In-Forest Debarking of Pinus radiata to Improve Supply Chain Efficiency

Milestone 3 Report: 9 December 2016

Prepared for

New Zealand Forest Growers Levy Trust

by

Dr Glen Murphy

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Forest Engineering Research and Consulting

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Executive Summary

All Milestone 3 requirements have been met. The project was completed on schedule. This report focuses on activity related to Milestone 3 (July to December 2016) but includes for completeness the Milestone 1 and Milestone 2 reports as Appendices.

In-Forest Debarking was shown to be economically viable for both New Zealand and Australia.

A six-page summary report covering the full project is provided under a separate cover.

Project Goal and Objectives:

Bark is a low-value product that adds cost from forest to customer. Eliminating it early in the supply chain was expected to improve the forest grower's profitability.

The objectives of the project are to

- quantify the potential costs and benefits of in-forest debarking of Pinus radiata, and
- identify the potential of, and maximum capital costs that could be paid for, modifying mechanized harvester/processor heads.

The project involves:

- seasonal bark loss benchmarking trials
- seasonal relative drying rate trials
- debarker feasibility and productivity trials
- a safety review
- systems analyses extending from pre-harvest through to mill or port
- economic analyses

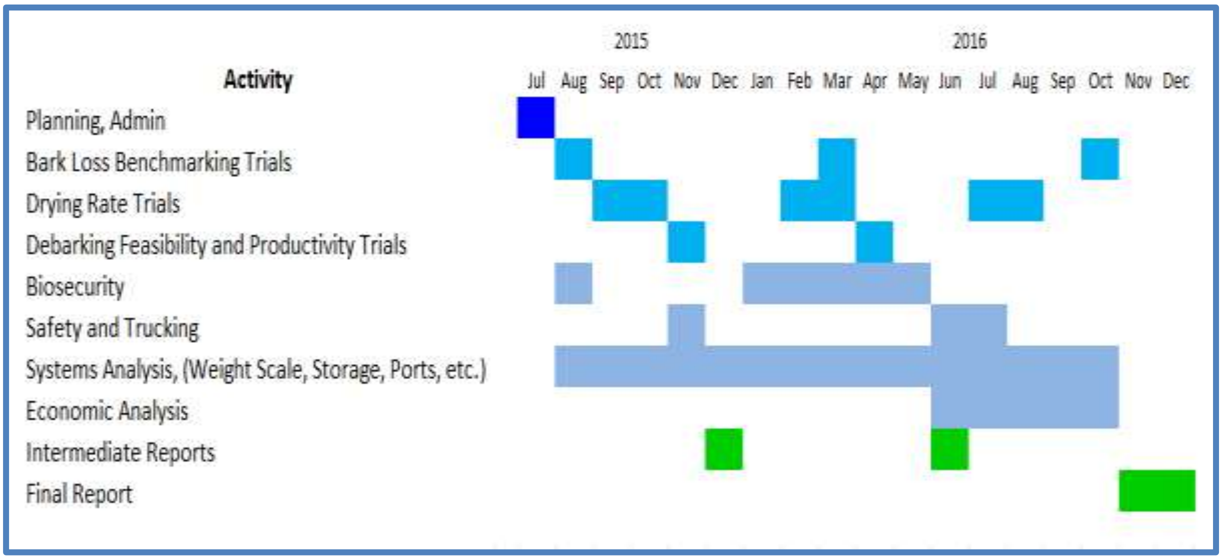

Figure 1. Gantt Chart of Planned Activity for the In-Forest Debarking Project

Milestone Requirements:

Milestone 1: Project planning, completion of first round of field trials (bark loss benchmarking trials and drying rate trials in both Australia and New Zealand, and feasibility trials in New Zealand), initial exploration of safety and biosecurity issues, delivery of first intermediate written report at end of six months, verbal update to the Technical Committee.

Milestone 2: Completion of the second round of field trials, completion of work on impacts on biosecurity, port storage, and handling, and log handling safety, delivery of second intermediate written report at the end of 12 months, verbal update to the Technical Committee.

Milestone 3: Completion of the third round of field trials (bark loss and drying rate trials only), completion of systems analyses and economic analyses, delivery of final report (in written and conference-suitable presentation form), verbal update to the Technical Committee.

Project Participants:

- Professor Glen Murphy, GE Murphy & Associates Ltd (formerly of Waiariki Institute of Technology, Rotorua)
- Professor Mark Brown and Dr Mauricio Acuna, University of the Sunshine Coast (USC), Australia
- Mr Warwick Batley, Satco Ltd., Tokoroa
- Mr Weytze van Heerden, Southstar Equipment Ltd, Tauranga. [Southstar agreed to participate in the project after its initiation.]

Milestone 3 Achievements and Key Findings:

Achievements

* The final benchmarking data set was gathered in Winter 2016 for four ground-based, tree-length logging crews in Kaingaroa Forest. The crews mechanically felled trees at the stump, extracted the stems to a landing, and then mechanically bucked the stems into logs. Two of the crews used Woodsman PRO 800 processor heads mounted on excavators. These processor heads are fitted with four delimbing knives and spiked rollers. One crew used a 4-knife Waratah 625C processor head fitted with spiked rollers. The remaining crew used a 2-knife Waratah 626 processor head fitted with spiked rollers. The purpose of the data set was to determine the effect of the number of delimbing knives on bark removal.
* A manuscript describing all of the eleven benchmarking trials was prepared and submitted to the International Journal of Forest Engineering. The manuscript was accepted for publication in October 2016. [Murphy, G. Acuna, M. 2016. Effect of Harvesting Season, System and Equipment on In-forest Pinus radiata Bark Removal in Australia and New Zealand. International Journal of Forest Engineering. [http://dx.doi.org/10.1080/14942119.2016.1253269.]
* The final New Zealand drying rate trial was carried out in winter (July 2016) in Bay of Plenty. 57 logs (27 with the bark left largely intact, and 30 with the bark removed) were weighed at the beginning and end of a 10 day period. The logs were from four diameter classes (<150 mm, 150-250mm, 250-350mm, and >350 mm). The climatic conditions for the trial period were as follows: mean temperature 7^{o}C, mean wind speed 7 km per hour, total rainfall 27 mm. All Australian data and all New Zealand data from the five log drying trials were analysed using StatGraphics statistical software. The Australian data and the New Zealand drying data were analysed separately. “Bark On” and “Bark Off” models were developed for each site. The dependent variables for both sets of models were Weight Loss (kg). Independent variables included in the models were Initial Weight (kg), Bark On (%), and Season.
* Discussions with Southstar in the second quarter of 2016 indicated that they were developing a debarking head for pine species. It was hoped that a feasibility trial to determine the efficacy and efficiency of a modified processor head for debarking radiata pine could be undertaken in the third milestone period. Unfortunately, the debarker head was not available for trialling before the end of the project. If funding is available, it is recommended that this machine be studied in 2017.

* A small trial was undertaken in October 2016 to assess the static coefficient of friction of small *Pinus radiata* logs with bark present and bark removed. A test bed was set up of two radiata pine logs that were about 3 m long. Most of the bark was present on the upward surface of these logs. Two 2 m long logs, weighing 30 and 38 kg, were then used to assess the coefficient of friction. Two coach bolts were screwed into the end of each log. A wire strop was attached to the bolts. A mechanical weigh scale (50 or 100 kg max.) was attached to the wire strop. A ratchet winch (="come-along") was applied to the other side of the weight scale (see Figure 2). A force was applied until the top log began to move. The force required was read from the weigh scale. The force to move the log divided by the log weight was the coefficient of friction. The test was repeated at least 5 times. An average coefficient of friction was calculated. Three sets of tests were carried out; with bark on, with bark removed, and with bark removed and logs wetted.

Figure 2. Test bed for measuring static coefficient of friction of Pinus radiata logs with and without bark present.

* Dr Murphy met with the USC collaborators (Dr Mauricio Acuna and Mr Mark Brown) in Queensland in September 2016 to undertake a supply chain level systems analysis of in-forest debarking. The systems level analysis was qualitative and identified the advantages and disadvantages of in-forest debarking.

- Two models were developed within Excel spreadsheets that allowed quantification of the costs and benefits of in-forest debarking. One model was volume-based, the other model was weight-based. The models were populated with data from the benchmarking and drying trials, relevant published data, industry reports, and information supplied by industry personnel. The models span from forest establishment through to delivery of logs to mills or shipside.
- The models were used to assess the economic viability of in-forest debarking for two sets of base case conditions; one set for Australia and one set for New Zealand. The main difference between the two sets of conditions was that log exports were not included for Australia. Sensitivity of economic viability to a range of key variables was undertaken for both sets of conditions.
- The models were also used to determine the breakeven price for a processor head suitable for in-forest debarking. In-forest debarking costs were increased to the point where the benefits became neutral. A breakeven-price for a debarker head was then back-calculated based on standard costing procedures.
- A final written report for the project (this report) was prepared. In addition a seven-page summary document was prepared for distribution to members of the Steep Country Harvesting technical committee in lieu of the planned presentation to the technical committee before the end of the project period; the technical committee will not meet until February 2017.
- Further dissemination of the results from the project was planned for 2017, beyond the project period (see **Planned Activity beyond the Third Milestone Period**).

Key Findings

<u>Effect of Number of Delimbing Knives on Bark Removal (Data Set NZ9)</u>

There was no statistically significant difference ($\alpha = 0.05$) in bark removal between the two 4-knife processor heads (45.5 vs 48.1%) (Table 1). There were significant differences, however, between the 4-knife Waratah (45.5%) and the 2-knife Waratah processor heads (53.1%), but not between the 4-knife Woodsman (48.1%) and the 2-knife Waratah processor heads (53.1%). Further analysis showed that the difference between the 4-knife and 2-knife Waratah processor heads was primarily due to differences in bark removal on small logs, generally found in the top half of the stem, but not large logs.

Table 1. Effect of number of delimbing knives on mean bark removal (%). Standard errors are shown in parentheses ( ). Number of logs are shown in brackets [ ]. Means that have the same letter are not statistically different at the α = 0.05 level.

Data Set	Processor head	Number of delimbing knives	Bark removal (%)
NZ9	Waratah 626	2	53.1 a (1.7) [128]
NZ9	Waratah 625C	4	45.5 b (1.9) [146]
NZ9	Woodsman PRO 800	4	48.1 ab (1.7) [222]

Results of All Log Drying Trials

Average drying rates for a 10 day drying period in Australia (11%) were much higher than average drying rates in New Zealand (3%). This result was climate related; temperatures were higher and rainfall lower in Australia (Table 2).

Table 2. Climate data for the five log drying trials

Climate data	Australia		New Zealand		
	Spring	Autumn	Spring	Summer	Winter
Total Rainfall (mm)	0	0	12	12	27
Average Temperature (^{o} C)	19	23	11	16	7
Average Wind Speed (km/hr)	16	15	16	10	7

Drying rates were related to log size, season and presence of bark. The four models are shown below:

Bark On Data – Australia

$$Ln(Wt\ Loss + 1) = 0.775 + 0.462234*Ln(Init\ Wt) - 0.00289*BarkOn\% + 0.5308*Autumn - 0.00434*Autumn*BarkOn\%$$

R^2 = 89.4%, MAE = 1.1 kg, n = 56

Bark Off Data – Australia

$$Ln(Wt\ Loss + 1) = 0.4855 + 0.53907*Ln(Init\ Wt) + 0.371*Autumn$$

R^2 = 93.8%, MAE = 1.1 kg, n=56

Bark On Data – New Zealand

$$Ln(Wt\ Loss + 1) = -1.2506 + 0.6819*Ln(Init\ Wt) - 0.00691*BarkOn\% - 0.4873*Winter - 0.00946*Summer*BarkOn\%$$

R^2 = 78.5%, MAE = 1.3 kg, n= 81

Bark Off Data – New Zealand

$$Ln(Wt\ Loss + 1) = 0.5691 + 0.2428*Ln(Init\ Wt) + 133133*Summer*Ln(Init\ Wt) + 0.5396*Winter*Ln(Init\ Wt) - 3.1336*Winter$$

R^2 = 70.0%, MAE = 1.3 kg, n=98

Where: *Wt Loss* is the loss in weight (kg) for a 10 day period

Init Wt is the initial weight (kg) of the log

BarkOn% is the estimated amount of the bark on the log at the beginning of the drying period.

