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Short Log Supply Chain Impacts in Hardwood Plantations

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Short Log Supply Chain Impacts in Hardwood Plantations

Prepared for

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by

Glen Murphy and Mauricio Acuna
Forest Industries Research Centre
University of the Sunshine Coast

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Researcher/s: Glen Murphy and Mauricio Acuna

Forest Industries Research Centre,
University of the Sunshine Coast,
QLD

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Australian Government
Department of Agriculture,
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Forest and Wood Products Australia
Level 11, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@nifpi.org.au
W www.nifpi.org.au

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EXECUTIVE SUMMARY

The main goal of this study was to determine if adding short saw logs to the current basket of log grades would have a positive or negative impact on net revenues in hardwood plantations.

The study design included evaluation of three treatments to be carried out at three sites in northern Tasmania. Two of the sites would be in unpruned stands of high and low quality (UHQ and ULQ) and one would be in a high-quality pruned stand (PHQ).

The current basket of log grades was represented by the Longs treatment. Adding short saw logs to the current basket was represented by the Mix treatment. The Shorts treatment provided additional information, although interest by industry was not in replacing long saw logs with short saw logs.

Harvesting, forwarding, loading and trucking activities were studied using a mix of standard time and motion methods, operator completed forms, and digital tracking systems. These studies allowed determination of hourly machine productivity values. Standard machine costing procedures were used to obtain hourly costs. Gross revenues were calculated based on a combination of log prices supplied by the industry participants, assessed stand volumes and log grade yields.

The impacts of short logs on mill processing and mill log yard handling activities was also assessed through a brief literature review and an available model of log marshalling activities at a marine port.

Based on the results from both the UHQ and the ULQ sites adding short saw logs to the current basket of logs would be expected to reduce net revenues by 5% to 12%. Adding short saw logs to the basket generally decreased productivity and increased costs for all activities – harvesting, forwarding, loading and trucking – by 5 to 10%.

The relative cost increases found for harvesting and transport from the unpruned sites were not dissimilar to those reported elsewhere in the literature. They are also similar to those found for mill yard (5 to 8%) and mill processing (6%) activities.

There was little to no improvement obtained in gross revenue by adding short logs to the basket in the unpruned stands. This was largely due to there being only a 4% difference in assumed log prices for saw logs compared with pulp logs.

It can be concluded that, in unpruned hardwood plantation stands, harvesting and transport cost increases would not be expected to be covered by the additional revenue obtained from adding short saw logs to the current mix, particularly if there is little difference between short saw logs and pulp logs in log prices.

The conclusion, based on the results from the pruned site (PHQ), confirm those from the unpruned site - the additional revenue obtained, if any, from adding short saw logs to the current mix would not be expected to meet increases in harvesting and transport costs.

INTRODUCTION

Land owners and wood producers operate in a globally competitive marketplace. Not only do they compete with other timber and fibre producers around the world but they also compete with producers of alternative materials (e.g. steel, aluminium, plastics, concrete). This necessitates that they have a focus on cost control and select and utilise equipment and work practices that are cost efficient.

Plantation forestry, as a land use, must also compete with alternative uses for the land; evidence of this is the recent conversion of hardwood and conifer plantation forests to dairy and beef farms in Australia and New Zealand. This necessitates that landowners also have a focus on maximizing value recovery from their estates.

To satisfy the requirements of different log buyers and to ensure that maximum value and quality are obtained from the raw material, trees must be cut and sorted into a variety of products with different specifications, including length specifications. Cutting of the stems into different lengths and separation into multiple log sorts can have an impact on a range of harvesting, handling and transport production variables such as equipment requirements, waste generation, productivity, cost and the number and size of loading bays. Multiple log sorts can also have an impact of storage and handling requirements at mills and marine ports. These in turn can all affect the economics of the operations.

FWPA’s Strategic Plan 2018-2023 has identified the need to “develop and adopt improved techniques for the allocation of standing trees, logs, timber and fibre to the most appropriate use using new technologies and data analysis techniques”. Amongst other approaches this will require looking at “longer” sections of the forest-to-customer supply chain than single activities and focusing on both value recovery and cost control.

Logs valued at $1.979 billion, with a total volume over 16 million cubic metres, were harvested from Tasmanian, South Australian, and Victorian hardwood and conifer plantation forests in 2016/17 (ABARES Forest and Wood Products Statistics). The value of logs harvested from Tasmanian plantation forests alone was $0.273 billion in 2016/17.

Hardwood plantations account for over 300,000 ha of forest land in Tasmania. Shining gum (*Eucalyptus nitens*) is the dominant plantation hardwood species. Total harvest from hardwood plantations exceeds 3 million tonnes (PFT 2019, STT 2019). Approximately 80% of the harvest volume is exported as woodchips and a large portion of the remainder exported as veneer logs and saw logs.

Log markets, particularly export log markets, have moved to a greater acceptance of short log lengths over the past decade or so. This provides an opportunity for greater value capture, but potentially at higher costs, if the best mix of short and long logs is not selected.

Landowners in Tasmania and the Green Triangle region are also interested in making better use of their plantation forests through improving volume recovery (fixed costs are spread across more volume) and reducing wastage. Logging waste is seen by the public as evidence of poor utilisation and is visually unappealing. Logging waste is also considered to be a pest and fire hazard for the landowner.

This report focuses on the impacts of short logs on hardwood supply chain economics. The full project consists of a mix of time and costing studies of harvesting and transport activities, value recovery analyses, and economic analyses based on three case-study sites of different quality and silvicultural management in hardwood plantations in Tasmania. This report presents the results from studies carried out at the three sites.

