pine through Quantitative and Molecular Genetics	2002/2007	Researchers: Tony McRae plus many from CSIRO and several from QFRI. Organisations: Southern Tree Breeding Association, CSIRO Forestry and Forest

			Products, Queensland Forestry Research Institute
2. PG98.400 ($75,000)	Inheritance of Wood Properties in Slash x Caribbean Pine Hybrids	1998/2001	Researchers: Dominic Kain, Peter Kanowski (supervisor) Organisations: Australian National University
3. PN01.1904 ($866,351)	Breeding Radiata Pine to Maximize Profit from Solid Wood Production	2003/2005	Researchers: Wu H, Ivkovic M, McRae T, and Powell M Organisations: CSIRO Forestry and Forest Products (Canberra), Southern Tree Breeding Association Inc. (Mount Gambier)
4. PN02.1910 ($143,090)	Improvement of Wood and Fibre Stiffness through Microfibril Angle (MfA)	N.A.	Researchers: Colin Matheson, CSIRO Canberra Organisations: CSIRO Forestry and Forest Products, Canberra
5. PN03.1915 ($1,439,059)	An Advanced Genetic Evaluation System For Forest Tree Improvement (TREEPLAN)	2003/2007	Researchers: Tony McRae and others Organisations: Southern Tree Breeding Association, CSIRO Forestry and Forest Products, Animal Genetics and Breeding Unit (UNE)
6. PN012.96 ($296,400)	Molecular Markers for Enhanced Selection of Dothistroma resistance in *Pinus Radiata*	1997 to 2000 (plus extension)	Researchers: Sadanandan Nambiar (CSIRO Forestry and Forest Products, Canberra) Organisations: CSIRO Forestry and Forest Products, Forestry Commission of NSW (State Forests), Southern Tree Breeding Association
7. PNO5.3012 ($618,450)	National Genetic Resource Centre	2004/2005	Researchers: Tony McRae and others Organisations: Southern Tree Breeding Association

Objectives

The common objective of the seven projects was to generate improved planting materials with enhanced quality characteristics. Objectives of each of the individual projects are reported in Table 2.

Table 2: Objectives of the FWPRDC Pine Breeding Projects

Project	**Objectives**
1.PN03.1916	The Juvenile Wood Initiative aims to improve juvenile wood (or reduce its amount) of radiata pine and slash/Caribbean hybrid pine in the STBA and QFRI breeding and deployment populations to substantially increase timber value for the Australian softwood industry. Specific objectives are as follows: (i) Develop non-destructive methods, including acoustic techniques, to predict juvenile wood properties and stiffness (MoE- Modulus of Elasticity) for breeding purposes (ii) Quantitative genetic analysis of juvenile wood characteristics (MoE, basic density, MfA and other traits) in radiata and slash/Caribbean hybrid pine populations (iii) Quantify genetic control of transition from juvenile to mature wood in radiata and slash/Caribbean hybrid pine populations (iv) Estimate parental and individual breeding values of third-generation progeny in radiata pine breeding populations, and of second-generation progeny in slash/Caribbean hybrid populations (v) Identify candidate genes for juvenile wood traits through differential gene expression (vi) Characterise selected genes by sequencing and expression analysis (vii) Develop single nucleotide polymorphic (SNP) markers and map candidate genes from microarrays and sequence databases in radiata and slash/Caribbean populations (viii) Conduct QTL analyses for wood traits using SNP and microsatellite markers (ix) Develop selection strategies to integrate quantitative and molecular information into the breeding program for improved juvenile wood in radiata and slash/Caribbean hybrid pine
2. PG98.400	To examine the genetic basis of variation in wood and growth traits in a progeny test of *Pinus elliottii var. elliottii* (PEE), *Pinus caribaea var. hondurensis* (PCH) and their F1 and F2 hybrids (PEE×PCH).
3. PN01.1904	To develop breeding objectives for radiata pine solid wood production in Australia. Developing breeding objectives for the radiata pine tree improvement program included three major components: (1) deriving economic weights for breeding objective traits, (2) estimating genetic variance and covariance matrices, and (3) sensitivity analyses.
4. PN02.1910	Previous research into MfA inheritance in Australian *Pinus radiata* had not generated