Summer = 1 if summer season, 0 otherwise

Autumn =1 if autumn season, 0 otherwise

Winter = 1 if winter season, 0 otherwise.

Drying rates increased with log size in terms of weight (kg) but decreased in terms of percent of the initial weight of the log. Figure 3 provides an example for the summer drying season in New Zealand based on the Bark Off regression model.

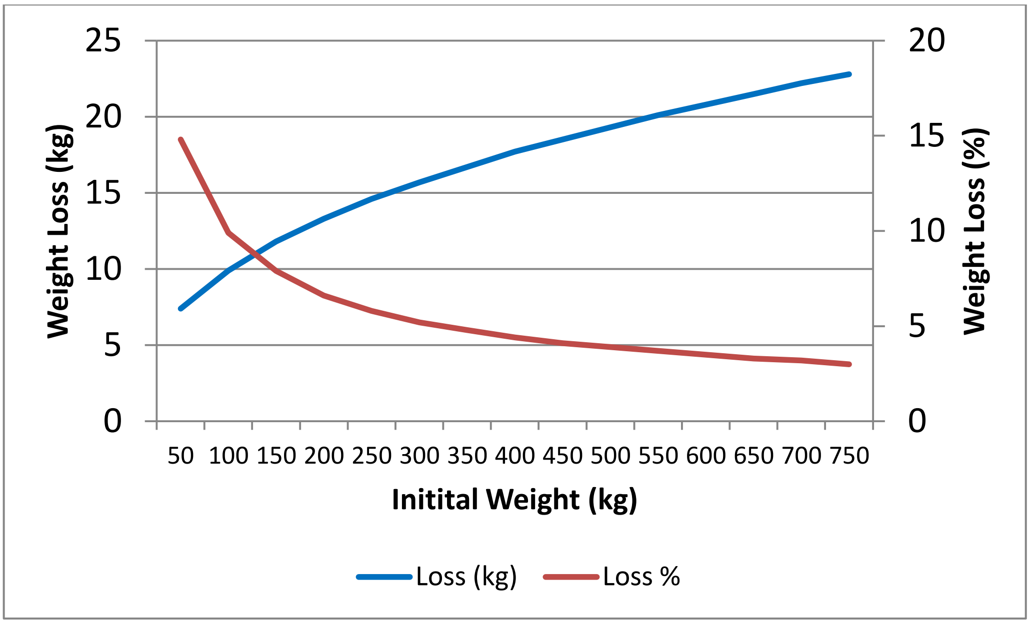

Figure 3. Weight loss for Bark Off Logs for a 10-day period in summer in New Zealand as a function of the initial log weight.

Drying rates were highest in summer. Figure 4 provides an example for New Zealand based on the Bark Off regression model. Weight loss is higher in Spring than Winter for logs under 300 kg. This would be expected from the warmer temperatures and lower rainfall during the Spring trial. However, the reverse trend occurs for logs over 300 kg; the reason for this is unknown.

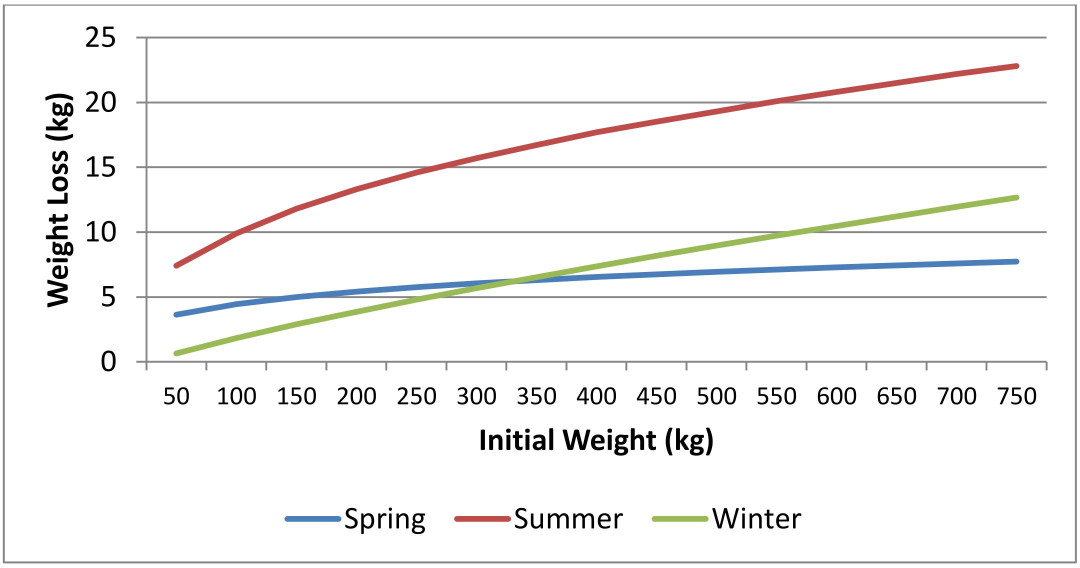

Figure 4. Weight loss for Bark Off Logs for a 10-day period for three seasons in New Zealand as a function of the initial log weight.

Drying rates were higher with bark off than bark on. Figure 5 provides examples for both Australia and New Zealand based on regression models and a log size of 265 kg. The average initial weight of logs in both Australia and New Zealand was about 265 kg.

The ratio of weight loss (BarkOff/BarkOn) ranged from 0.96 for Summer in New Zealand to 2.06 for Autumn in Australia for logs of 265 kg initial weight. This ratio is based on Bark Off logs having 0% bark intact and Bark On logs having 100% of bark intact.

Visser et al. (2014) reported summer drying rates of about 2.8% for un-debarked radiata pine logs for the first week of drying in Otago. This, not unexpectedly, is about 30% less, in relative terms, than found for the summer trial in Kaingaroa.

The ratio between Bark Off and Bark On drying rates was substantially lower than the factor of three reported by Defoe and Brunette (2006) for aspen in North America. The highest ratios found were for very small logs (~50 kg) or for the Autumn drying trial in Australia. No drying trials were carried out in Australia in Summer so it is possible that ratios closer to three could be found during this season in Western Australia.

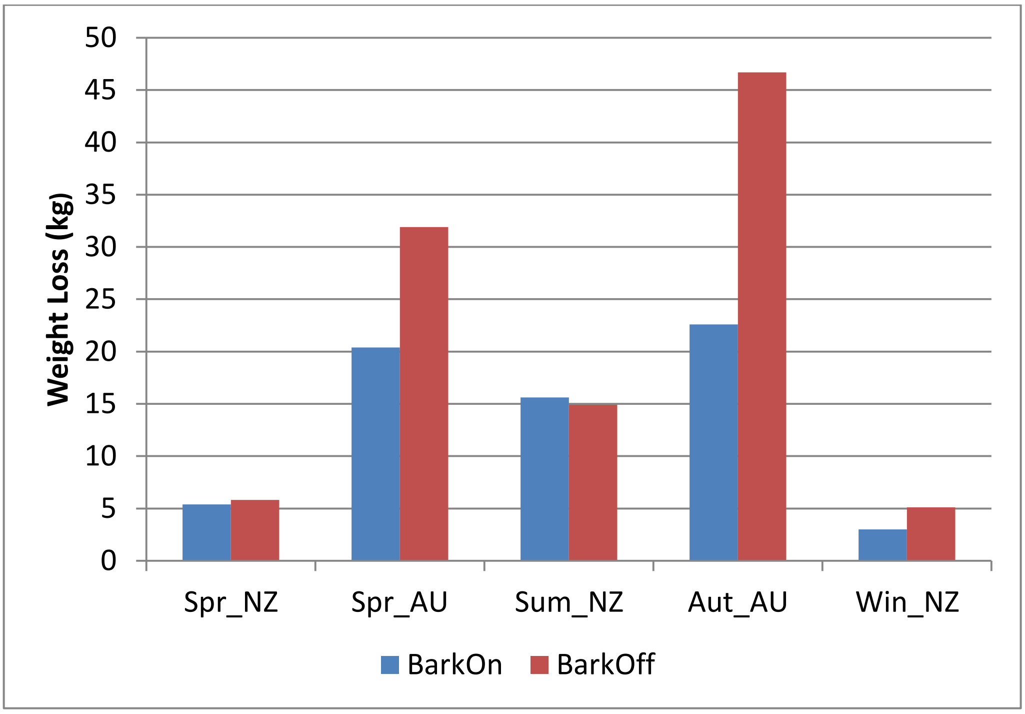

Figure 5. Weight loss for Bark Off vs Bark On Logs for a 10-day period in Australia and New Zealand for a log with an initial log weight of 265 kg. Bark Off and Bark weight losses are based on 0% and 100% of bark on respectively.

Static Coefficient of Friction

The static coefficient of friction ranged between 0.6 and 1.0 for logs with the bark on (Table 3). When the bark was removed the coefficient of friction was reduced to 0.5 to 0.7. When water was added to the debarked logs the coefficient of friction ranged from 0.4 to 0.7 for one of the logs, but was as high as 0.9 for the other log. These values are similar to those reported in the Safety Review (Appendix 2).

Table 3. Effect of the presence of bark on static coefficient of friction for Pinus radiata logs.

Test	Log Number 1		Log Number 2	
	Average	Range	Average	Range
Bark On	0.74	0.58-0.88	0.89	0.75-0.99
Bark Off	0.54	0.49-0.58	0.60	0.51-0.68
Bark Off plus Water	0.49	0.39-0.68	0.75	0.61-0.87

It was noted in these sets of tests that the logs were not in full contact with each other. Nodal swelling affected the amount of contact between logs. It also affected the static coefficient of friction. It was obvious in some of the tests that the logs were caught on nodal swellings. On these logs the coefficient of friction increased by a factor of almost 3.