Objective

The research presented in this report focused on modifying hardwood supply chains in northern Tasmania. The main objective of this study was to determine the impacts of an increased mix of short log lengths on optimal equipment configurations, value recovery, machine productivity, production costs, and the overall supply chain economics from the stump to the mill or marine port.

LITERATURE REVIEW

To satisfy the requirements of different log buyers and to ensure that maximum value and quality are obtained from the raw material, trees must be cut and sorted into a variety of products with different specifications, including length specifications. Cutting of the stems into different lengths and separation into multiple log sorts can have an impact on a range of harvesting, handling and transport production variables such as equipment requirements, waste generation, productivity, cost and the number and size of loading bays (Murphy et al. 2003). These in turn can affect the economics of the operations. A conceptual model of the economic effects of number of log sorts can be seen in Figure 1.

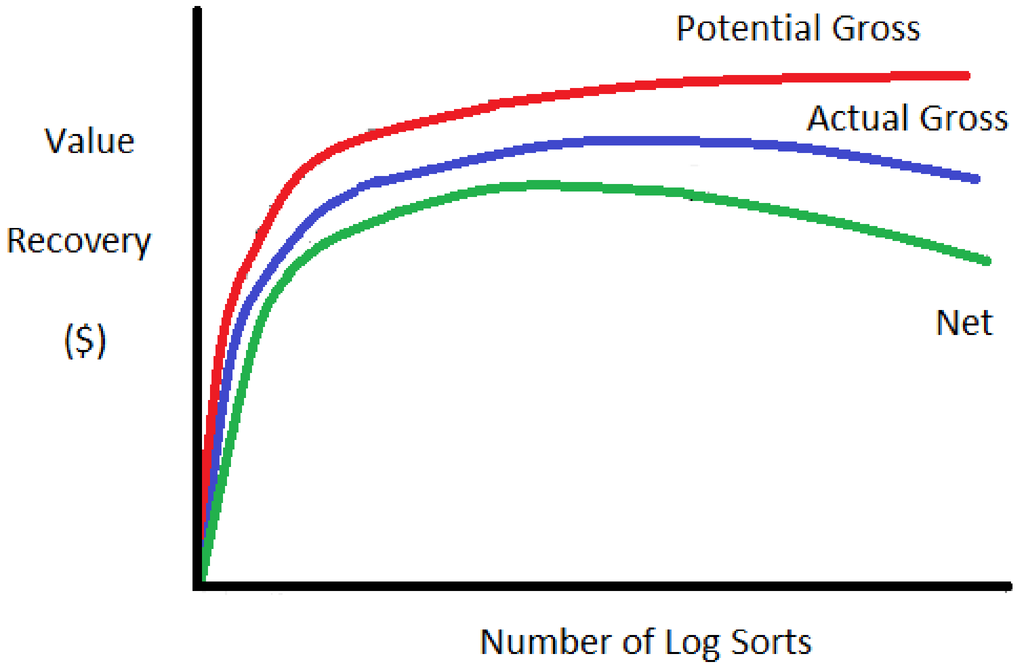

Figure 1: Conceptual model of the effect of number of log sorts on potential, actual and net value recovery. (Source: Murphy et al. 2003)

As the number of sorts increases (1) the theoretical or potential gross value recovery increases rapidly and then plateaus, (2) actual gross value recovery increases then decreases as machine operators have difficulty measuring stems accurately and making decisions on the best products to cut, (3) production costs increase for a variety of reasons, and (4) net value recovery at first increases and then decreases.

Adding a greater number of short log sorts to the production mix is likely to improve gross value recovery for the forest grower since it tends to be greater with short logs than long logs (unless there is a strong premium for long length logs). However, once the optimum number of logs sorts is reached, net value recovery may fall. "What is the optimum number of log sorts?", and "what is the optimum mix of log sorts?", are not clear in the research literature.

Blinn and Sinclair (1986) looked into the profitability of various timber-harvesting systems as affected by product sorting and stand parameters. They modelled the impact of three levels of sorting intensity (2, 5 and 6 log sorts) on productivity, costs and profitability of 13 stands in the north-eastern USA. They found that profitability generally increased with sorting intensity, indicating that the increased delivered product value of the expanded product mix exceeded the increase in production costs and the decrease in productivity. They also found, however, that the level of profitability was stand and harvesting system dependent. Their analyses did not include transportation and other handling costs.

Gingras and Favreau (2002) found that harvesting productivity decreased 1 to 4% per additional log sort for to cut-to-length (CTL) systems in Canada. This is higher than the 1% productivity decrease per additional log sort found in studies of CTL systems in Sweden (Brunberg and Arlinger 2001). Dems et al (2013) reported harvesting cost increases of 0.5% per additional log sort based on modelling and optimisation of a wood procurement in Eastern Canada.

Costs of handling logs are a function of average piece size and of variability in piece size (McNeel and Nelson 1991). The average piece size being handled is one of the key factors determining harvesting costs; if piece size is too low or too high for the system being used machine productivity falls and costs rise (Visser 2009).

Mousavi (2009) compared productivity and costs of short-log versus long-log hardwood supply chains in Northern Iran. Productivity of the processing, extraction, loading, trucking, and unloading activities were all lower with the short-log supply chain. Total costs were 6.7% greater with the short-log chain. Stem volumes were very high (1 to 20 m^3) compared with those in Tasmanian hardwood plantations. The harvesting system employed was also less mechanised (chainsaw felling and skidder extraction) than found in Tasmanian plantations.

Sawmilling productivity is lower and costs higher with short logs than long logs (Mischon and Smith 1964). Thunell (1984) shows a cost increase of 5.9% resulting from changing 6 m to 4 m log lengths in Sweden.

Waste wood produced from log-making, if left on site, can provide a breeding ground for insect and pathogen pests, can be a fire and debris slide risk, and may be perceived as unsightly and wasteful by the public (Brown and Daniel 1986). The inclusion of short logs in the marketing mix helps to reduce wood waste.