	any clear results. This project aimed to overcome earlier problems because both the sample size and methodology have been improved. A key objective was determining optimal sampling methods for MfA and developing a greater understanding of the genetic control of MfA.
5. PN03.1915	The project aimed to develop an advanced genetic evaluation system for forest tree improvement and greatly improve the rate of genetic gain captured by the Australian softwood and hardwood plantation industry. Specific objectives included: • Further develop "industrial strength", analytical software ('TREEPLAN') for the routine and efficient estimation of genetic (breeding and deployment) values in trees. • Integrate information at the DNA level (candidate genes, genetic markers) with performance and pedigree data; exploit clonal information (additive and non-additive genetic effects); and better model environmental effects (spatial auto-correlation and random regression) while estimating breeding and deployment values. • Characterise genotype by environment (GxE) effects for all measured traits of commercial importance in plantation forestry. Define target production environments for improved *P. radiata* genotypes. • Conduct routine genetic analyses for the national *P. radiata* and *E. globulus* tree improvement programs, including the estimation of genetic parameters (variances and associations between traits).
6. PN012.96	The project was conducted to identify molecular markers which are associated with Dothistroma resistance in *Pinus radiata*. Specific objectives included: determination of the number and map position of genes controlling resistance to Dothistroma, characterise a suite of molecular markers linked to these genes for application as early selection tools and testing the efficiency of using markers for selection of disease resistance.
7. PNO5.3012	The plan is to establish a National Genetic Resource Centre (NGRC) at Mount Gambier for breeding and gene conservation purposes in *Pinus radiata*, *Eucalyptus globulus* and other plantation species. Key objectives are: • Develop integrated breeding facilities at Mount Gambier. • Reduce costs for cross-pollination activities. • Improve the quality and quantity of crosses made. • Facilitate modern rolling front breeding strategies with overlapping generations. • Facilitate gene conservation for *P. radiata* and archives for E. globulus. • Secure germplasm and manage intellectual property for Members. • Reduce exposure to catastrophic loss from fire, drought and neglect.

Investment Costs

The total nominal cost of the evaluated projects was estimated to be $7.6 million. This total cost includes the contribution of industry and research partners. Table 3 provides the total costs broken down by year and by the FWPRDC and the other contributions.

Table 3: Investment in the Selected Breeding Projects (Nominal $)

Year ended June	FWPRDC	Industry and Research Partners	Total
1999	22,500	73,800	96,300
2000	37,500	73,800	111,300
2001	40,000	73,800	113,800
2002	129,965	104,965	234,930
2003	375,131	630,131	1,005,262
2004	885,331	1,774,040	2,659,371
2005	905,711	1,444,710	2,350,421
2006	466,283	526,633	992,916
Total	2,862,421	4,701,879	7,564,300

Principal Outputs

Table 4 reports the principal outputs for each of the seven FWPRDC projects.

Table 4: Summary of Principal Outputs from the Seven Projects

Project	Principal Outputs
PN03.1916	Trees with early transition time from juvenile to mature wood and with high juvenile wood stiffness are being selected in this project for breeding and deployment by the Southern Tree Breeding Association in its Australasian breeding program for radiata pine (the STBA uses a multi-trait index, which incorporates growth, form and wood quality traits) and by Queensland Forestry Research Institute (QFRI) in its international slash/Caribbean hybrid breeding program. The work is still underway, as QFRI will select the best planting materials using the most effective stiffness method for their second-generation hybrid program during 2005-2007. Also, elite genotypes (across generations) are being selected by STBA for use in the national breeding and deployment populations using the most effective acoustic stiffness method. Controlled pollination is occurring among the final selections for STBA members' deployment in their new plantings in 2005-2007.
2. PG98.400	The research further supported the results from previous studies that recurrent selection in composite hybrid populations is likely to provide a powerful future tool for tree breeders in complementary interspecific hybrid tree taxa. This study found that low wood density and moderate spiral grain angles in the inner growth rings of the F1 hybrid will require improvement in order to meet wood quality criteria. Simultaneous improvement of density and volume in some populations is complicated by a negative genetic correlation between productivity and quality traits. Additionally, pure species selection is likely to be an efficient alternative breeding strategy to direct selection in some F1 hybrids.
3. PN01.1904	As a result of the research models have been developed, genetic and phenotypic variance - covariance matrices constructed and economic weights used to construct