Systems Analysis

The following advantages were noted for in-forest debarking:

- The solid wood (m^3) content on trucks can be increased if bark and water are reduced
- Improved volume storage in mill yards on the same footprint
- Reduced fumigation costs, assuming wood exported to China can be debarked to an acceptable standard
- Reduced debarking costs at port for pruned wood
- Improved volume storage at ports on the same footprint – leads to reduced distances wood is carried and reduced handling costs
- Opportunity to eliminate weigh scaling systems if more accurate underbark measurements can be gathered on harvesting/processing machines

- Reduced environmental impacts caused by loose bark at ports
- Bark is left on site in the forest – reduced fertiliser costs
- The need for ships to travel to a fumigation port to pick up above deck cargo is eliminated, saving on port fees and shipping fees
- Collection, transport and disposal costs for bark waste in ports and mills are eliminated

The following disadvantages were noted for in-forest debarking:

- An additional machine (and cost) is required for debarking in forest
- Or productivity is reduced and cost increased for a processor that also has to debark logs
- Additional solid wood (m^3) has to be sent to customers, to replace bark and water, if wood is sold to customers on a weight basis after it has been allowed to dry
- Additional truck loading time due to handling slippery logs and attaching an extra tie-down per packet of logs
- Additional handling time at mills and ports due to handling slippery logs
- Additional site preparation costs from clumps of bark left around landings
- Larger landings to accommodate additional drying days
- Larger landings to accommodate on landing debarking for tree length systems
- Increased value losses due to sapstain
- Increased contamination losses in tree length systems due to dirt and grit getting into wood
- Reduced revenues from bark sales

Economic Models and Analyses

Worksheets from the In-Forest Debarking Economic Model (*m^3 version*) are presented in Appendix 4. The *weight version* of the model is very similar to the *m^3 version*. The main differences between the two models relate to how costs and revenues are expressed (on a per m^3 basis or a per tonne basis).

New Zealand Scenarios

The base case conditions for the New Zealand set of analyses are shown in the 10 worksheets in Appendix 4. The key scenario parameters are:

- Under bark volume is 100,000 m^3.
- Wood is harvested in summer by a Ground-Based Tree-Length system.
- Logs are left for 5 days before being trucked to the customer.
- Truck payload increase is 2.9%
- 55% of the volume is exported, 65% of export volume is exported to China
- Fumigation of above-deck logs is currently carried out at the port.
- An extra visit is required to the port to pick up above deck cargo.
- In-forest debarking is carried out by a separate machine at a cost of $4.75 per m^3.
- Some, but not all, bark generated at mills and ports can be sold. The remainder is dumped.

For the New Zealand base case conditions, there is a 3.2% gain in net revenue as a result of in-forest debarking. This is equivalent to $2.32 per m^3. Sensitivity of these results to changes in key parameters is shown in Table 4.

Table 4. Sensitivity of gain in net revenue to changes in key parameters for the NZ analyses

Parameter	Change	Gain in Net Revenue	
		%	$ per m^3
Base Case Conditions	Summer	3.2	2.32
Harvesting Season	Autumn	3.2	2.32
Harvesting Season	Winter	3.2	2.30
Harvesting Season	Spring	3.1	2.27
Harvesting System	Cable Logging	4.3	2.78
Harvesting System	Cut-to-Length	5.5	3.98

Table 4. Sensitivity of gain in net revenue to changes in key parameters for the NZ analyses (continued)

Parameter	Change	Gain in Net Revenue	
		%	$ per m^3
Drying Days	Reduce to Zero	3.5	2.58
Drying Days	Increase to 10	0.1	0.05
Export %	Reduce to 45%	2.8	1.92
Export %	Increase to 65%	3.5	2.73
China Volume %	Reduce to 55%	3.1	2.24
China Volume %	Increase to 75%	3.3	2.41
Extra Port Visit	Not required	-0.5	-0.35
In-Forest Debarking Cost, Separate Machine	Reduce to $3.80	4.5	3.27
In-Forest Debarking Cost, Separate Machine	Increase to $5.70	1.9	1.37
In-Forest Debarking Cost, Single Processing/Debarking Machine	Increase handling time by 75%	3.6	2.63
Loading Time Adjustment	Reduce to 20%	3.3	2.44
Loading Time Adjustment	Increase to 30%	3.0	2.21
Truck Payload Adjustment	Reduce to 1.8%	2.9	2.14
Truck Payload Adjustment	Increase to 4.0%	3.4	2.51
Mill Debarking Cost	Reduce to $7 per t	2.0	1.47
Mill Debarking Cost	Increase to $11 per t	4.4	3.18
Fumigation Cost	Reduce to $4.40 per JAS	3.0	2.22
Fumigation Cost	Increase to $6.60 per JAS	3.3	2.43
Port Debarking Cost	Reduce to $6.90 per JAS	2.9	2.12
Port Debarking Cost	Increase to $10.30 per JAS	3.5	2.53
Bark sales from ports	Increase bark utilisation to 60%	2.8	2.05
Waste Disposal Costs	Reduce to $17 per t	3.1	2.29
Waste Disposal Costs	Increase to $25 per t	3.2	2.36

Table 4. Sensitivity of gain in net revenue to changes in key parameters for the NZ analyses (continued)

Parameter	Change	Gain in Net Revenue	
		%	\$ per m^3
Additional Site Preparation Costs	Reduce to 10%	3.3	2.40
Additional Site Preparation Costs	Increase to 20%	3.1	2.25
Interest Rate	Increased to 5%	2.4	1.65
Daily ship costs	Reduce to $15000	2.0	1.51
Daily ship costs	Increase to $35000	4.4	3.14
Bark Revenues	Increase all revenues by 20%	3.1	2.24
Sapstain Losses	Increase to 5%	0.1	0.05
Contamination Losses	Reduce losses to 0%	5.4	3.92
Contamination Losses	Increase losses to 7%	1.0	0.73
Base Case Conditions	Weight-Based Model	4.2	2.51

If we use a change of \$0.50 per m^3 as a criteria for being sensitive or not then we can say that the results are NOT sensitive to:

- Harvesting season
- The proportion of export volume exported to China
- Truck loading time adjustments or assumed increases in truck payload
- Fumigation costs
- Port debarking costs
- Bark waste disposal costs
- Additional site preparation costs
- Bark prices
- Whether a volume or weight-based analysis is carried out.

We can also say that the results ARE sensitive to:

- Use of cut-to-length harvesting systems
- Number of drying days (in Spring and Summer only)

- The proportion of volume that is exported
- Whether a ship has to visit a second port to pick up fumigated logs for above deck cargo
- The assumed cost for a separate in-forest debarking machine
- Mill debarking costs
- The utilisation of bark generated at ports
- Daily shipping costs.
- Sapstain losses
- Contamination losses

The breakeven cost for in-forest debarking would be $7.07 per tonne. At an assumed production rate of 300 tonnes per day, this equates to a daily cost of about $2120. Subtracting labour costs of $260 per day leaves $1860 per day to cover machine costs. This must cover the cost of the base excavator plus the cost of the debarker head.

A 35 tonne excavator costs about $990 per day, leaving about $870 per day to cover the costs of a debarker head. The ratios of daily cost to current purchase price for ground-based harvesting machines range between 0.0018 and 0.0021 (Source: Informe Harvesting 2013). Based on these ratios, and an assumed production of 300 tonnes per day, a breakeven cost for a debarker head would be somewhere between $410,000 and $480,000.

If the assumed production was only 250 tonnes per day, a breakeven cost for a debarker head would be somewhere between $245,000 and $285,000.

These breakeven costs compare with reported costs for processor heads of $270,000 to $300,000 (Source: Informe Harvesting 2013).

Australian Scenarios

The key scenario parameters for Australia for the base case conditions are:

- Underbark volume is 100,000 m^3.
- Wood is harvested in summer by a Cut-to-Length system.
- Logs are left for 5 days before being trucked to the customer.
- 0% of the volume is exported
- Truck payload increase is 8.3% (greater drying rates and more bark has to be removed in Australia than in New Zealand).

- In-forest debarking is carried out by a separate machine at a cost of \$4.75 per m^3.
- Some, but not all, bark generated at mills and ports can be sold. The remainder is dumped.

For the Australian base case conditions, there is a 9.5% gain in net revenue as a result of in-forest debarking. This is equivalent to \$4.25 per m^3. Sensitivity of these results to changes in key parameters is shown in Table 5.

Table 5. Sensitivity of gain in net revenue to changes in key parameters for the Australian analyses

Parameter	Change	Gain in Net Revenue	
		%	\$ per m^3
Base Case Conditions	Summer	9.5	4.25
Harvesting Season	Autumn	9.3	4.18
Harvesting Season	Winter	9.0	4.06
Harvesting Season	Spring	9.7	4.32
Drying Days	Increase to 10	-12.7	-5.70
Drying Days	Increase to 20	-11.9	-5.42
In-Forest Debarking Cost, Separate Machine	Reduce to \$3.80	11.6	5.20
In-Forest Debarking Cost, Separate Machine	Increase to \$5.70	7.4	3.30
Loading Time Adjustment	Reduce to 20%	9.7	4.36
Loading Time Adjustment	Increase to 30%	9.2	4.14
Truck Payload Adjustment	Reduce to 6.6%	8.8	3.96
Truck Payload Adjustment	Increase to 10.0%	10.1	4.54
Mill Debarking Cost	Reduce to \$7.20 per t	5.5	2.54
Mill Debarking Cost	Increase to \$10.80 per t	13.8	5.96
Waste Disposal Costs	Reduce to \$16.80 per t	9.4	4.22
Waste Disposal Costs	Increase to \$25.20 per t	9.6	4.28
Bark use for energy at mills	Reduce to 64%	10.8	4.79
Bark use for energy at mills	Increase to 95%	8.3	3.75
Bark Revenues	Increase by 20%	8.8	3.99
Sapstain Losses for less than 10 days drying	Increase to 5%	-1.8	-0.80

If we use a change of \$0.50 per m^3 as a criteria for being sensitive or not then we can say that the results are NOT sensitive to:

- Harvesting season
- Truck loading time adjustments or assumed increases in truck payload
- Bark waste disposal costs
- Bark prices

We can also say that the results ARE sensitive to:

- Number of drying days
- The assumed cost for a separate in-forest debarking machine
- Mill debarking costs
- Utilisation of bark at mills
- Sapstain losses

The breakeven cost for in-forest debarking would be \$9.00 per tonne. At an assumed production rate of 300 tonnes per day, this equates to a daily cost of about \$2700. Using the same method as was used for the New Zealand scenario and an assumed daily production of 300 tonnes a breakeven cost of somewhere between \$690,000 and \$800,000 would be calculated for a debarker head.

If the assumed production was only 250 tonnes per day, a breakeven cost for a debarker head would be somewhere between \$475,000 and \$555,000.

Conclusions from Economic Analyses

For both Australia and New Zealand it would appear that in-forest debarking is an economically viable alternative to debarking further along the supply chain. The potential gains for Australia are larger than those for New Zealand mainly due to their greater use of cut-to-length systems (which tend to retain greater quantities of bark in comparison to tree-length systems and carry the logs – thereby reducing contamination losses) and their faster drying rates for debarked logs. New Zealand tends to benefit from reduced fumigation costs and multiple-port visiting costs.

Breakeven capital costs for a debarker head were calculated to be a minimum of \$245,000 for New Zealand and \$475,000 for Australia.

It should be noted that the economic viability of in-forest debarking was very sensitive to the assumed additional value loss associated with sapstaining when logs were left to dry for 10 days or less. A 5% value loss associated with sapstaining would reduce the net revenue gain to almost zero for New Zealand and to less than zero for Australia. The implications of this for both countries is that the breakeven cost for a debarker head would be substantially lower than the current cost for a small processor head (ranging from less than $0 to as much as $105,000). Further effort should be put into quantifying losses due to sapstain.

Planned Activity Beyond the Third Milestone Period:

The In-Forest Debarking Project was completed before the end of December 2016. It is our intention to present key findings gathered from the project in verbal form at national forestry conferences in Australia and New Zealand and in written form through a New Zealand Journal of Forestry manuscript and an Australian Forest Operations Research Alliance publication. Some of this activity will be funded from the grant promised by FWPA Australia.