The study of time and motion is one of the most highly used research tools for evaluating the performance of various technical systems. Traditional time and motion methods, which are considered to be the backbone of forestry related production studies (Heinemann 2007) in many parts of the world, are based on manual approaches and require trained people to collect field data. Greater use is being made of digital data collected by harvesting machines (Strandgard et al. 2013, Olivera et al. 2016). A mix of traditional methods and on-board harvester computers provides a toolbox of data collection techniques.

The impacts of adding a novel product (such as biomass (Murphy et al. 2010)), changing the location of an operational activity (such as debarking in-forest (Murphy et al. 2017)), or expanding product specifications (such as wood properties or lengths (Murphy and Moore 2018)) can be addressed through the development of new models that extend along the supply chain. They can also be addressed through the use of existing models that address parts of the supply chain, the results of which can be combined in spreadsheet applications.

Productivity and costing models, such as ALPACA ("Australian Logging Productivity and Cost Analysis") and FASTTRUCK, which have been developed and maintained by University of the Sunshine Coast (USC), help to identify the most cost-effective harvesting and transport systems for given conditions (Brown et al 2011, Acuna et al. 2012). Value optimisation software, such as VALMAX, can be used to determine the potential value that can be obtained from alternative log mixes (Murphy 2014). Marine port facilities layout software, such as OPTILOGS, can be used to determine, among other things, the impact of short logs on storage capacity and handling costs on the wharf or in log yards (Murphy 2016).

In summary, a review of the literature identified suitable methods for answering the question "will the additional value and volume recovery generated from an increased mix of short logs from plantation forests outweigh any additional supply chain costs?" It did not, however, provide a direct answer that is applicable to the hardwood plantations of Tasmania.

METHODOLOGY

Treatments and site selection

The study design included three treatments replicated at three sites in *Eucalyptus nitens* plantations in northern Tasmania, each site to be harvested by CTL systems.

The three sites for the replication of treatments were selected by industry participants to be representative of:

- Unpruned, high-quality sites (UHQ)
- Unpruned, low-quality sites (ULQ)
- Pruned, high-quality sites (PHQ)

The UHQ and ULQ sites were harvested in late 2019. The harvest of the PHQ site was delayed by close to twelve months due to the COVID-19 pandemic and was not carried out until late 2020.

The three treatments were designated as Longs, Shorts and Mix. There slight differences between the two unpruned sites (UHQ and ULQ) and the pruned site (PHQ) due to differences in tree size and markets:

For the unpruned sites the treatments were as follows:

- Longs – long unpruned saw logs (5.2 or 6.0 m), long veneer logs (6.2 m), pulp logs (2.4 to 6.8 m random, 5.5 m preferred)
- Shorts – short unpruned saw logs (4.0 m), short veneer logs (3.7 m), pulp logs (2.4 to 6.8 m random, 5.5 m preferred)
- Mix – long (5.2 or 6.0 m) and short (4.0 m) unpruned saw logs, long (6.2 m) and short (3.7 m) veneer logs, pulp logs (2.4 to 6.8 m random, 5.5 m preferred).

No veneer logs were produced during the study period at the unpruned sites, however.

For the pruned site the treatments were:

- Longs – long pruned saw logs (6.2 m), long veneer logs (5.2 m), pulp logs (2.4 to 6.0 m random)
- Shorts – short pruned saw logs (3.7 m)[1], long veneer logs (5.2 m), pulp logs (2.4 to 6.0 m random)
- Mix – long (6.2 m) and short (3.7 m) pruned saw logs, long veneer logs (5.2 m), pulp logs (2.4 to 6.0 m random)

The three treatments were carried out on adjacent blocks at each site. Forest industry participants marked out sufficient area in each block to provide a minimum of 17 truckloads of harvest volume (giving a planned minimum total of 153 truckloads for the 9 blocks (3 treatments X 3 replications).

Figure 2. Saw log ends at the PHQ site were treated to reduce splitting. This required a significant time commitment on the part of the harvester and forwarder operators.

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[1] The order that the treatments was carried out at the PHQ site was Longs, then Shorts, and then Mix. While undertaking the trial for the Shorts treatment the forest owner noted a high degree of splitting of log ends in short sawlogs. This considerably reduced their value. The machine operator was asked to limit the number of short sawlogs produced. This request undoubtedly affected the number of short logs produced in both the Shorts Treatment and the Mix Treatment which followed it.

Harvesting and transport equipment

Equipment used at each site is shown in Table 1 and Figures 3 to 6.

Table 1. Equipment used in the Short Log Supply Chain project.

Site	Harvesting	Forwarding	Loading	Trucking
UHQ	Caterpillar 538 (122 kW) with Waratah HTH622B head	Komatsu 895 (210 kW, 20 t capacity)	Caterpillar 324D (126 kW)	mainly 3-bunk trailers
ULQ	Tigercat LH822D (210 kW) with Waratah HTH623C head	Ponsse Elephant King (210 kW, 20 t capacity)	Caterpillar 324D (126 kW)	mainly 2-bunk trailers
PHQ	Tigercat LH822D (210 kW) with Waratah HTH623C head	Ponsse Elephant King (210 kW, 20 t capacity	Komatsu 270 (140 kw)	mainly 2-bunk trailers

Figure 3: A Komatsu 895 forwarder and a Caterpillar 538 excavator with Waratah HTH622B harvesting head were used at the Unpruned High-Quality (UHQ) site.

Figure 4: A Tigercat LH22D harvester with Waratah HTH622B harvesting head and a Ponsse Elephant King forwarder were used at the Unpruned Low-Quality (ULQ) and Pruned High-Quality (PHQ) sites.