	breeding objective and selection indices. These weights and selection indices are being used routinely by the STBA in the national breeding program for radiata pine and for selection of genotypes in deployment for radiata pine industry members in Australia.
4. PN02.1910	Using SilviScan-2 instrumentation it has been demonstrated that selection to reduce MfA should be successful. Additionally, the predicted stiffness of corewood can also be improved through genetic selection. Incorporation of this information into the breeding program will lead to an enhanced genetic rate of gain in these traits, which are discussed in the outcomes section of this report.
5. PN03.1915	TREEPLAN has been integrated with the STBA web based data management system (STBA-DMS) and national databases have been used for modelling purposes during the development phase. Workshops have been undertaken with industry to facilitate better use of breeding values and research data.
6. PN012.96	The markers identified in this project could be used to select families within the breeding program for disease resistance. These markers need to be confirmed as conferring resistance as this was not confirmed in the research to date. It has been difficult to use the results and findings of this research in the national breeding program for *Pinus radiata*. With advances made in TREEPLAN®, use of this type of data in genetic analysis can now be done.
7. PNO5.3012	STBA acquired land for $618,450 (28.5 ha) and established grafted selections for *P. radiata* and *E. globulus* in late 2005. Fencing was replaced and the site is now managed intensively by STBA. Conservation plantings of *Pinus radiata* have been established.

Principal Outcomes

Over the last 50-60 years *P. radiata* productivity has improved from 1.5 generations of selection and breeding. Two key developments have recently refocused the breeding program, with firstly the development of TREEPLAN a computer-based analytical program, which improves selection efficiency, and secondly, greater attention on wood quality issues. STBA anticipate (Dutkowski *et al.* 2006) the rate of genetic gain in the plantation sector to more than double through the use of better genetic models and the tactical approaches associated with TREEPLAN. Optimal use will be made of the genetic resource (using full pedigree and multi-generation data) with this new approach.

All of the breeding projects outlined in this evaluation will contribute to improved selection and breeding of pine, with an increased wood quality being a likely outcome. The TREEPLAN project aims to further develop the TREEPLAN software leading to more efficient and routine processing of pedigree, performance and molecular information associated with the national tree improvement programs for *P. radiata*, *E. globulus* and other species. There is no equivalent ‘industrial strength’ software available in the international market for trees. Genetic analyses are usually conducted on disjointed subsets of data. Sub-optimal statistical methods of analysis have in effect also restricted tree improvement programs to discrete generation breeding.

Juvenile wood has been recognised to be of inferior quality having high levels of spiral grain, low basic density, high moisture content before heartwood formation, above average amount of compression wood, moderate to high longitudinal shrinkage, timber prone to warp, a low percentage of cellulose and short tracheids. These characteristics lead to poorer grade recovery, lower strength, more distortion and surface checks, and poorer finishing properties for structural timber. In general, wood quality traits, including juvenile wood quality were not included in the first- and second-generation improvement programs for radiata pine and in the previous slash/Caribbean hybrid breeding program.

Recent development of new technologies for measuring wood quality traits, such as non-destructive acoustic methods for measuring stiffness have made the detailed examination of relationship between stiffness and wood quality traits such as basic density, cell dimension and structure much easier. These techniques have been used in the on-going juvenile wood project and will lead to the identification of individuals and breeding strategies to improve wood quality. The consolidation of the breeding program at the National Genetic Resource Centre will help facilitate the identification and incorporation of these traits in improved planting materials. A number of new techniques and devices will be used and developed in these projects. Research into the inheritance of MfA in *Pinus radiata* in both Australia and New Zealand will also help identify inheritance characteristics and optimal strategies for improving wood quality.

Markers have had no impact to date on the operational programs. This type of information has been considered independent of other performance data in the past. The TREEPLAN system will facilitate use of this type of data in future, delivering benefits to industry beyond the research phase.

Benefits

Economic
The key benefit to be derived from this series of investments will be an improved quality of pine sawn timber products and more timber meeting structural grading thresholds. This improvement will be in the form of increased stiffness, over the stiffness expected without the investment. The improvement is expected to allow a higher proportion than otherwise of pine timber to be graded into the structural market, so increasing overall profit for the industry.

Environmental
The outcomes from the investment are considered to be environmentally positive through the reduction in greenhouse gas emissions from the use of forest products in house construction (compared with concrete, brick and steel). The degree of reduction will be dependent on the impact the higher quality product will have on the substitution between other building materials and timber for housing. In so far as the quality improvements maintain or increase the size of the pine plantation industry, the investment will help to maintain the carbon sequestration function that the plantation industry performs.