APPENDIX 1

Milestone 1 Achievements and Key Findings:

Achievements

- Overall project planning was undertaken in June and July 2015. Contractual arrangements for delivery of the milestones were completed between Waiariki and New Zealand Forest Growers Association, between Waiariki and USC, and between Waiariki and GE Murphy & Associates (after departure of Dr Murphy from Waiariki). Dr Murphy and Dr Acuna (USC) met in Sydney on 10th December 2015 to review achievements for the first six months of activity on the project and to plan for the second six month period.
- Three sets of bark loss benchmarking trials were completed in Australia and New Zealand.
    - The Australian bark loss benchmarking trial was carried out in Western Australia in Spring 2015. 623 logs from 121 loads arriving at Wespine's sawmill near Bunbury were photographed and measured using the line intersect method. All logs were delimbed and cut into logs using a mechanised harvester/processor. Note that the Spring benchmarking trials were carried out ahead of schedule in the first six-month period instead of in the third six month period.
    - The first New Zealand bark loss benchmarking trial was carried out in the Bay of Plenty in Winter 2015. 337 logs from 85 loads arriving at the Port of Tauranga were photographed and measured using the line intersect method. Logs were delimbed and processed using three methods; manual with chainsaw, static delimber with chainsaw bucking, and mechanised.
    - The second New Zealand bark loss benchmarking trial was also carried out in the Bay of Plenty in Spring 2015. 518 logs from 117 loads arriving at the Port of Tauranga were photographed and measured. Logs were recorded as being delimbed and bucked using manual with chainsaw, or static delimber with chainsaw bucking, or mechanised delimbing and bucking.
- Two sets of drying rate trials were completed in Australia and New Zealand.
    - The Australian drying rate trial was carried out in Spring (October) in Western Australia. 56 logs (28 with the bark left largely intact[1], and 28 with the bark removed) were weighed at the beginning and end of a 10 day period. The logs were from four diameter classes (<150 mm, 150-250mm, 250-350mm, and >350 mm). The climatic conditions for the trial period were as follows: mean temperature 19^{o}C, mean wind speed 16km per hour, total rainfall 0 mm.
    - The New Zealand drying rate trial was carried out in Spring (September) in Bay of Plenty. 61 logs (28 with the bark left largely intact, and 33 with the bark removed)

[1] It should be noted that it was difficult in both Western Australia and New Zealand to obtain any logs with all the bark present in Spring. An estimate was made for each log of the amount of bark missing at the beginning of the trial for the Bark On logs.

were weighed at the beginning and end of a 10 day period. The logs were from four diameter classes (<150 mm, 150-250mm, 250-350mm, and >350 mm). The climatic conditions for the trial period were as follows: mean temperature 11^{o}C, mean wind speed 20km per hour, total rainfall 12 mm.

Figure A1.1. Image of load of logs with lines overlaid in preparation for measurement of bark loss using the line intersect method.

Figure A1.2. Logs used in Australian Spring drying rate trial (left) and log being placed on weight scales (right).

Figure A1.3. Logs with bark largely intact (left) and with bark largely removed (right) in New Zealand Spring drying rate trial.

- Two sets of debarking feasibility trials were completed in New Zealand and Australia.
  - The New Zealand debarking feasibility trial was carried out in Spring (August) in a radiata pine stand about 15 km to the south of Rotorua. A 22 inch SATCO eucalypt debarking head on a Caterpillar excavator base was being used by Phelan Logging to delimb and shovel log stems. The debarking head was too small for many of the logs being handled. Multiple handling of the logs resulted in significant bark loss for some logs. A short study of delimbing and debarking of about 20 stems was carried out. Video footage was gathered and a time study undertaken. It should be noted that the goal of the trial was not to see how much bark could be removed. Rather it was to see how much bark was removed with “normal” operations.
  - The Australian debarking feasibility trial was carried out in Spring in Western Australia. The trial was fortuitous in that it was not included in the original plan for the project. The sponsor for the trial was interested in retaining, rather than removing, as much bark as possible. Eight treatments were carried out by the sponsor. Four with a standard Waratah processor head along with various combinations of roller and knife pressures, and four with modified rollers (Moipu) along with various combinations of roller and knife pressures. Bark weight was determined by weighing packets of logs with the bark on for each treatment and then debarking the logs and weighing the bark from each packet separately. A ratio of bark weight to underbark log weight was compared for each treatment. A line intersect method was also used to compare bark retention for 344 logs. Note that the Australian debarking feasibility trial meets the requirements of the second planned debarking trial, using alternative rollers, that was scheduled to be carried out in the second six month period.

Figure A1.4. Moipu outer feed rollers similar to the one above and manufactured by Moisio Oy in Central Finland were included in the Australian debarking feasibility trial.

- In addition to the New Zealand and Australian trials it has come to our attention that SouthStar have been carrying out trials on debarking of radiata pine in New Zealand. An attempt was made, without success, in late November 2015 to talk with SouthStar about their trials. This will be followed up again in early 2016.

- A preliminary review of safety issues associated with handling and transporting debarked logs was carried out by Professor Mark Brown (USC). This will be extended and finalized in the second six month period.
- A preliminary review of biosecurity requirements, including approaches for measuring bark retention, was carried out by Dr Glen Murphy. This will be extended and finalized in the second six month period.
- A proposal was submitted to the New Zealand Chartered Institute of Logistics and Transport for additional funding to quantify the effect of bark on space utilisation at various points in the supply forestry supply chain. Space utilisation could affect storage capacities in-forest, in-mill yard, and at wharf. It could also affect cargo capacity on truck and on-ship. Specifically, the CILT grant will be used to assess space utilization of fully debarked versus non-debarked logs for a range of log-types during four seasons of the year. The work will be carried out at the Port of Tauranga if the grant application is successful.
- A verbal update of progress on the In-Forest Debarking Project was presented in October 2015 to the FFR Steepland Harvesting Technical Steering Committee.
- This report, the first intermediate written report for the project, will be presented to NZFOA Research Manager, Russell Dale, on 17 December 2015.

Additional work, beyond Milestone 1 requirements, was completed when a manuscript[2] on standing tree radiata pine bark volume and weight was written and published in the New Zealand Journal of Forestry Science by Dr Glen Murphy and Dr Dave Cown. Over-bark and under-bark diameter measurements recorded from over 1000 disks taken from fixed heights in 150 trees were used to estimate bark volume percentages. The mature trees were from a single seed source and had been planted at 17 sites throughout New Zealand. Bark volume percentages were converted to bark weight percentages using data from 390 trees from the central North Island of New Zealand.

Key Findings

Bark Loss Benchmarking Trials

The percentage of bark removed during normal harvesting practices varied between seasons, harvesting system, and location (Table A1.1).

Overall average bark loss was higher in Spring (74%) than Winter (56%) for the two New Zealand trials. Bark loss is known to be higher for many species once the sap starts rising in Spring.

Table A1.1. Bark Loss (%) Benchmark Data for Two Seasons, Two Locations and Three Harvesting Systems

Location	Season	Harvesting System			
		Mechanized Delimbing and Bucking	Static Delimbing and Chainsaw Bucking	Manual Chainsaw Delimbing and Bucking	Overall Average
New Zealand	Winter	60.4	53.7	31.7	55.5
New Zealand	Spring	77.0	62.2	53.7	74.4
Australia	Spring	47.4	-	-	47.4

The harvesting system also affects how much bark is lost. The two New Zealand trials showed that 7 to 15% more bark was lost with mechanized delimbing and bucking than with static delimbing and bucking. The amount of bark lost was even greater (23 to 28%) for mechanized delimbing and bucking than with manual chainsaw delimbing and bucking.

Only mechanized delimbing and bucking was undertaken in Australia. Thirty percent less bark was removed during spring in Australia than in New Zealand. The reason for this is uncertain at this stage. It could be due to climatic factors – Western Australia being warmer and drier in spring than the Bay

[2] Murphy, G. and Cown, D. 2015. Within tree, between tree and geospatial variation in estimated *Pinus radiata* bark volume and weight in New Zealand. New Zealand Journal of Forestry Science (published online).

of Plenty. It could also be due to the harvesting system employed. In Western Australia, cut-to-length (CTL) mechanized systems are used. In CTL systems the stems are delimbed and bucked at the stump and then loaded onto a forwarder. In the Bay of Plenty the dominant mechanized system is tree length. Trees are felled (and possibly delimbed), dragged to a landing, and then delimbed and bucked with a processor. The tree length system has more opportunities for bark loss due to handling and abrasion during extraction.

Earlier research by Murphy and Pilkerton (2011)[3] and Murphy and Logan (2015)[4] have indicated that bark loss may be higher on upper portions of the stem than lower portions. This may be related to bark thickness and ease of removal for a given species. Preliminary results from the New Zealand benchmarking trials are providing some confirmation of this, but further analysis is required.

<u>Drying Rate Trials</u>

Drying rates over a 10-day period in spring differed between location, log size and the presence or absence of bark. The results are presented in Tables A1.2 and A1.3.

Table A1.2. Weight loss (%) and drying rate comparisons for the Western Australia Drying Rate Trial

Log Size Class (SED)	Drying Weight Loss (%)		Ratio of Weight Loss % (Bark Off/Bark On)
	Bark On	Bark Off	
< 150 mm	14.9	20.1	1.35
150-250 mm	11.5	18.0	1.57
250-350 mm	8.5	13.1	1.54
350-450 mm	6.9	9.5	1.37

Average Bark Off % for Bark On logs for WA trials was 28%.

[3] Murphy, G.E., and Pilkerton, S.J. 2011. Seasonal impacts on bark loss by mechanized processors in Oregon. International Journal of Forest Engineering 22(1): 35-41.

[4] Murphy G.E., and Logan O. 2015. Radiata pine bark removal associated with two on-landing, log processing methods. Forest Products Journal. (accepted September 2015)

Table A1.3. Weight loss (%) and drying rate comparisons for the New Zealand Drying Rate Trial

Log Size Class (SED)	Drying Weight Loss (%)		Ratio of Weight Loss % (B_Off/B_On)
	Bark On	Bark Off	
< 150 mm	4.6	5.3	1.16
150-250 mm	4.1	4.5	1.09
250-350 mm	2.8	2.5	0.91
350-450 mm	2.6	1.3	0.50

Average B_Off% for Bark On logs for NZ trials was 48%.

Logs dried at close to four times the rate in Western Australia (overall average ~ 12.8% weight loss) than they did in New Zealand (~3.5% weight loss). Wind, temperature and precipitation are some of the key drivers of drying rates in logs. Wind speeds were similar between the two locations, temperatures were considerably higher in Western Australia (19^{o}C vs 11^{o}C), rainfall was absent in Western Australia and 12 mm total for the New Zealand trial.

The Drying Weight Loss (%) was found to decrease as log size increased for both sets of trials. Small logs dried at 2 to 4 times the rate (% weight loss) of large logs.

Greater weight loss (%) was generally found for the Bark Off Logs than for the Bark On Logs. This was the case for all of WA log size classes and the smaller NZ log size classes. We found the reverse trend, however, for the larger NZ log size classes. This was put down to two factors; (1) more bark was missing to start with for the NZ Bark On logs (48% for NZ vs 28% for WA), and (2) we were unsure exactly when the trees were harvested for the New Zealand trial and it was possible the stems had been drying for a few days before they were delivered to the mill. The WA logs had been harvested the day prior to the trial beginning. More control will be put in place as to the time of felling and delivery for the next round of NZ trials in Summer.