Figure 5: A Caterpillar 324D log loader loading a truck and 2-bunk trailer at the Unpruned Low-Quality (UHQ) site.

Figure 6: A Komatsu 270 log loader loading a truck and 2-bunk trailer at the Pruned High-Quality (PHQ) site.

Data collection and analysis

Stand data

Each of the unpruned sites was cruised using the Silmetra Plotsafe overlapping feature method (Figure 7). The method entailed establishing 10 fixed-size bounded plots throughout the stand. All trees within each plot were measured at breast height (1.3 m) for diameter over bark and at least three trees were also measured for height in each plot.

When cruising, an alphanumeric code was used to record stem quality (such as branching or straightness), while heights were recorded for the positions on the stem where quality changes occurred. Other features of each tree which affect log grades, such as forks, diameter reductions, dead and broken tops, were also recorded. Table 2 shows the stem quality codes used in the Plotsafe cruising procedure.

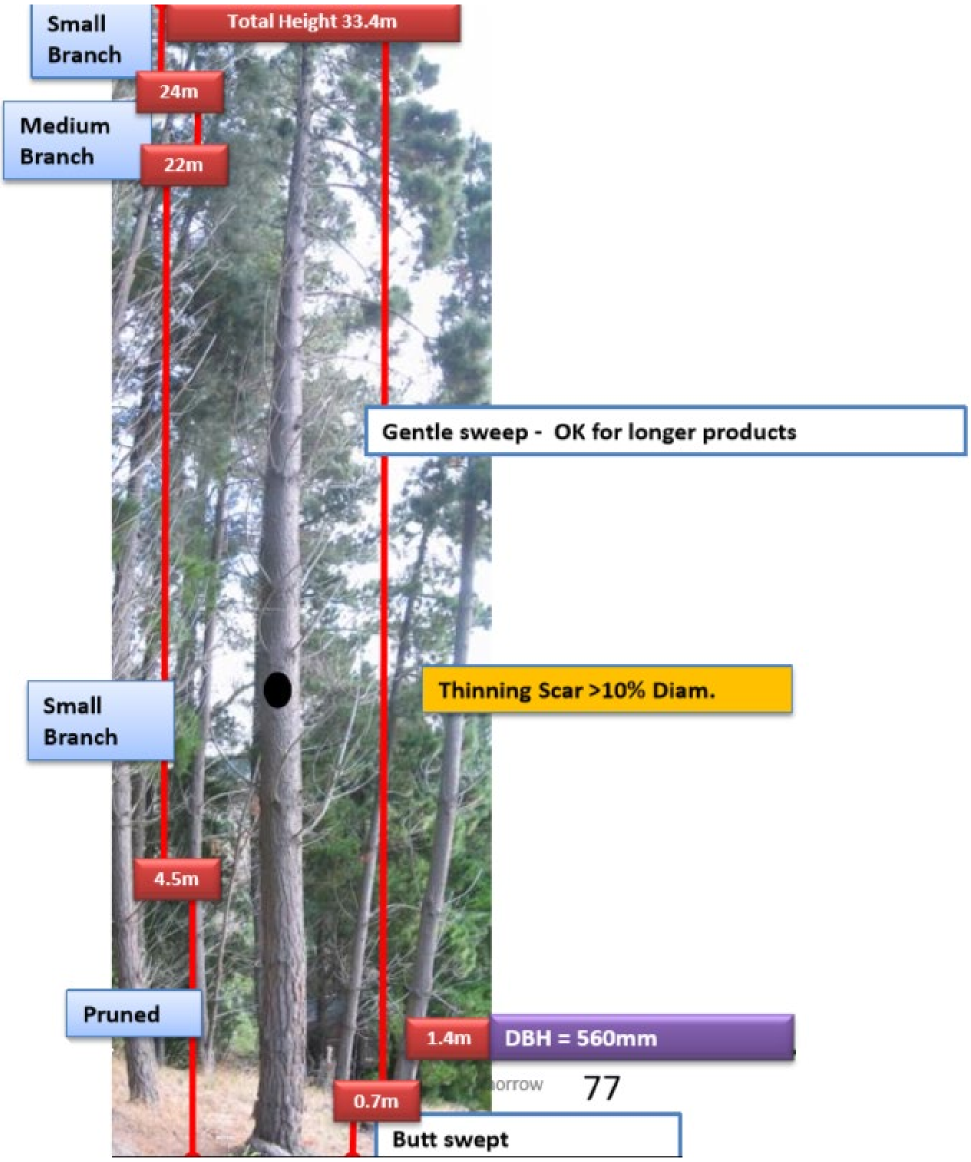

Figure 7: Example of describing stems using the Plotsafe overlapping feature method. (Photo: courtesy of Interpine Ltd.)

Table 2. Plotsafe cruising dictionary used in the Short Log Supply Chain project.

Code	Description	Code	Description
Sweep (S)		Features (F)	
SL	Sweep less than or = SED/4 over 6.2 m	C	Crutch
S4	Sweep less than or = SED/4 over 2.4 m	D	Damage/Scar > 10% depth
S3	Sweep less than or = SED/3 over 2.4 m	F5+	Fluting > 5cm
S1	Sweep less than or = SED/1 over 2.4 m	N7	Nodal swelling > 7 cm
SX	Sweep greater than SED/1	O1.2	Ovality, longest diameter > 1.2X shortest diameter
SK	Kink (max distance 0.5 m)	O2+	Ovality, longest diameter > 2X shortest diameter
SW	Wobble greater than 5 cm over 2.4 m	R	Rot
		T	Dead
Internode (I)		Branching (Br)	
I3+	More than 3 branch whorls per 1 m	Br0	Pruned or completely clear
		Br5	Branches less than or = to 5 cm
		Br7	Branches less than or = to 7 cm
		Br10	Branches less than or = to 10 cm
		Br99	Branches greater than 10 cm

Petersen height equations were developed for each unpruned site and used to predict heights of trees that did not have heights measured. Volume per hectare was calculated for each plot using a proprietary taper function.