Social
A social benefit is that the increased profits over the counterfactual scenario of poorer quality timber and lowered profits being produced in the future is likely to help maintain the Australian forest communities dependent on pine industry growing and processing. The investment also has built the capacity for further breeding initiatives for pine species in Australia.

A summary of the principal types of benefits associated with the investment is provided in Table 5.

Table 5: Summary of the Economic, Environmental and Social Benefits from the Investment

Economic	**Environmental**	**Social**
Improved selection and breeding of pine Increase in the value of radiata and slash/Caribbean pine sawn timber products due to improved quality	Likelihood of reduced greenhouse gas emissions by maintaining a competitive structural pine industry in Australia	Maintenance of Australian softwood plantation dependent communities

Public versus Private Benefits
Most of the benefits identified will be of a private nature and will be captured by the forest and wood products industry. However, there will be some spinoff benefits to the wider public from the outputs of the research investment in that some benefits in the form of increased consumer surplus from the improved quality will be captured by wood consumers. The greenhouse implications of maintaining a competitive structural pine industry in Australia also contributes to public benefits.

It is likely that some investment in breeding would have been made in the situation where the levy contribution from the Australian Government was less than it was at the time of funding these projects. However, depending on the extent of the reduction, some of the seven projects probably would have not been funded at all, and others would have been funded at a reduced level. Overall it is estimated that without any government contribution less than half of the total investment would have resulted, possibly around 40% of the investment that was reported in this analysis.

The main impact of this reduction would have been on the extent of genetic gain achieved. It is estimated that about 40% of the expected gain would have been achieved without any government contribution. As is reported later this would have potentially reduced the expected value of the total investment from a net present value of $239 m to $96.6 m.

Distribution of Benefits Along the Sugar Supply Chain
Some of the producer surplus will be captured by processors and others adding value along the marketing chain.

Match with National Priorities
The Australian Government's national and rural R&D priorities are reproduced in Table 6.

Table 6: National and Rural R&D Research Priorities 2007-08

Australian Government	
National Research Priorities	**Rural Research Priorities**
1. An environmentally sustainable Australia 2. Promoting and maintaining good health 3. Frontier technologies for building and transforming Australian industries 4. Safeguarding Australia	1. Productivity and adding value 2. Supply chain and markets 3. Natural resource management 4. Climate variability and climate change 5. Biosecurity *Supporting the priorities:* 1. Innovation skills 2. Technology

The pine breeding projects make a positive contribution to National Research Priority 1 and Rural R&D Priority 3 in terms of sustainable resource management via maintaining the greenhouse friendly nature of wood production versus other building materials.

National Research Priority 3 is also addressed via frontier technologies used in these tree breeding projects, some of which were novel to previous tree breeding technologies. Innovation skills have been clearly demonstrated (supporting Rural R&D Priorities).

A significant contribution has also been made to Rural Research Priorities 1 and 2 through the higher quality products anticipated, the adding value outcomes and the impact on the future demand for wood products.

Quantification of Benefits

Assumptions

If the investment in breeding for quality had not been undertaken, no quality improvement would have been achieved. The future could have seen structural pine timber prices fall, the industry could have lost market share to steel with a contraction in the size of the Australian pine growing industry, or more structural grade pine may have been imported.

The key outcome of the breeding projects included in this evaluation will be an increase in the value of radiata and slash/Caribbean pine sawn timber products. Key assumptions required to evaluate the economic benefits from this outcome include an estimate of the size and dynamics of the industry, estimating the value of the quality improvement and the extent and rate of adoption of improved planting material generated from the selected projects.

Industry Size

In the 1970s and 1980s there was significant public investment in new plantations, based on a perceived need to develop a new wood resource and to reduce dependence on imported timber. Extensive areas of exotic softwood, mainly radiata pine, were established in this period.

As a result, softwood log removals from plantations have increased, although a large proportion of new plantations in the late 1990s were established with short rotation eucalypts for the pulpwood market. The shift in investment was driven by limited capacity of the domestic market absorbing further softwood, increasing international pulpwood demand and a desire for a faster turnaround on funds invested (Love, Grist, and Hansard, 2000). The same authors suggest industrial wood removals are projected to increase over the next ten to fifteen years.

