

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

Milestone 1 Report: 17 December 2015



Prepared for

New Zealand Forest Growers Levy Trust

by

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Executive Summary

All Milestone 1 requirements have been met. The project is ahead of schedule in that some activities planned for the second and third six month periods have already been completed; i.e. the second debarking feasibility trial and the Spring bark loss benchmarking trials. Additional work is now planned.

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

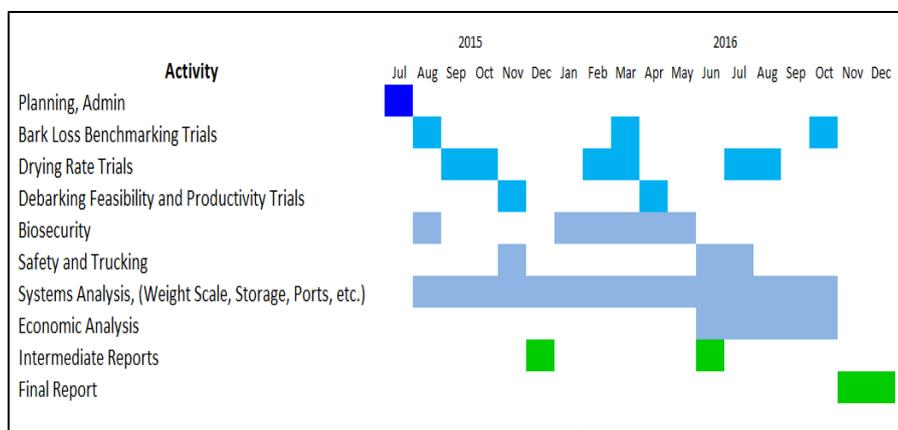


Figure 1. Gantt Chart of Planned Activity for the In-Forest Debarking Project

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.

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 delimiting and bucking.



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

- 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 intact¹, 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°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

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.

conditions for the trial period were as follows: mean temperature 11°C, mean wind speed 20km per hour, total rainfall 12 mm.



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 delimiting 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.

- 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 manuscript² 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 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 Delimiting and Bucking	Static Delimiting and Chainsaw Bucking	Manual Chainsaw Delimiting 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 delimiting and bucking than with static delimiting and

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).

bucking. The amount of bark lost was even greater (23 to 28%) for mechanized delimiting and bucking than with manual chainsaw delimiting and bucking.

Only mechanized delimiting 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 delimited 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 delimited), dragged to a landing, and then delimited 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.

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%.

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 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.

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 cm² 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).

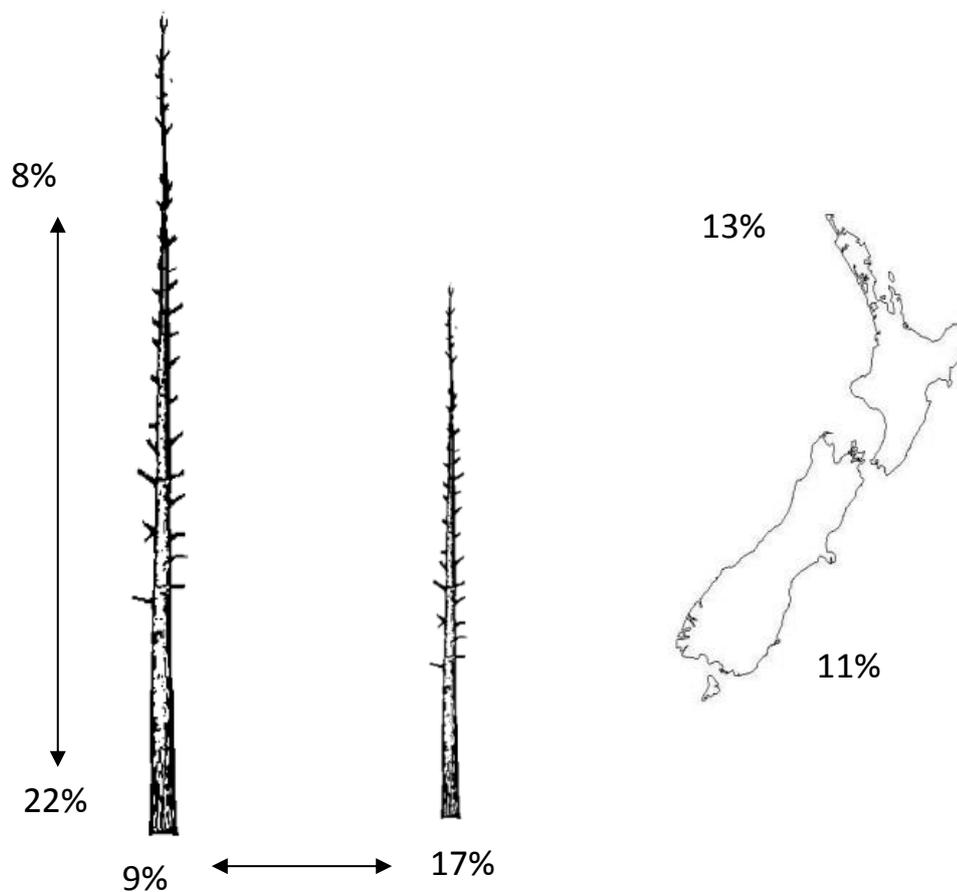


Figure 8. Bark, as a percentage of overbark volume in standing trees, varies with height in a tree, with tree size, and with site conditions.

Interim Conclusions Based on Key Findings

- * 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 delimiting 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.

Milestone 2: Planned Activity for 6 Month period 1 January 2016 to 30 June 2016

- * Complete the summer bark loss benchmarking trials in New Zealand and Australia.
- * Complete the summer drying rate trials in New Zealand and Australia.
- * Complete safety review related to transport, storage and handling of debarked logs.
- * Complete investigation into phytosanitary requirements and the feasibility of debarking to phytosanitary standards in-forest.
- * Assess the impacts of various levels of bark removal on processing productivity for cut-to-length and tree length handling systems.
- * Hold discussions with processor manufacturers and carry out a third debarking feasibility trial if possible.
- * Initiate detailed studies on the effect of bark on log storage at ports if the application for funds from the Chartered Institute of Logistics and Transport is successful.
- * Deliver the second intermediate written report at the end of June 2016.
- * Give a verbal update on progress on the project to the FFR Steepland Harvesting Technical Steering Committee.