The method used at the pruned site (PHQ) was similar to that used at the unpruned sites except for the following; (1) simple alphabetic codes, which combined a number of stem features (e.g., sweep, branch size, and rot), were used to record stem quality (Figure 7), and (2) volume per hectare was calculated using a publicly available taper function (Kozak-Eerikäinen model as described in Thompson and Goodwin, in prep.).

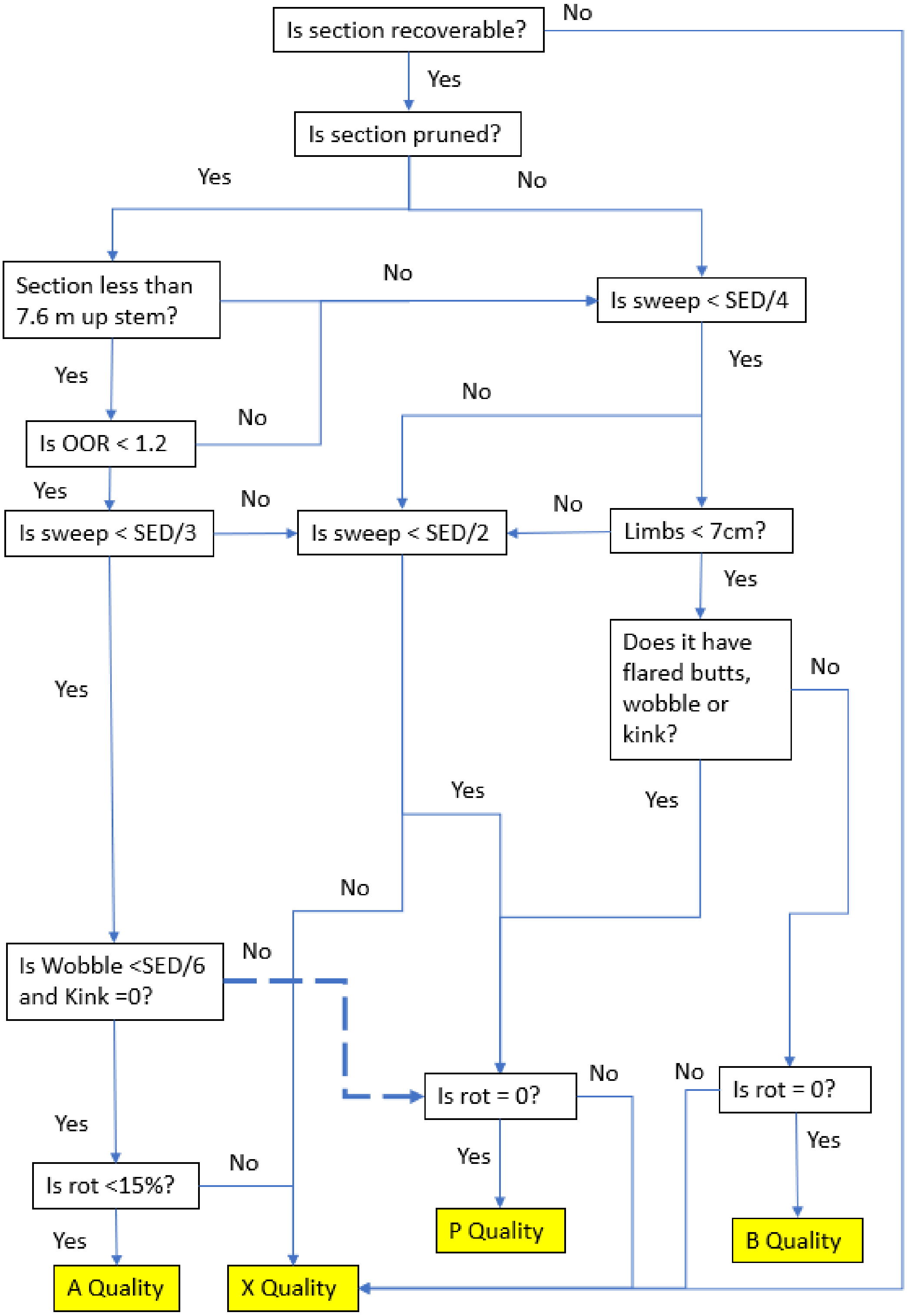

Figure 7: Decision tree used to determine qualities on stems when inventory cruising at the PHQ site.

Time and motion data

Times and volume data were collected for harvesting activities (at least 225 trees), forwarding activities (at least 17 forwarder loads), and loading, unloading and transport activities (at least 17 truckloads) for each treatment at each site. Times and volumes were used to calculate hourly productivity first on a delay-free productive machine hour basis (PMH), and then on a scheduled machine hour basis (SMH) which included expected short-term and long-term delays.

Harvesting

Harvesting times were broken down into the following time elements:

- Productive time:
  - Clear brush
  - Felling
  - Processing
  - Moving between trees
  - Moving piles of logs
  - Travelling
- Delays:
  - Operational delays
  - Personal delays
  - Mechanical delays

Times were recorded to the nearest second on an electronic tablet and converted to centiminutes. A record was kept for each stem felled of its condition (live or dead), and the number logs from the stem by grade and length class.

Samples of logs, by grade and length class, were collected at the end of each study day so that representative average log volumes could be determined. Measurements of small and large end diameters and log lengths were gathered. The total number of logs measured were 418, 345, and 486 at the UHQ, ULQ, and PHQ sites, respectively.