The ratio of Bark Off to Bark On weight loss was 1.35 to 1.57 for the Western Australia trials, and 1.09 to 1.16 for the small log size classes for the New Zealand trials.

Debarking Feasibility Trials

A visit to Gene Phelan's logging operation in August 2015 indicated that many of the smaller stems, in particular, were almost free of bark. Phelan Logging was using a SATCO Eucalypt debarking head in their operation. The debarking head was used as an ancillary machine to assist with shovel logging and remove slovens from felled stems, but its presence provided an opportunity to see how well it worked in radiata pine with respect to bark removal.

Figure A1.5. Small almost fully debarked stems (left), Caterpillar excavator with SATCO head (centre), 22 inch SATCO eucalypt debarking head (right)

Twenty three stems were felled near a roadside. The stems had their slovens removed, and then were delimbed and passed to a grapple loader for stock-piling. Some stems were too big for efficient handling by the debarking head. Table A1.4 presents the results of a short time study of the operation. The average time for handling broken top pieces was 0.07 minutes per stem, “machine suitable” stems was 1.16 minutes per stem, and “too large” stems was 5.25 minutes per stem.

Table A1.4. Handling times for a Eucalypt debarker head in radiata pine.

Piece description	Average log handling time (minutes per stem)	Number of stems or top pieces
“Machine Suitable” stems	1.16	20
“Too Large” stems	5.25	3
Broken top pieces	0.07	3

* Times for broken top pieces are prorated across all stems

The eucalypt debarking head did a poor job of removing bark from the stems that were too big. A significant amount of the bark was removed from the smaller stems but possibly no more than would have been removed by a conventional processing head for radiata pine. The logging contractor, Gene Phelan, and the machine operator both thought that a conventional head would have done a better job of removing radiata pine bark. They believed that the amount of bark removed with the eucalypt debarking head was more a function of how many times a stem was handled (particularly with using the debarker to assist with shovel logging) than the type of head being used.

Results from three of the eight treatments included in the Australian bark retention trial are shown in Table A1.5. The same conclusions were drawn from both the bark weight method and the line-intersect method. The greatest bark retention was obtained with the standard Waratah rollers and pressures. Reducing the roller and knife pressures for both the standard rollers and the adapted rollers resulted in lower bark retention. Differences in bark retention were significantly different between Treatments 1 and Treatments 4 or 8. There was no significant difference between Treatments 4 and 8.

Two additional findings from this trial are of interest. Firstly, the ratio of Treatment 1 (bark on) to Treatment 4 (or 8) was similar (~1.10) for both the bark weight method and the line intersect method. This is of interest since the line intersect is a much easier exercise to undertake logistically – a camera and computer software are the main tools required. Secondly, the bark retention (81%) for the conventional processor head was much higher than found for the same type of heads for the Australian Spring benchmarking trial (53%). The cause of the difference is unknown, although it is possible that the machine operator for the bark retention trial was taking more care handling logs than is normal practice.

Table A1.5. Effect of Processor Head Characteristics on Bark Retention

Treatment	Bark Retention (kg Bark/t Solid Wood)	Statistical significance ($p = 0.05$)	Bark Retention (%) based on line-intersect measurement	Statistical significance ($p = 0.05$)
1. Conventional Waratah Rollers and Standard Roller and Knife Pressures	62	-	81	-
4. Conventional Waratah Rollers and Reduced Roller and Knife Pressures	55	1 vs 4 Sign. Diff.	72	1 vs 4 Sign. Diff.
8. Moipu Outer Rollers and Reduced Roller and Knife Pressures	57	1 vs 8 Sign. Diff. 4 vs 8 Not Sign. Diff.	73	1 vs 8 Sign. Diff. 4 vs 8 Not Sign. Diff.

Preliminary Review of Safety Issues

Changing the form or condition of the log in the forest by removing the bark introduces different safety concerns in the handling, storage and transport of the logs that will need to be properly understood and addressed with planning, training and safety systems.

A key difference between logs with bark on and debarked logs is the coefficient of friction on the log surfaces and how that is affected when the logs are wet. Due to the rough irregular surface created by pine log bark the coefficient of friction between the logs and any solid surfaces they rest on are relatively high and relatively unaffected when the logs are wet. With the bark removed the logs become much smoother and thus have a much lower coefficient of friction that is significantly reduced by a small amount of water on the surface.

There have been a number of trials conducted around these coefficients of friction of logs as it relates to load securement in transport and these have become the underpinning knowledge for load securement standards in North America, Australia and New Zealand. Though the trees across these regions are quite different the effective coefficient of friction is similar. For logs with bark on the static coefficient of friction tends to be between 0.8 and 0.7 (i.e. a force equivalent to 70% to 80% of the weight of the log is required to get the log sliding) and the dynamic coefficient of friction drops to about 0.5 (i.e. once the log is sliding it requires a force equivalent to about half the weight of the log applied to keep in moving). For logs with bark removed the static coefficient of friction typically drops to 0.6 to 0.5, with more dense (harder) woods tending to have a lower coefficient when they are dry and as low as 0.3 if they are wet (under rainy conditions). The dynamic coefficient of friction for dry debarked logs is typically between 0.4 and 0.3 and as low as 0.2 for wet logs. This reduction in the coefficient of friction, particularly under wet conditions will have important safety implications for the handling, storage and transport of the logs in the supply chain.

Figure A1.6. Load securement of debarked logs during transport has been identified as a potential risk in the preliminary review of safety

Recent incidences of debarked logs slipping out of the forks of loading and unloading machines in New Zealand mills give some safety concerns over handling of debarked logs. Preliminary reviews of equipment options, however, indicate that handling and storage issues are likely to be relatively minor and primarily will be addressed through operator training and some minor consideration in equipment selection.

For loading and unloading equipment it will be preferable to use equipment for handling the debarked logs that are able to squeeze logs and bundles of logs tightly ideally with a defined metal edge to overcome a lack of friction in handling wet logs. In most cases this will be minor equipment features like choosing a bypass grapple.

In the training solutions it will be of key importance to ensure operators understand how slippery the debarked logs are and how significant the reduction in friction will be when the logs are wet. Under known wet conditions it will be advisable to handle the logs in smaller bundles when loading and unloading to reduce risk of log slippage. Similarly under wet conditions consideration will need to be given to pile technique in storage to ensure piles are even, level and well supported to compensate for the difference in friction.

Further investigation will need to be conducted to better define the details on these equipment selection and best practices suggestions where the application of in-forest debarking is implemented.

Compared with handling and storage issues, transport will be a bigger safety concern, primarily around how best to secure the logs on the trucks to ensure there is no increased risk of load loss with the reduced coefficient of friction on the debarked logs. There has been some investigation of this in Australia as it relates to debarked eucalypt logs.

Literature based research in 2013 on the development of safe load securement guidelines indicated that under wet conditions debarked logs could require up to twice as many load tie down devices to provide the same load security as dry or logs with bark, depending on the type of load tie down device used and the level of pretension.

As an alternative to the increased number of load tie down devices, it could also be possible to introduce headboards and/or tail boards to the trailer to contain the load and block any log slippage. This is not a particularly efficient solution as the extra weight significantly reduces payload and by constraining the loading space can make log loading more difficult and time consuming.

There are field trials currently being conducted within the Australian eucalypt industry looking specifically at load securement of debarked logs in both dry and wet conditions. They have noted that the fresher the logs are the greater the impact water has on reducing the coefficient of friction, effective and sustained pretension in the tie down device is critical (automatic tensioners) and the load tie down device choice is important (web straps have too much stretch and allow the logs to pass into dynamic friction situations before they take effect and thus need to deal with a much lower coefficient of friction). As an ongoing study the details of this work are yet to be compiled and analysed but are expected to be available and a valuable guiding resource for this project.

<u>Preliminary Review of Biosecurity Issues</u>

ISPM 15 (International Standards for Phytosanitary Measures) states that long thin pieces of bark are acceptable if they are less than 3 cm wide. If they are more than 3cm wide the piece of bark has to be less than 50 cm^2 in area.

New Zealand biosecurity rules for log export require that bark amounts to no more than 2% on a batch of logs and 5% on a single log where logs are not fumigated. There is no standard method to assess this, however. The inspection organization is responsible for developing a method which MPI can accept or reject.

One un-named organization relies on a "calibrated eyeometer" approach. That is the inspector estimates how much bark is present in a batch of logs or on a single log. To calibrate the eye, large and small end diameters along with log length are used to determine log surface area [based on seeing approximately 60% of a log] from a look-up table. Bark segments are then measured, summed and the total calculated as a percent of the log surface area. A total of 10 logs are selected as being representative of a batch of logs.

This is a semi-subjective, but cost effective technique for measuring bark. It is based on bark area, not bark volume. Logs are not turned. At this stage, it is unknown whether this approach results in an over or under-estimate of bark area. Further work is planned for the next six month period.

Variation in Bark Volume and Weight on Standing Trees

The study by Murphy and Cown (2015) confirmed earlier research that bark accounts for 12 to 13% of over-bark volume and 7 to 8% of over-bark green weight for mature radiata pine boles prior to felling and log handling. It also showed that bark volume percent varied

- with location in a stem (decreasing exponentially from the base of the stem [~22%] to the merchantable limit [~8%]),
- with tree size (small trees [17%] accounting for about 7% more overbark volume than large trees [9%],

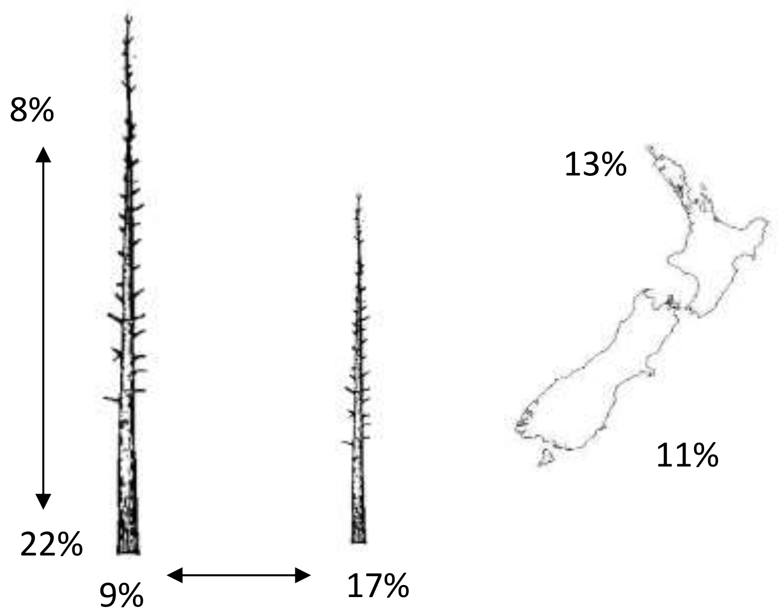

Figure A1.7. Bark, as a percentage of overbark volume in standing trees, varies with height in a tree, with tree size, and with site conditions.

- with site (a small decrease in bark volume with mean average temperature decrease was noted; equivalent to about one quarter of a percent of over-bark volume per degree decrease in mean average temperature).