For the purposes of this evaluation, it is assumed the pine plantation area will grow by 1% per annum. This increase in area, along with annual replacement of the existing production base forms the target market for the new genetic material. Nationally, there are currently about 985,000 hectares of pine plantations

Value of Quality Improvement

Juvenile wood has characteristics that affect the quality of timber, including poorer grade recovery, lower strength, more distortion and surface checks, and poorer finishing properties for structural timber. By targeting wood quality in the breeding cycle, it is assumed that the proportion of juvenile and poorer quality wood can be reduced.

It should be noted that growth and wood quality traits are negatively correlated. Baltunis and Wu (2006), indicate, however, that there is potential for selection of correlation breakers, allowing juvenile wood properties to be improved with minimum adverse effect on growth.

Research undertaken as part of the juvenile wood initiative predicts genetic gains of between 15 and 40% for whole core MOE (stiffness) with selection intensity between 1 to 10% (Baltunis and Wu, 2006).

Based on the economic evaluation of breeding values undertaken by Dutkowski *et al.* (2006) a one unit (GPa) increase in stiffness would increase industry profit by $977 per hectare on a net present value basis. Improved stiffness increases profitability largely as a result of a higher proportion of timber being recovered as higher structural grades.

This premium is assumed to be constant in real terms across the evaluation period of 50 years. Corresponding with this assumption, it is estimated that any supply increases in the structural timber market derived from enhanced wood quality would not decrease prices received, as any added production will be absorbed into future increases in demand for structural product.

Love et al (1999) examined long-term trends in both world and Australian wood and wood based products prices. In real Australian dollar terms, the world import prices for roundwood and sawnwood have trended downward at rates of around A$1.50 and A$1.05 per cubic metre a year respectively and the FAO does not expect product prices to rise significantly over the projection period, although upward pressure on the prices of certain types of wood, typically the higher grades, may occur.

For the purposes of the cost-benefit analysis, it is assumed that a 0.5 unit increase in GPa could be achieved without any detriment in other production attributes. This increase is within the lower limit of stiffness gain outlined by Baltunis and Wu (2006) and is valued at $489 per hectare.

Adoption of improved planting materials
Most new Australian pine plantations are established using improved planting materials developed by QFRI and STBA. For historical (and cheaper seed) reasons, Forests NSW deploy material based on New Zealand bred material.

It is estimated conservatively that 70% of Australian plantings are derived from these programs and the results of the FWPRDC - financed research has been incorporated into the relevant breeding programs.

It is assumed that new planting material from 2006 onwards has benefited from this research, which means that plants first harvested in 2041 (30 year production cycle and 5 years for seed production) will have improved wood quality characteristics.

This assumes that new genetic material will be propagated over a 5 year period and the bulk of harvested timber products will occur in 30 years. In terms of the propagation of planting materials, the orchard system typically used to produce radiata seed and seedlings has a longer lag time when compared to grafting systems used for hybrids. Therefore, a 30 year propagation and plantation production cycle is assumed to be an average across northern and southern production areas.

Further it is estimated that 3.3% of existing production base is replaced each year in plantation cycles. In association with this rotation at least 2.3% (i.e. 70% of 3.3%) of the existing growing area will be planted to improved planting materials each year, while 70% of the new plantations established each year under the assumed 1% expansion will also include improved pine planting materials.

Research undertaken in the Juvenile Wood Initiative has developed tools and approaches to target improved timber quality in the pine breeding programs, along with suggesting the order of possible genetic gains that are possible. It is some time before improved genetic material will be selected, incorporated in planting materials and harvested. A probability of success of 70% is included in the cost-benefit framework to accommodate the risk that the estimated genetic gains will not be captured.

A summary of the assumptions made is provided in Table 7.

Table 7: Assumptions for Estimating Impact of Pine Breeding Projects

Item	**Value**	**Source**
Projection of benefits and costs	Maximum of 45 years after the last year of research investment	Consultant estimate
Pine plantation area	985,000 ha	Derived from BRS (2006)
Industry benefit of 0.5 GPa increase in stiffness ($ NPV per hectare)	$489 NPV per hectare (equivalent to $1684 per ha per annum)	Derived from $977 per hectare increased profit from 1 unit (GPa) increase in stiffness (Treeplan Breeding value)*
Impact of 0.5 GPa increase in stiffness on other production indices e.g. growth.	Negligible	Assumes 0.5 GPa improvement in stiffness is achieved with no impact on other production criteria, as assumption conservative given 15-40% gain predicted by Baltunis and Wu (2006)
Projected real value of quality improvement	Constant	Love et al (1999) indicated the long term real price of timber has been declining or constant for most products. For higher grade, demand is expected to absorb any increased supply
Adoption of improved planting materials in new growing areas	70%	Consultant estimate
Rate of adoption of improved planting materials within current growing area	2.3 % per annum	Based on 3.3% annual replacement of plantations and 70% use of improved planting materials for all new plantings
Rate of expansion in growing area	1 % per annum	Consultant estimate derived from Love et al. (2000) growing area projections modified from discussions with industry personnel