Forwarding

Forwarding times were broken down into the following time elements:

- Productive time:
  - Clearing debris
  - Travel empty
  - Loading
  - Travelling while loading
  - Travel loaded
  - Unloading
  - Travelling
- Delays:
  - Operational delays
  - Personal delays
  - Mechanical delays

Times were recorded to the nearest second on an electronic tablet and converted to centiminutes. A record was kept for each forwarder load of the grade and length class, the number of loading grabs, and the number logs loaded. A GPS data logger was fitted to the forwarder to record travel distances. A range finder was also used to gather estimates of travel distance.

Forwarder load sizes were determined by multiplying number of logs loaded by the average log size for the type of log loaded.

Loading, Trucking, and Unloading

A form was developed that allowed collection of times for loading, trucking and unloading activities. The form was filled out by the truck driver. The following information was collected from the form:

Truck ID
Driver's name
Date
Load docket number
Study treatment (Longs, Shorts, Mix)
Log grade and length class
Arrival time in forest
Number of trucks waiting to be loaded or being loaded
Odometer reading in forest
Start loading time
End loading time
Number of bunks loaded
Departure time from forest
Arrival time at mill
Number of trucks waiting to be unloaded or being unloaded
Odometer reading at mill
Start unloading time
End unloading time
Departure time from mill
Delay times and comments

The data collected allowed calculation of pre-loading and waiting times in forest, loading times, post-loading times, travel times to and from the mill, travel distances, pre-unloading and waiting times at mill, unloading times, post-unloading times, and delay times.

Almost half of the trucking forms were either not completed or were lost at the PHQ site. Fortunately, an electronic recording system fitted to most trucks allowed the data gaps to be filled albeit at a coarser level with respect to times. Waiting times and delays were lumped in with the loading and unloading time elements. Total average round trip times, based on completed forms, was within 0.5% of total average round trip times based on electronic data.

Truck net payloads (tonnes) for the unpruned sites were determined from the docket numbers and converted to cubic volume (m^3) based on an average conversion factor supplied by the forest industry participant. Some loads were weight scaled and some were volume scaled at the pruned site. Similar to the unpruned sites, all loads from the pruned site were converted to cubic volume based on an average conversion factor supplied by the forest industry participant.

Gross revenue data

Log specifications and indicative prices at mill gate or wharf gate were supplied by the forest industry participants for the log grades and length classes produced at the UHQ and ULQ sites and at the PHQ site. The same specifications and prices were used at both unpruned sites. Different prices and specifications were used at the pruned site.

Two measures of gross revenue data were calculated, one based on inventory data and one based on actual harvest data.

Inventory-based gross revenues ($ per ha) were determined using VALMAX and the prices supplied by the forest industry participants. Plotsafe stand data was converted to a format that is compatible with VALMAX optimal log bucking software. This format included information on predicted under-bark stem diameter and stem quality at decimetre increments up each stem. VALMAX determined the optimal bucking pattern, that maximized value, for each individual stem in each plot based on the log specifications and prices provided by the user. It then calculated the total value, total volume, and volume for each grade and length class on a per hectare basis for the plot. It also provided a predicted log count by grade and length class.

Actual gross revenues were based on study estimates of yield percentages, by grade and length class, multiplied by prices supplied by the forest industry participants, multiplied by inventory predictions of total volume per hectare. Revenues for short saw logs at the PHQ site were reduced to pulp log values in our analyses because of a high incidence of end splitting and capping (D. Williams, pers. comm.)

Cost data

Standard costing procedures, similar to those used in the ALPACA model and expert opinion of industry participants were used to derive hourly machine and system costs for the stump-to-on-truck activities. Key assumptions used in the costings of the harvesters, forwarders and loaders are provided in Table 3. Trucking costs were calculated using a web-based calculator (http://www.freightmetrics.com.au/Calculators/TruckOperatingCostCalculator/tabid/104/Default.aspx) for SKEL single and SKEL B-double configurations. Key assumptions used in the truck costings are provided in Table 4.

Table 3. Key cost calculation assumptions used for harvesting, forwarding and loading activities

Variable	Harvester	Forwarder	Loader
Purchase price ($)	700,000	650,000	425,000
Operating days per year	235	235	235
Shifts per day	1	1	1
Scheduled hours per shift	10	10	11
Utilisation rate (%)	75	75	75
Machine life (years)	5	6	5
Salvage value (% of purchase price)	20	20	20
Repairs and Maintenance (% of depreciation)	75	75	65
Interest rate (% of average yearly investment)	9	9	9
Insurance and tax rate (% of average yearly investment)	6	6	6
Fuel cost per litre less rebates ($)	0.98	0.98	0.98
Oil & lubricant (% of fuel cost)	50	20	20
Labour cost ($ per SMH)	46.50	37.50	30.00
Supervision (% of Labour costs)	10	10	10
Overheads (% of total costs)	11	11	11
Margin for risk and profit (% of grand total costs)	9	9	9
Calculated hourly costs ($ per SMH)	226	198	135

Table 4. Key cost calculation assumptions used for trucking activities

Variable	Semi (2-bunk)	B-Double (3-bunk)
Purchase price ($)	356,000	455,000
Operating days per year	235	235
Shifts per day	1	1
Hours per shift	11	11
Utilisation rate (%)	85	85
Machine life (years)	5 tractor, 10 trailer	5 tractor, 10 trailer
Salvage value (% of purchase price)	20 tractor, 10 trailer	20 tractor, 10 trailer
Repairs and Maintenance ($/km)	0.135	0.156
Interest rate (% of average yearly investment)	9.5	9.5
Insurance rate (% of purchase price)	3.5	3.5
Truck and trailer registration ($/day)	28.50	64.21
Fuel cost per litre less rebates ($)	0.98	0.98
Tyres ($/km)	0.103	0.155
Labour cost ($ per SMH)	28.84	28.84
Overheads* ($/day)	147	147
Margin for risk and profit (% of grand total costs)	10	10
Calculated hourly costs ($ per SMH)	142	152

* overhead costs assumed to be spread across 2 vehicles.