Interim Conclusions Based on Key Findings from Milestone 1 research

- It will be easier to intentionally remove radiata pine bark
    - during the spring season than the winter season
    - at the top of the stem than at the base
    - at sites where bark is thinner (e.g. colder sites)
- When the bark is removed (in spring)
    - logs lose up to 0.6% more water per day than logs with the bark left largely intact.
    - drying rates of small logs are higher than that of large logs
    - drying rates are dependent on location (i.e. climatic conditions)
- The harvesting system, including the delimbing and bucking subsystem, effects how much bark is removed. Mechanized systems will result in more bark removal than manual and semi manual systems. Tree length systems may result in more bark removal than cut-to-length systems.
- The design of the processor head for mechanized systems, in terms of roller type, roller pressures, and knife pressures can affect the amount of bark removed. Fully debarking stems is likely to have an impact on productivity due to increased handling and processing time.
- Compared with current practices, assuming mechanized systems are used, the increase in solid wood volume from fully debarked stems that could be transported in a truck load is roughly estimated to be 3% in New Zealand and 8% in Australia.
- Changes to tie-down systems for log transport and log handling equipment are likely to be necessary for fully-debarked logs to deal with safety issues.
- At this stage of the project it is too early to say if all logs can be debarked to phytosanitary standards in-forest at an acceptable cost.

APPENDIX 2

SAFETY REVIEW: LOG HANDLING AND TRUCKING

Safety implication for handling debarked logs in the supply chain

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Introduction

This project is exploring opportunities to improve the efficiency of New Zealand log supply chains by removing the bark from the logs in the forest. Bark removal before the logs are transported will reduce the weight of material transported from the forest that is not likely to make a valuable product and it is expected to promote quicker reduction in moisture content without degradation of log quality. The combined result is the amount of wood that is transported per truck load can be maximised and thus reduce the overall unit cost. By changing the form or condition of the log in the forest by removing the bark also introduces different safety concerns in the handling, storage and transport of the logs that will need to be properly understood and addressed with planning, training and safety systems.

Coefficient of friction

A key difference between logs with bark on and debarked logs is the coefficient of friction on the log surfaces and how that is affected when the logs are wet. Due to the rough irregular surface created by pine log bark the coefficient of friction between the logs and any solid surfaces they rest on are relatively high and relatively unaffected when the logs are wet. With the bark removed the logs become much smoother and thus have a much lower coefficient of friction that is significantly reduced by a small amount of water on the surface.

There have been a number of trials conducted around these coefficients of friction of logs as it relates to load securement in transport and have become the underpinning knowledge for load securement standards in North America, Australia and New Zealand, **Figure A2.1**.

Figure A2.1: TERNZ log friction trials

Though the trees across these regions are quite different the effective coefficient of friction is similar. For logs with bark on the static coefficient of friction tends to be between 0.7 and 0.8 (i.e. a force equivalent to 70% to 80% of the weight of the log is required to get the log sliding) and the dynamic coefficient of friction drops to about 0.5 (i.e. once the log is sliding it requires a force equivalent to about half the weight of the log applied to keep in moving). For logs with bark removed the static coefficient of friction typically drops to 0.5 to 0.6, with more dense (harder) woods tending to have a lower coefficient when they are dry and as low as 0.3 if they are wet (under rainy conditions). The dynamic coefficient of friction for dry debarked logs is typically between 0.4 and 0.3 and as low as 0.2 for wet logs. This reduction in the coefficient of friction, particularly under wet conditions will have important safety implication for the handling, storage and transport of the logs in the supply chain.

Handling and storage

Preliminary reviews of equipment options indicate that handling and storage issues will be relatively minor and primarily will be addressed through operator training and some minor consideration in equipment selection.

While much of the literature acknowledges the impact reduced coefficients of friction can have of stack stability, most do not make specific recommendation to modify handling and stacking procedures. Swift (1999) noted debarked timber had an increased risk of slippage and movement in log stack but apart from noting it as a general risk to be aware of made no specific recommendations on adjusting the stacking procedure.

For loading and unloading equipment it will be preferable to use equipment for handling the debarked logs that are able to squeeze logs and bundles of logs tightly ideally with a defined metal edge to overcome a lack of friction in handling wet logs. In most cases this will be minor equipment features like choosing a bypass grapple, Figure A2.2.

Figure A2.2: examples of bypass grapples

In the training solutions it will be key to ensure operators understand how slippery the debarked logs are and how significant the reduction in friction will be when the logs are wet. Under known wet condition it will be advisable to handle the logs in smaller bundles when loading and unloading to reduce risk of log slippage. Similarly under wet conditions consideration will need to be given to pile technique in storage to insure piles are even, level and well supported to compensate for the difference in friction.

Transportation

As compared to handling and storage issues for transport will be a bigger safety concern, primarily around how best to secure the logs on the trucks to ensure there is no increased risk of load loss with the reduced coefficient of friction on the debarked logs. There has been some investigation of this in Australia as it relates to debarked eucalypt logs.

The 2003 VicRoads Guide to Restraining Logs and Timber makes no special mention of debarked logs, even though they would be relatively common in Victoria, and provide load tiedown guides for logs generally. The North American Cargo Securement Standard also makes no distinction between debarked and bark on logs.

A 2004 Ternz study also makes a very specific recommendation related to debarked logs with a dynamic coefficient of friction below 0.4, like spring logs. The suggestion from the study was to have one additional tie-down on each bunk. Similarly the 2012 Log Transport Safety Council, Load Securing Requirements require one additional load tie-down when transporting debarked logs, Figure A2.3.

Figure A2.3: Placement of load tie-downs

An alternative to the increased number of load tie down devices, it could also be possible to introduce headboards and/or tail boards to the trailer to contain the load and block any log slippage. This is not a particularly efficient solution as the extra weight significantly reduces payload and by constraining the loading space can make log loading more difficult and time consuming.

The 2007 Tasmanian Forest Safety Code has a consistent requirement for load securement of logs regardless of whether they are debarked or not except in the case where debarked, short plantation logs are being transported on the rear bunk of the trailer, there is an added requirement of rear load restraining guard or gate capable of retaining a 500N applied horizontally over a 400mm circle and retain all logs in the stack. Examples of the guards are shown in Figure A2.4. This specifically references short plantation eucalypt logs but it is expected that this is the only short debarked log expected in Tasmanian operation and based on having similar frictions issues would apply to other short debarked logs.

Figure A2.4: Rear guards on log trailers

In all cases best practice in load security suggests the use of auto tensioning devices to ensure the quality of the load securement is maintained throughout the trip. Noting the reduced coefficients of friction expected with the debarked logs the use of auto-tensioning devices, shown in Figure A2.5, for the load securement would be important.

Figure A2.5: Auto-tensioning devices

Suggestions and Impacts

In reviewing the literature and observing operations for many operations the differentiation between logs with bark on and debarked logs is not specifically addressed because it is not uncommon to have bark removed form significant portions of logs through normal handling and processing, shown in Figure A2.6. As such any safe work procedures are likely to be required to accommodate at least a portion of the logs being without bark and for safety reasons base their limits of best practice on the lower coefficients of friction that are potentially present with bark free logs.

Figure A2.6: Large log pile including bark free logs

That said, specifically in the literature around load security, when all logs are bark free in a given stack the reduced friction needs to be managed for.

The suggestions and impacts provided are based on the literature and general experience and would need to be further explored through operational trials with debarked logs.

It is expected that there would be negligible impact on the production of log handling once initial training and minor equipment modifications (bypass grapples, etc.) were addressed. Because a certain portion of bark free logs would already exist in the supply chain it is expected that storage locations on landings and at mills are already designed to provide firm, level and stable storage surfaces that will easily accommodate the debarked logs with very minor reductions in stack height seeing peek storage capacity reduced by a few percent in some cases.

The real potential for impact would be in the transportation of the logs. Most of the literature that recognises debarked logs as a different commodity for transportation refers to eucalypt logs. If we assume debarked logs are similar to debarked eucalypt logs then safe transport may require the addition of rear load guard in addition to the regular load securement. These guards will add up to 1000kg in weight to the trailer. The resulting increase in tare weight would increase the cost of transport between 5% and 7%. If an extra tie-down on each bunk of wood were used the impact would be less, assuming an extra 5 minutes per trip to deal with the extra tie-downs the impact on the transport cost would be less than 2%.

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APPENDIX 3

Milestone 2 Achievements and Key Findings:

Achievements

- Five sets of bark loss benchmarking trials were completed in Australia and New Zealand.
  - The second Australian bark loss benchmarking trial was carried out in Western Australia in Autumn 2016. 543 logs from 181 loads arriving at Wespine's sawmill near Bunbury were photographed and measured using the line intersect method. All logs were delimbed and cut into logs using a mechanised harvester/processor.

Figure A3.1. Logs arriving at Wespine mill in Western Australia for the Autumn Bark Loss Benchmarking Study. Also note the headboard fitted to the front of the truck to stop logs sliding forward.

  - The third New Zealand bark loss benchmarking trial was carried out in the Bay of Plenty in Summer 2016. 493 logs from 1055 loads arriving at the Port of Tauranga were photographed and measured using the line intersect method. Logs were delimbed and processed using three methods; manual with chainsaw, static delimber with chainsaw bucking, and mechanised.
  - The fourth New Zealand bark loss benchmarking trial was carried out in the Bay of Plenty in Autumn 2016. 711 logs from 162 loads arriving at the Port of Tauranga were photographed and measured. Logs were recorded as being delimbed and bucked

using manual with chainsaw, or mechanised delimbing and bucking. No static delimbed logs were noted.

- The fifth New Zealand bark loss benchmarking trial was carried out in the Bay of Plenty in Autumn 2016. 122 logs from 7 log grades stacked on landings in Kaingaroa Forest were photographed and measured. Logs were cut to length at the stump and extracted to roadside with rubber-tyred forwarder.

- Three sets of trials comparing bark loss during the felling and extraction phase with bark loss after felling, extraction and processing were completed in New Zealand. All trials were carried out in Kaingaroa Forest. Each trial relates to a single, but not the same, logging crew.
  - The first comparison was carried out in Spring 2015. 69 logs were photographed and measured. Stems were extracted tree-length to a landing then mechanically processed into logs
  - The second comparison was carried out in Summer 2016. 144 logs were photographed and measured. Stems were extracted tree-length to a landing and then mechanically processed into logs.
  - The third comparison was carried out in Autumn 2016. 29 stems were extracted to a landing and then photographed and measured. The stems were later trucked to Kaingaroa Processing Plant where they were processed into logs.
- Two sets of drying rate trials were completed in Australia and New Zealand.
  - The second Australian drying rate trial was carried out in Autumn (March 2016) in Western Australia. 56 logs (28 with the bark left largely intact[5], and 28 with the bark removed) were weighed at the beginning and end of a 10 day period. The logs were from four diameter classes (<200 mm, 200-250mm, 250-350mm, and >350 mm). The climatic conditions for the trial period were as follows: mean temperature 23^{o}C, mean wind speed 15km per hour, total rainfall 0 mm.
  - The second New Zealand drying rate trial was carried out in Summer (February 2016) in Bay of Plenty. 61 logs (26 with the bark left largely intact, and 35 with the bark removed) were weighed at the beginning and end of a 10 day period. The logs were from four diameter classes (<150 mm, 150-250mm, 250-350mm, and >350 mm). The climatic conditions for the trial period were as follows: mean temperature 16^{o}C, mean wind speed 10km per hour, total rainfall 12 mm.

[5] It should be noted that, similar to the drying trials undertaken as part of Milestone 1, it was difficult in both Western Australia and New Zealand to obtain any logs with all the bark present. An estimate was made for each log of the amount of bark missing at the beginning of the trial for the Bark On logs.

Figure A3.2. Debarked logs being weighed in New Zealand for the Autumn Drying Rate Study.