Probability of technical and commercial success	70%	Consultant estimate
Year industry first captures benefits from genetic improvement	2041	Assumes an average 35 year propagation and growing cycle

* Assume 30 year production cycle length and 5% discount rate.

Results

The resulting investment criteria are presented in Tables 8 and 9. The maximum period of analysis was for 45 years after the last year of investment. The results are expressed in 2006/07 $ terms and all benefits and costs are discounted to the 2006/07 year.

Table 8: Investment Criteria for Total Investment and Total Benefits

(Discount Rate 5%)

Criterion	0 years	5 years	10 years	15 years	20 years	40 years	45 years
Present value of benefits (m$)	0	0	0	0	0	92.6	248.8
Present value of costs (m$)	9.4	9.4	9.4	9.4	9.4	9.4	9.4
Net present value (m$)	-9.4	-9.4	-9.4	-9.4	-9.4	83.1	239.3
Benefit cost ratio	0	0	0	0	0	9.8	26.4
Internal rate of return (%)	Negative	Negative	Negative	Negative	Negative	11.1	13.3

Table 9: Investment Criteria for FWPRDC Investment and Benefits to FWPRDC

(Discount Rate 5%)

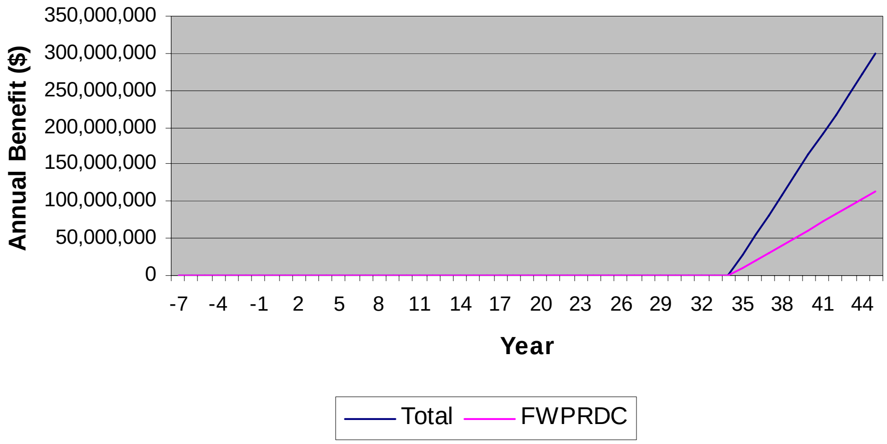
Criterion	0 years	5 years	10 years	15 years	20 years	40 years	45 years
Present value of benefits (m$)	0	0	0	0	0	34.9	93.9
Present value of costs (m$)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Net present value (m$)	-3.5	-3.5	-3.5	-3.5	-3.5	31.4	90.3
Benefit cost ratio	0	0	0	0	0	9.8	26.5
Internal rate of return (%)	Negative	Negative	Negative	Negative	Negative	11.2	13.3

The net present value for the FWPRDC investment is $90 million over 45 years and the benefit-cost ratio is over 26:1 at a 5% discount rate. Estimated pay-off is sensitive to assumptions relating to the assumed value of the quality gain, discount rate and use of improved planting materials. The sensitivity of investment criteria to these assumptions is outlined in the next section.

In terms of the quantified benefits, 100% could be attributed to the productivity and adding value component of the rural research priorities.

The cash flow of benefits is shown in Figure 1 for both the total investment and for the FWPRDC investment.

Figure 1: Annual Benefit Cash Flow



Sensitivity Analysis

Sensitivity analyses are reported in Tables 10 to 12. These analyses and results refer to the 45 year period after the last year of investment and are based on the FWPRDC investment only.

A reduction in the value of the quality improvement to $245 per ha would decrease the net present value of the investment by $47 million at a discount rate of 5% (Table 10).