Port and mill yard data

Data was not collected on either mill yard or port log handling activities. The first author of this report (Glen Murphy) has, however, developed for a New Zealand log marshalling company a facilities layout and planning model (OPTILOGS) that, among other things, can be used to evaluate the impacts of log length on log storage capacity and log handling costs. The OPTILOGS model is based on productivity and cost data gathered at seven ports around New Zealand. Model verification and validation was carried out with the assistance of operations managers from the log marshalling company.

OPTILOGS was used to evaluate the impact of different levels of short log percentages at a fictitious log handling facility (MyPort) on log handling costs. MyPort is described in detail in Murphy (2016). MyPort is 4.75 ha in area; which is about 30% smaller than the logyard at Heybridge in Northern Tasmania and about 40% larger than the log storage area at the Port of Burnie.

Underlying productivity numbers and costs within the OPTILOGS model are proprietary to the log marshalling company that funded its development. Only relative cost changes will be presented in the results section.

Data analysis and modelling

All collected time and motion data were input into Excel spreadsheets. Pivot tables were used to calculate average values for element times, log volumes, truck payloads, etc. Excel's statistical package was used to develop regression models where appropriate. Productivity values (m^3 per SMH) were calculated for each activity (harvesting, forwarding, loading and trucking) at each site.

Inventory plot data was input into Excel spreadsheets and summarised at a site level. Calculated average tree volumes based on inventory data were compared for each site with average tree volumes based on grade-weighted average measured log volumes and log counts. This resulted in a significant under-estimate of stem size at one of the unpruned sites and an under-estimate at the other unpruned site. Some plots were excluded from the final analyses to better match stem size measured at the time of harvesting for these sites. Estimated stem size (3.72 m^3) closely matched actual stem size (3.88 m^3) at the pruned site so all plots were used in the analysis for this trial.

A simple system economics model was constructed in Excel that allowed the calculation of gross revenues, costs (harvesting, forwarding, loading and trucking), and net revenues for each site for each treatment. A "cold deck" costing approach was used, whereby it was assumed that productivity (and unit costs) of each activity is independent of the productivity of the other activities. Two sets of analyses were evaluated using the model; one based on inventory predictions of log yields, and one based on actual log yields[2, 3].

RESULTS

Stand details

Stand details, based on 10 to 15 plots measured at each site, are presented in Table 5. The table also includes the stand details based on the plots selected in the unpruned sites to best match inventory-predicted stem size with actual stem size.

Table 5. Stand details for the UHQ, ULQ and PHQ study sites

Site	Basis*	Number of plots	Live stocking (spha)	Mean DBH (mm)	Mean tree height (m)	Live volume (m^3 ha^{-1})	Live volume standard error (m^3 ha^{-1})	Average stem size (m^3)
UHQ	All	10	855	241	31.7	470.5	19.1	0.550
	Matching	8	794	251	31.7	481.9	21.3	0.607
ULQ	All	10	697	229	25.0	265.0	14.2	0.380
	Matching	3	556	259	25.0	287.7	20.4	0.504
PHQ	All	15	171	557	42.1	636.6	30.4	3.722

* "All" means all plots included. "Matching" means those plots which are included best match actual stem size.

Average stocking, live tree volume, tree height and average stem size were higher at the UHQ site than at the ULQ site. Mean DBH was slightly smaller at the UHQ site. Stocking at the PHQ was considerably lower than those at the unpruned sites. Volume per hectare and tree size at the PHQ site were much larger than those at the unpruned sites.

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[2] It should be noted that all logs from the UHQ and ULQ sites, including saw logs, were sent to a single facility. The harvester operator knew that some of the saw logs would end up being chipped. It was evident during the study that some "saw logs" cut would be unlikely to meet stringent sweep specifications. For trial purposes this was accepted since it resulted in more saw log handling productivity data than would otherwise have been gathered.

[3] Actual log yield percentages were based on truck delivery data for the PHQ site and harvester data for the UHQ and ULQ sites; missing truck volumes and recording of log grades made truck data an unreliable for determination of log yield percentages at the unpruned sites.

Harvester times, volumes and productivity

Average logs sizes are presented in Tables 6.

Table 6. Average log sizes, volume (m^3) and length (m), for the UHQ, ULQ and PHQ study sites

Site	Variable	Long Saw	Sample size	Short Saw	Sample size	Long Veneer	Sample size	Pulp Logs	Sample size
UHQ	Volume	0.379	105	0.218	128	-	-	0.122	185
	Length	6.01		4.00		-		5.41	
ULQ	Volume	0.347	90	0.250	105	-	-	0.133	150
	Length	6.01		4.02		-		5.77	
PHQ	Volume	1.404	158	0.808	158	0.724	83	0.540	87
	Length	5.21		3.70		5.27		5.21	

Elemental times, volumes and productivities for harvesting activities are presented in Tables 7 and 8.

Some brief comments are provided below.