- A safety review related to the transport, storage and handling of debarked logs was completed.
- A meeting was held with Paul Norris, the Operations Manager for IVS. IVS are responsible for checking that logs leaving New Zealand ports meet the phytosanitary requirements of those countries that the logs are being sent to. Discussions focused on how phytosanitary compliance is monitored.
- Production equations from Australia and New Zealand were assembled that will be incorporated into an economic analysis model in Milestone 3 period and should allow evaluation of the impacts of various levels of bark removal on processing productivity for cut-to-length and tree length handling systems. Additionally a copy of the FORME report on log processor heads prepared for STIMBR was obtained. This will also contribute to evaluation of the economic impact of in-forest debarking to phytosanitary standards.
- Nineteen harvesting crews in the Central North Island, all using mechnanised processors, were visited to assess, among other things, the types of processors being used and how work methods might affect bark removal.
- Discussions were held with SouthStar about participating in a third debarking feasibility trial. SouthStar are now planning on undertaking trial, with our assistance, beginning in late June or July.
- The application for funding from the Chartered Institute of Logistics and Transport, to carry out detailed studies on the effect of bark on log storage at ports, was not successful. The impact of bark on storage at ports assessed using other information.
- Economic data on the costs of berthage and other port fees, and costs related to operating weighbridges were assembled for later use in the In-forest Debarking economic analysis model.
- Galley proofs of a manuscript, entitled "Radiata pine bark removal associated with two on-landing, log processing methods", were approved for publication in the July 2016 issue of Forest Products Journal[6].

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[6] Murphy, G. and Logan, O. (2016): For.Prod.J. 2016 Vol 66, No.3-4, pp192-195.

- A manuscript, on the Western Australia processor head trials noted in the Milestone 1 report, has been prepared for publication in an international journal by Martin Strandgard and Brad Barr (Australia) and Glen Murphy (New Zealand).
- A verbal update on progress on the project was given in February 2016 to the FFR Steepland Harvesting Technical Steering Committee.
- This report, the second intermediate written report for the project, will be presented to NZFOA Research Manager, Russell Dale, on 22 June 2016.

Key Findings

Second Round of Bark Loss Benchmarking Trials

There was little difference in overall average bark loss (34 to 37%) for the two autumn trials in Australia and New Zealand where cut-to-length harvesting systems were used. Where tree-length harvesting was the main system there was also little difference in overall average bark loss (65%) between the summer and autumn trials in New Zealand. Similar to the findings given in the Milestone 1 Report, mechanised tree length delimbing and bucking resulted in higher bark loss (70%), than static delimbing and chainsaw bucking (58%), and manual chainsaw delimbing and bucking (54%). Cut-to-length mechanised systems resulted in the least bark loss (~36%).

Table A3.1. Bark Loss (%) Benchmark Data for Two Seasons, Two Locations and Four Harvesting Systems

Location	Season	Harvesting System			
		Mechanized Delimbing and Bucking	Static Delimbing and Chainsaw Bucking	Manual Chainsaw Delimbing and Bucking	Overall Average
New Zealand	Summer	69.9	58.3	54.0	64.8
Australia	Autumn*	33.8	-	-	33.8
New Zealand	Autumn	67.1	-	57.1	65.3
New Zealand	Autumn*	37.1	-	-	37.1

* Cut-to-Length Harvesting system

When information from this Milestone 2 Report is combined with information from Table A1.1 of the Milestone 1 report (see Appendix 1) it can be seen that there is the same trend with respect to seasons for all harvesting systems, tree-length and cut-to-length, mechanised and manual. Bark loss is greatest in spring, when the sap is rising, then decreases slowly through summer and autumn, and is at its lowest in winter.

The benchmark data from all four seasons indicates that bark loss in Autumn and Winter tends to be greater in grades that are found in the bottom portion of the tree (67 to 74%) than in the top portion of the tree (52 to 65%). In summer and spring this trend tends to be reversed; that is, bark loss tends to be marginally greater (3 to 5%) in the top portion of the stem. More detailed analysis is needed to confirm these findings.

Pre- and Post-Processing Comparison Trials

The Spring and Summer trials indicate that most (~75%) of the bark loss occurs during the felling and extraction phases (Table A3.2). No comparison could be made for the autumn trial since the logs were not processed at the landing in the forest. If the same pre/post processing ratio were applied to the Autumn trial a post-processing bark loss of 47% would be calculated. This is much lower than the 67.1% shown in Table A3.1 above. The reason for this is unknown.

Table A3.2. Bark Loss (%) Pre and Post-Processing of Extracted Stems into Logs in New Zealand

Season	Harvesting Activities	
	Felling and Extraction	Felling, Extraction and Processing
Spring	62	82
Summer	57	79
Autumn*	35	-

* Full stem to landing. Stems later trucked to Kaingaroa Processing Plant

Second Round of Drying Rate Trials

Drying rates over a 10-day period are presented in Tables A3.3 and A3.4 for drying studies carried out in Autumn in Australia and in Summer in New Zealand.

Table A3.3. Weight loss (%) and drying rate comparisons for the WA Autumn Drying Rate Trial

Log Size Class (SED)	Drying Weight Loss (%)		Ratio of Weight Loss % (B_Off/B_On)
	Bark On	Bark Off	
< 200 mm	15.1	21.2	1.41
200-250 mm	10.4	19.5	1.86
250-350 mm	8.2	15.3	1.88
350-450 mm	7.8	11.0	1.41

Average B_Off% for Bark On logs for WA trials was 34%.

Table A3.4. Weight loss (%) and drying rate comparisons for the New Zealand Summer Drying Rate Trial

Log Size Class (SED)	Drying Weight Loss (%)		Ratio of Weight Loss % (B_Off/B_On)
	Bark On	Bark Off	
< 150 mm	7.2	10.0	1.39
150-250 mm	6.0	6.5	1.09
250-350 mm	5.8	4.6	0.79
350-450 mm	4.0	4.0	0.99

Average B_Off% for Bark On logs for NZ trials was 55%.

Logs dried at two to three times the rate in Western Australia in Autumn than they did in New Zealand in Summer. As noted in the Milestone 1 report, wind, temperature and precipitation are some of the key drivers of drying rates in logs, with greater wind speeds and temperatures favouring drying and greater precipitation hindering drying. All three factors were more favourable for drying in Western Australia than in New Zealand (wind 15 vs 10 km h^{-1}, temperature 23°C vs 16°C, and rainfall 0 vs 12 mm) during the trial periods. Drying rates were slightly higher in Autumn than Spring in Western Australia and substantially higher in Summer than Spring in New Zealand.

Similar to the Spring drying rate trials in Australia and New Zealand it was found that the percentage weight loss due to drying consistently decreased as log size increased and was greater with all bark removed than with the bark present for all log size categories in Australia and the small log size categories in New Zealand. Drying rates were lower with bark off than bark on, however, for the two largest log size categories in the New Zealand Summer Drying Trial. This was also found for the Spring Drying Trial in New Zealand. Again it should be noted that it was difficult to find large logs with much bark present in New Zealand; on average the large log categories only had 30% of the bark present for the Summer drying trial.

A preliminary regression model was developed based on the combined New Zealand Spring and Summer drying data for "bark on" logs.

*Weight Loss (kg) = 3.14 + 0.027*Initial Weight (kg) – 0.048*BarkOn (%) + 4.869*Season*

$R^2 = 0.78, p<0.001$

where Season = 0 if Spring and 1 if Summer.

Based on the above regression it would be expected that a 350 kg log (equivalent to the 250 to 350 mm log size class) would lose about 3.6% of its weight over a 10 day period if all the bark was present and about 5.0% of its weight if all of the bark was missing.

Safety Implications of Handling Debarked Logs in the Supply Chain

The safety review is attached as Appendix 2 to this report.

Coefficient of friction (COF) is a measure of the relative force required to slide one body across another. Static COF relates to two bodies that are initially at rest. Dynamic COF relates to two bodies in motion relative to each other. Static COF would be important for logs stacked in a log yard or on a landing. Dynamic COF would be important for logs resting on a braking truck or in the grab of a moving log loader.

Dynamic COF tends to be a half to two-thirds that of static COF. Dry logs with the bark removed have static and dynamic COF's that are two-thirds to three quarters that of dry logs with the bark on. Wet logs with the bark removed have static and dynamic COF's that are about half that of dry logs with the bark removed. Wet debarked logs will have a dynamic COF that is less than half that of dry logs with the bark on.

It is expected that there would be negligible impact on the production of log handling once initial training and minor equipment modifications were addressed to overcome lower frictional forces of debarked logs. Because a certain percentage of bark free logs would already exist in the supply chain it is expected that storage locations on landings and at mills are already designed to provide firm, level and stable storage surfaces that will easily accommodate the debarked logs with very minor reductions in stack height. Peek storage capacity could perhaps be reduced by a few percent in some cases.

The greatest potential for impact would be in the transportation of the logs. Most of the literature that recognises debarked logs as a different commodity for transportation refers to eucalypt logs. If we assume debarked radiata pine logs are similar to debarked eucalypt logs then safe transport may require the addition of a rear load guard in addition to the regular load securement. These guards will add up to 1000 kg in weight to the trailer. The resulting increase in tare weight would increase the cost of transport between 5% and 7%. If an extra tie-down on each bunk of wood were used – as specified in the NZ Log Transport Safety Council Industry Standards (2012) for debarked logs – the impact would be less; assuming an extra 5 minutes per trip to deal with the extra tie-downs the impact on the transport cost would be less than 2%.

Meeting Phytosanitary Requirements

China is the only country that will accept debarking as an alternative to chemical treatment of logs to control insect risk, etc. Debarked logs are allowed a tolerance of up to 5% on an individual log and up to 2% on an inspection unit. An inspection unit is usually a row of logs that the log marshallers present to the inspection service.

A visual system is used for assessing bark content. If the assessor thinks an inspection unit is "borderline" he can ask for a sample (not specified how big this is) of logs to be pulled out of the row. Bark area is manually measured and then converting to a percentage using lookup tables. Measurements are taken on one side of the log only. If two or less logs do not meet the <5% tolerance the row is passed but the "failed" logs are set aside. If more than two logs do not meet the tolerance the row is "failed" and the log marshaller can then either treat all logs as non-debarked or carefully go through the row and remove all >5% logs.

The 2% tolerance for an inspection unit appears to be is solely based on guess-work and experience of the assessor. There is no system for accurately quantifying it. Currently there is no easy system to determine how many logs are inspected, how many fail, and what grades are most likely to fail.

Logs that have been through a ring debarker on or off port can and do still fail inspection. Bark can still be found around branches, fluting area, in forks, etc. Some suppliers of debarked logs have fewer failed inspections than others.

It is expected that the economic viability of debarking will increase when the costs of reclaiming methyl bromide are added to the costs of applying it.

FORME's 2015 report to STIMBR indicated that in-forest debarking to phytosanitary standards could be achieved for some log grades but could take up to five times the number of passes of the processor head to do so. Smaller head logs, and rougher logs may not be debarked to minimum phytosanitary requirements. A revision to costing information in the report for STIMBR should see a substantial reduction in estimated production costs for in-forest debarking increasing its economic viability in comparison to alternative on-port treatments.

Visits to close to 20 Central North Island logging crews indicated that many mechanized processing operators make a point of removing as much bark as possible from the bottom portion of the stem. This may take several passes of this portion of the stem. It is done to improve the accuracy of under-bark diameter measurements on the logs for optimal bucking and log volume determination reasons, rather than for phytosanitary reasons. Debarking for phytosanitary purposes may also improve value recovery and woodflow management (from more accurate volume measurements).