Table 10: Sensitivity of Investment Criteria to Value of Quality Improvement (FWPRDC Benefits and Costs) (Discount Rate of 5%)

Investment Criteria	**$245 per ha**	**$489 per ha (Base)**	**$734 per ha**
Present Value of Benefits (m$)	47.0	93.9	140.8
Present Value of Costs (m$)	3.5	3.5	3.5
Net Present Value (m$)	43.4	90.3	137.3
Benefit–cost Ratio	13.2	26.5	39.7
Internal Rate of Return (%)	11.5	13.3	14.4

There is a considerable lag between the development of improved genetic material in the breeding program and the realisation of the benefit of that improvement through improved product quality and productivity at harvest. In the case of pine, the lag is around 35 years, so the assumed rate of discounting of benefits into a present day value is a major assumption.

A sensitivity analysis has been conducted in Table 11 to gain an appreciation of the effect of different discount rates on the present value of benefits and costs and other related investment criteria. It is evident that the economic value of the investment in the pine breeding program is far more when discounting is not used (0% discount) rate, and when a 20% discount rate is assumed the projects are estimated to have a negative economic impact.

Table 11: Sensitivity of Investment Criteria to Discount Rate
(FWPRDC Benefits and Costs)

Investment Criteria	**0% Discount Rate**	**5% Discount Rate (Base)**	**10% Discount Rate**	**20% Discount Rate**
PV of Benefits	676.9	93.9	14.5	0.5
PV of Costs	3.1	3.5	4.1	5.3
Net Present Value	673.8	90.3	10.5	-4.8
Benefit–cost Ratio	218.8	26.5	3.6	0.1

The percentage of pine plantings derived from improved genetic materials is critical in determining benefits from the project (Table 12). At least 3% of existing plantings will need to be derived from the improved genetic materials generated at as a result of the above project investments to justify an investment return of 5%.

Table 12: Sensitivity of Investment Criteria to Adoption of Improved Planting Materials
(FWPRDC Benefits and Costs; Discount Rate of 5%)

Investment Criteria	**35% (Low)**	**70% (Base or Expected)**	**100% (High)**
PV of Benefits ($m)	46.9	93.9	134.1
PV of Costs ($m)	3.5	3.5	3.5
Net Present Value ($m)	43.4	90.3	130.6
Benefit Cost Ratio	13.2	26.5	37.8
Internal Rate of Return (%)	11.5	13.3	14.3

An additional table is presented below (Table 13) that shows the sensitivity of the Net Present Value based on total benefits and costs at low (35%) expected (70%) and high (100%) adoption levels.

Table 13: Sensitivity of Net Present Value ($m) to Adoption of Improved Planting Materials
(Total Benefits and Costs; Discount Rate of 5%)

Period	**0 years**	**5 years**	**10 years**	**15 years**	**20 years**	**45 years**
Adoption Level						
Low (35%)	-9.44	-9.44	-9.44	-9.44	-9.44	115.0
Expected (70%)	-9.44	-9.44	-9.44	-9.44	-9.44	239.3
High (100%)	-9.44	-9.44	-9.44	-9.44	-9.44	346.0

Finally, the scenario of no government funding is tested. The assumptions are made that this would have resulted in 40% of the total investment being made and 40% of the genetic gain being achieved with no change in timing or costs and benefits. The results for this are reported in Table 14. The results show there is a reduction in net present value of $143 m or 60% under this scenario.

Table 14: Sensitivity of Investment Criteria to Reduction in Investment and the Associated Genetic Gain Achieved
(Total Benefits and Costs) (Discount Rate of 5%)

Investment Criteria	**Existing Costs and Benefits**	**Reduced Costs and Benefits**
Present Value of Benefits (m$)	248.8	99.5
Present Value of Costs (m$)	9.4	2.9
Net Present Value (m$)	239.3	96.6
Benefit–cost Ratio	26.4	34.0
Internal Rate of Return (%)	13.3	14.0

Conclusions

Cost-benefit analysis undertaken in this report indicates that funds invested in pine breeding improvement will generate a substantial return. This impact is supported by the fact that a large proportion of industry support the STBA and most new planting materials are derived from the breeding research supported by FWPRDC. It should be noted that the long lags between plant breeding, progeny testing, propagation and harvesting of many plant and tree species curtail the estimated economic benefits of many breeding programs. In the case of radiata this lag is particularly acute with somewhere in the order of 35 years before the benefits from today’s investment in the industry’s breeding program will be captured by industry.

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