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

Milestone 2 Report: 22 June 2016

Prepared for

New Zealand Forest Growers Levy Trust

by

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Executive Summary

All Milestone 2 requirements have been met. The project is still ahead of schedule in that some activities planned for the third six month periods have already been completed; i.e. the safety review and the Spring bark loss benchmarking trials. Additional work is now planned; namely, a third debarking feasibility trial and an analysis of processor head knife configuration on bark removal. This report focuses on activity related to Milestone 2 (January to June 2016) but includes the Milestone 1 report as an Appendix for completeness.

Project Goal and Objectives:

Bark is a low value product that adds cost from forest to customer. Eliminating it early in the supply chain should 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

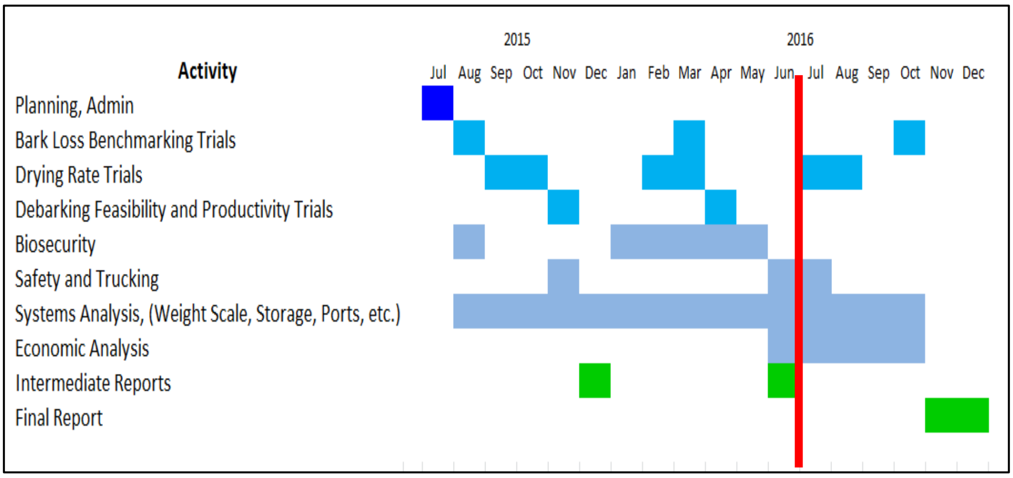

Figure 1. Gantt Chart of Planned Activity for the In-Forest Debarking Project

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 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 end of 12 months, verbal update to the Technical Committee.

Milestone 3: Completion of 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 have agreed to participate in the project since its initiation.]

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 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.

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    - 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 comparsion 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[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 (<200 mm, 200-250mm, 250-350mm, and >350 mm). The climatic conditions for the trial period were as follows: mean temperature 23°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°C, mean wind speed 10km per hour, total rainfall 12 mm.

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

[1] 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.

- 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.
- 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 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 systems resulted in the least bark loss (~36%).

Table 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 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. 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 1 above. The reason for this is unknown.

Table 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 3 and 4 for drying studies carried out in Autumn in Australia and in Summer in New Zealand.

Table 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 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.

$$\textit{Weight Loss (kg)} = 3.14 + 0.027 \cdot \textit{Initial Weight (kg)} - 0.048 \cdot \textit{BarkOn (\%)} + 4.869 \cdot \textit{Season}$$

$$R^2 = 0.78, p<0.001$$

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 reduction 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.

Planned Activity Beyond the Third Milestone Period:

The In-Forest Debarking Project is expected to be completed by 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.

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[2], 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) 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.

[2] 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.

Figure 2. Image of load of logs with lines overlaid in preparation for measurement of bark loss using the line intersect method.

Figure 3. Logs used in Australian Spring drying rate trial (left) and log being placed on weight scales (right).

Figure 4. 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 5. 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.

- o 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[3] on standing tree radiata pine bark volume and weight was written and published in the New Zealand Journal of Forestry Research 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

[3] 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).

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 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 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 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)[4] and Murphy and Logan (2015)[5] 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.

Drying Rate Trials

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 2 and 3.

Table 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 % (B_Off/B_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 B_Off% for Bark On logs for WA trials was 28%.

Table 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°C vs 11°C), rainfall was absent in Western Australia and 12 mm total for the New Zealand trial.

[4] 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.

[5] 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)

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 6. 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 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 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 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 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 7. 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.

Preliminary Review of Biosecurity Issues

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%] , and
- 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).

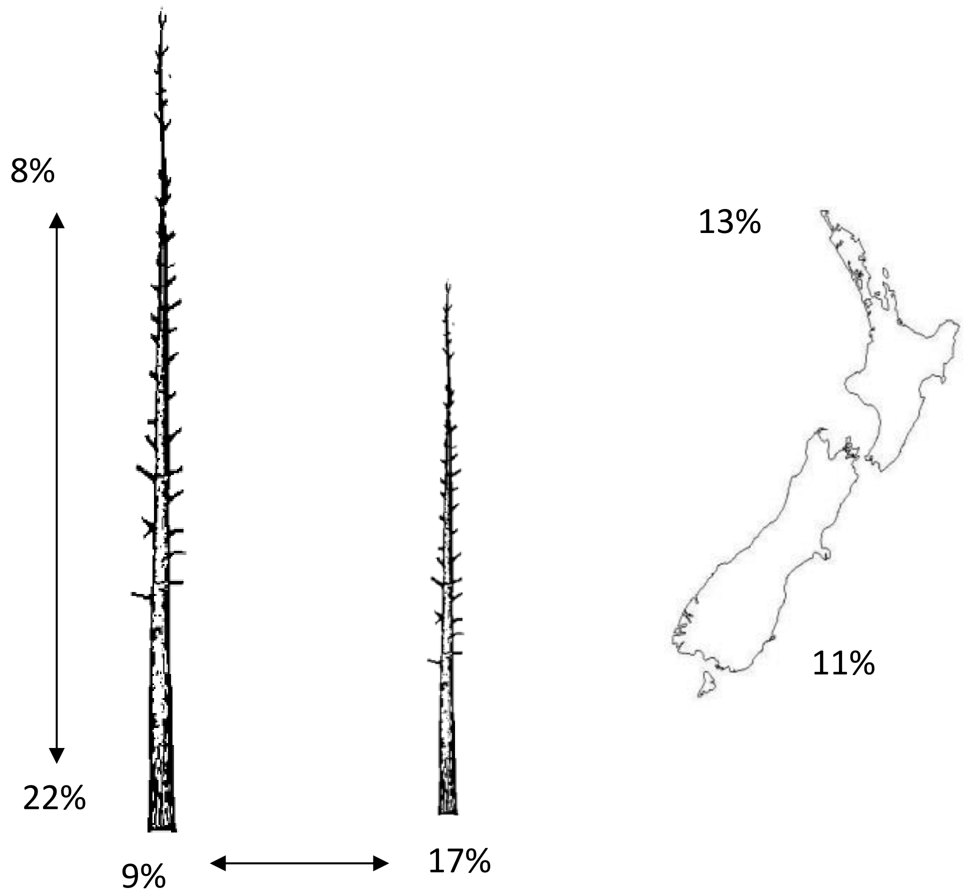

Figure 8. Bark, as a percentage of overbark volume in standing trees, varies with height in a tree, with tree size, and with site conditions.

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 effected 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 1**.

Figure 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 2.

Figure 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 3.

Figure 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 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 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 5, for the load securement would be important.

Figure 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 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 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 reduction 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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