Planned Activity for the Third Milestone Period:

- Compare bark loss on four processor heads used with ground-based logging operations in the Central North Island; two heads with a 2-knife configuration and two heads with a four-knife configuration.

Figure 3. Processor heads which will be compared in the third milestone period on the basis of bark removal. From top left and clockwise: Waratah 625 (4-knife), Woodsman Pro 800 (4-knife), SouthStar (2-knife), and Waratah 626 (2-knife)

- Assist SouthStar in determining the efficacy and efficiency of a modified processor head for debarking radiata pine. The modifications are expected to include a new roller design and modified knife pressures.
- Carry out a Winter Drying Rate trial in New Zealand. This will be the last field work related to the current In-Forest Debarking Project.
- Meet with the USC collaborators in Queensland to undertake of supply chain level systems analysis of in-forest debarking. This will be systems level analysis will be qualitative and will identify the advantages and disadvantages of in-forest debarking.
- Construct a spreadsheet-based model that will allow exploration and sensitivity analyses of the economic viability of in-forest debarking. The model will use the best quantitative information available but may not cover some of the benefits and costs identified in the systems level analysis. The model will also allow evaluation of the breakeven price for a processor head suitable for in-forest debarking.
- Prepare and deliver a final report (in written and conference-suitable presentation form) to the NZ Forest Growers Levy Trust.
- Provide a verbal update to the Steepland Harvesting Technical Committee.

APPENDIX 4

Worksheets from the In-Forest Debarking Economic Model (m^3 version)

Species	*P. radiata*
Input Volume (m3 ub)	100,000
Wood Weight Initial (incl bark)	101,931
Number of days drying	5
Season (S_ummer, A_utumn, W_inter, SP_ring)	S
Location	NZ
Wood Weight Final (NIFD)	94,752
Wood Weight Final (IFD)	92,340
Harvesting System (GB, C, SW)	GB
Export % of total	55
China % of Export	65
Fumigation Port	Y
Extra Port Visit Required	Y

	No In-Forest Debarking	In-Forest Debarking	Delta%
Total Revenue	$ 13,386,044	$ 13,185,925	-1.49%
Harvesting Costs	$ 2,451,852	$ 2,835,767	15.66%
Transport Costs	$ 1,710,000	$ 1,715,985	0.35%
Mill Yard Costs	$ 555,750	$ 182,115	-67.23%
Port Costs	$ 748,000	$ 582,511	-22.12%
Waste handling costs	$ 39,331	$ -	-100.00%
Other Costs	$ 309,615	$ 334,462	8.02%
Extra Shipping Costs	$ 268,889	$ -	-100.00%
Net Revenue	$ 7,302,607	$ 7,535,086	3.18%
Change in Net Rev.		3.18%	

Summary | Wood and Bark Data | Harvesting Economics | Transport Economics | Mill

Wood and Bark Data	
Species	*P. radiata*
Input Volume (m3 ub)	100,000
Standing Tree Wood Wt (tonne)	95,000
Standing Tree Bark Volume (m3)	14,416
Standing Tree Bark Wt (tonne)	6,931
Wood basic density (kg/m3)	380
Initial Wood Moisture Content %wb	60
Harvesting System (1=GB , 2 = C, 3 = SW)	1
Season	W
Days Drying	5
Location	NZ
Wood Weight Final (No In-Forest Debarkin	96,870
Wood Weight Final (In-Forest Debarking)	94,098
Bark Presence %	40
Bark Loss %	60

Standing Tree Bark Vol (OB)%	12.6	JASm3 to m3	1.125
Standing Tree Bark Wt (OB)%	6.8	JASm3 to tonne	1.069
GBD/GWD ratio	0.562		
Wood green density (t/m3)	0.950	Bark green density (t/m	0.481

System	Season	Bark Loss % NZ	Bark Loss % Aust
TreeLength	Summer	70	NA
	Autumn	67	NA
	Winter	60	NA
	Spring	77	NA
CTL	Summer	40	37
	Autumn	37	34
	Winter	30	28
	Spring	47	48

	Season	Drying Rates (% change per day) Bark On NZ	Bark On Aust	Bark Off NZ	Bark Off Aust
TreeLength	Summer	-0.49	NA	-0.56	NA
	Autumn	-0.34	NA	-0.38	NA
	Winter	-0.19	NA	-0.19	NA
	Spring	-0.38	NA	-0.22	NA
CTL	Summer	-0.49	-1.21	-0.56	-2.04
	Autumn	-0.28	-1.10	-0.38	-1.76
	Winter	-0.15	-1.00	-0.19	-1.48
	Spring	-0.30	-0.89	-0.22	-1.20

Summary | Wood and Bark Data | Harvesting Economics | Transport Economics | Mill

Harvesting Economics

	SW_GB	GB_TL	C_TL
Base Harvesting Costs ($/t)	$ 26.00	$ 26.00	$ 35.00
Base Harvesting Costs ($/m3)	$ 24.70	$ 24.70	$ 33.25
Total Harvest (NIFD) (t)	96,870	96,870	96,870
Total Harvest (IFD) (t)	94,098	94,098	94,098
Separate Debarking Machine	Y		

	No In-Forest Debarking						In-Forest Debarking					
	Base Alloc %	SW_GB	B.Alloc %	GB_TL	B.Alloc %	C_TL	% Chang	SW_GB	% Change	GB_TL	% Change	C_TL
Felling	12	$296,400	19	$296,400	16	$399,000	0	$296,400	0	$296,400	0	$399,000
Processing	18	$444,600	23	$444,600	19	$598,500	-25	$333,450	-25	$333,450	-25	$448,875
Extraction	33	$815,100	21	$815,100	36	$1,097,250	0	$815,100	0	$815,100	0	$1,097,250
Debarking	0	$0	0	$0	0	$0	100	$475,000	100	$475,000	100	$475,000
Loading	23	$568,100	23	$568,100	16	$764,750	5	$596,505	5	$596,505	5	$802,988
Other	14	$352,607	14	$334,977	13	$450,930	0	$342,515	0	$325,389	0	$450,930
Total Costs	100	$2,476,807	100	$2,459,177	100	$3,310,430		$2,858,970		$2,841,844		$3,674,042

Summary | Wood and Bark Data | **Harvesting Economics** | Transport Economics | Mill

Transport Economics

	km		
Travel Distance	100	Base Costs ($/t)	$ 18.00
Transported Volume	100,000	Base Costs ($/m3)	$ 17.10
Transported Weight (NIFD)	96,870		
Transported Weight (IFD)	94,098		
Loading as % of truck cycle	13		

		No In-Forest Debarking	In-Forest Debarking
Base Costs ($)		$1,710,000	$1,710,000
Payload Adjustment (%)	2.9	$0	-$49,590
Loading Time Adjustment (%)	25	$0	$55,575
Adjusted Costs		$1,710,000	$1,715,985

Summary | Wood and Bark Data | Harvesting Economics | **Transport Economics** | Mill

Port Economics

	Base Costs ($/ JAS m3)		Total Port Volume (m3)	Base Fumigation %	Base Debarking %
Fumigation Costs	$	5.50	55000	30%	25%
Debarking Costs	$	8.60			
Handling Costs	$	3.00			
Other Costs (e.g. Scaling, Storage	$	8.50			
Stevedoring	$	3.00			
Total (Weighted)	$	18.30			
Above Deck Log Cargo %		30			

	Change %	No In-Forest Debarking	In-Forest Debarking
Fumigation	-100	$80,667	$28,233
Debarking	-100	$105,111	$0
Handling	4.5	$146,667	$153,267
Other	-3.5	$415,556	$401,011
Stevedoring	0	$165,000	$165,000
Total Costs to Shipside		$748,000	$582,511

Port Economics / Waste Handling / Other Costs / Shipping / Revenues

Waste Handling Costs

	% of Total Waste
Energy from Mills	80
Landscaping from Mills	2
Other from Mills	3
Energy from Ports	15
Landscaping from Ports	5
Other from Ports	10
Collection Costs ($/t)	$ 10.80
Transport Costs (20 km haul) ($/t)	$ 10.00
Disposal Costs ($/t)	$ 21.00
Collection Costs ($/m3)	$ 5.19
Transport Costs (20 km haul) ($/m3	$ 4.81
Disposal Costs ($/m3)	$ 10.10
Total Mill Waste (m3)	2595
Total Port Waste (m3)	3172

Cost Item	No In-Forest Debarking	In-Forest Debarking
Mill Collection Costs	$ 2,021	$ -
Mill Transport Costs	$ 1,871	$ -
Mill Disposal Costs	$ 3,930	$ -
Port Collection Cost	$ 11,528	$ -
Port Transport Costs	$ 10,674	$ -
Port Disposal Costs	$ 22,416	$ -
Total Waste Costs	$ 52,441	$ -

Port Economics / Waste Handling / Other Costs / Shipping / Revenues

Other Costs

		Change %	No In-Forest Debarking	In-Forest Debarking
Weigh Bridge and Scaling Costs (per m3)	$ 0.45	-100	$ 45,000.00	0
Fertiliser (per ha)	$ 70	-30	$ 10,769.23	$ 7,538.46
Site Preparation Costs (per ha)	$ 1,000	15	$ 153,846.15	$ 176,923.08
Landing Costs (per m3)	$ 1.00	50	$ 100,000.00	$ 150,000.00
Interest rates %	0			
Rotation length yrs	30			
Volume m3 per ha	650	Total	$ 309,615.38	$ 334,461.54
Compound factor_3	1.00			
Compound factor_2	1.00			

Port Economics | Waste Handling | **Other Costs** | Shipping | Revenues

Additional Shipping Costs due to fumigation visit

Fumigation requires extra port visits Y

			No In-Forest Debarking	In-Forest Debarking
Export Volume (m3)	55,000			
Average Ship Volume (JAS m3)	30,000			
Above Deck Volume (JAS m3)	9,000			
Above Deck Volume (m3)	10,125			
Number of Visits	5.4			
Additional Port fees per visit	$ 12,000	Port fees	$65,185	$ -
Shipping Delays (days) per vis	1.5	Ship costs	$203,704	$ -
Daily Shipping Cost	$ 25,000			
		Total Costs	$268,889	$ -

Port Economics | Waste Handling | Other Costs | **Shipping** | Revenues

Revenues

			No In-Forest Debarking			In-Forest Debarking		
			Volumes	Price	Total	Volumes	Price	Total
			m3	$/JAS m3 fob	$	m3	$/JAS m3 fob	$
Logs				or $/m3 mill gate			or $/m3 mill gate	
	Export		55,000	$160	$8,800,000	55,000	$160	$8,800,000
	Domestic		45,000	$101	$4,545,000	45,000	$101	$4,545,000
	Contamination Losses (%)	3.5				45,000	-$4	-$159,075
	Sapstain Losses (%)	0				45,000	$0	$0
Bark at Mill								
	Energy		2,076	$17	$35,292	0	$17	$0
	Landscaping		52	$22	$1,142	0	$22	$0
	Other - Drainage, etc.		78	$17	$1,323	0	$17	$0
Bark at Port								
	Energy		476	$17	$8,088	0	$17	$0
	Landscaping		159	$22	$3,489	0	$22	$0
	Other - Drainage, etc.		317	$17	$5,392	0	$17	$0
Totals					$13,399,725			$13,185,925

Port Economics | Waste Handling | Other Costs | Shipping | Revenues