- Felling and processing activities combined occupied about 80% and 65% to 70% of delay free harvesting time per stem at the unpruned sites and pruned site, respectively.
- Average felling times at the PHQ site were 120% to 150% larger than those at the ULQ and UHQ sites respectively. The differences were mainly associated with larger average tree size at the PHQ site.
- Average processing times per stem at the ULQ site were about 9% lower than those at the UHQ site. This was largely due to fewer logs being cut per stem at the ULQ site (3.23) than at the UHQ site (3.97). Trees were close to 7 m shorter at the ULQ site than at the UHQ site.
- Average processing times per stem at the PHQ site were 215 to 245% than those at the UHQ and ULQ sites respectively. More logs per stem were cut at the PHQ site (5.97) from the longer and larger trees.
- At both unpruned sites the greatest processing times per log were for the Longs treatment and the least processing times were for the Shorts treatment. The Mix treatment processing times were between those of the Longs and Shorts treatments. At the pruned site the greatest processing times per log were for the Mix treatment. There was little difference between the Longs and Shorts treatment.
- The Clear Brush Limbs and Tops element took close to five times longer per stem at the ULQ site than at the UHQ site. Similarly, this element was over seven times greater per stem at the PHQ than at the UHQ site. The reason for these differences is unknown although it may have been due to the lower stockings at the PHQ and ULQ sites resulting in heavier crowns or more undergrowth brush.
- The Move Between Trees element was over two times greater at the ULQ site (0.065 minutes per stem) than at the UHQ site (0.029 minutes per stem). This is likely to be due to the lower stocking at the ULQ site. This element was much larger for the PHQ site (1.335 minutes per stem) than for both of the unpruned sites.

Calculated harvester productivities were 7 to 14% lower for the Mix treatments than for the Longs treatment for all three sites. Productivities were 6% higher for the ULQ site and 4% to 6% lower for the UHQ and PHQ sites for the Shorts treatments than for the Longs treatments.

Table 7. Elemental harvester times and volumes for the UHQ and ULQ study sites

Variable	UHQ Site			ULQ Site		
	Longs	Shorts	Mix	Longs	Shorts	Mix
Times (minutes per stem)						
Clear brush	0.051	0.043	0.045	0.348	0.130	0.232
Felling	0.334	0.302	0.350	0.363	0.380	0.377
Processing: Short saw logs	0.000	0.391	0.182	0.000	0.332	0.294
Processing: Long saw logs	0.266	0.000	0.240	0.298	0.000	0.078
Processing: pulp logs	0.663	0.433	0.613	0.499	0.447	0.529
Moving between trees	0.022	0.033	0.033	0.078	0.043	0.073
Moving log piles	0.012	0.006	0.005	0.032	0.012	0.019
Travelling	0.010	0.000	0.000	0.018	0.011	0.000
Total delay free time	1.439	1.473	1.616	1.637	1.354	1.603
Operational delays	0.004	0.207	0.056	0.011	0.050	0.040
Personal delays	0.062	0.020	0.017	0.161	0.118	0.135
Mechanical delays	0.016	0.038	0.075	0.021	0.000	0.155
Stems, log counts, log volumes (m^3), average stem size (m^3), and productivity (m^3 per SMH)						
Stems	428	460	396	400	423	391
Short saw logs per stem	0.000	0.737	0.652	0.000	0.991	0.760
Long saw logs per stem	0.643	0.000	0.553	0.668	0.000	0.182
Pulp logs per stem	3.278	2.857	3.199	2.328	2.135	2.632
Total logs per stem	3.921	3.593	4.404	2.995	3.125	3.573
Short log volume per stem	0.000	0.161	0.142	0.000	0.248	0.190
Long log volume per stem	0.244	0.000	0.210	0.232	0.000	0.063
Pulp log volume per stem	0.400	0.348	0.390	0.309	0.284	0.350
Average stem size	0.643	0.509	0.742	0.541	0.532	0.603
Productivity (m^3/SMH)**	19.6	18.8	16.8	14.0*	14.8*	12.5*

* An average time of 0.237 minutes per stem for the Clear Brush activity was applied to all treatments for the ULQ site since there was no obvious reason for such large differences between treatments. Productivities were adjusted accordingly.

** A machine utilisation factor of 75% was used to convert delay-free productivity (m^3/PMH) to long term expected productivity which includes delays (m^3/SMH).

Table 8. Elemental harvester times and volumes for the PHQ study site

Variable	PHQ Site		
	Longs	Shorts	Mix
Times (minutes per stem)			
Clear brush	0.581	0.307	0.130
Felling	0.760	0.869	0.862
Processing: Short saw logs	0.000	0.788	0.249
Processing: Long saw logs	0.568	0.000	0.583
Processing Veneer logs	0.424	0.552	0.614
Processing: pulp logs	1.583	1.865	1.507
Moving between trees	1.176	1.326	1.503
Total delay free time	5.091	5.707	5.450
Operational delays	0.556	1.403	2.445
Personal delays	0.975	0.814	0.752
Mechanical delays	0.252	0.068	0.272
Stems, log counts, log volumes (m^3), average stem size (m^3), and productivity (m^3 per SMH)			
Stems	375	226	409
Short saw logs per stem	0.000	1.049	0.240
Long saw logs per stem	0.731	0.000	0.611
Long veneer logs per stem	0.901	0.850	0.826
Pulp logs per stem	3.909	4.788	3.998
Total logs per stem	5.541	6.686	5.675
Short log volume per stem	0.000	0.847	0.194
Long log volume per stem	1.026	0.000	0.858
Veneer log volume per stem	0.653	0.615	0.598
Pulp log volume per stem	2.111	2.585	2.159
Average stem size	3.789	4.048	3.809
Productivity (m^3/SMH)**	29.1*	27.6*	27.2*

* Average times per stem for the Clear Brush, Felling and Moving activities, based on all three treatments, were applied to all treatments for the PHQ site since there were no obvious reasons for differences between treatments for these activities. Productivities were adjusted accordingly.

** A machine utilisation factor of 65% was used to convert delay-free productivity (m^3/PMH) to long term expected productivity which includes delays (m^3/SMH). A lower utilisation factor was used at the PHQ site than at the UHQ and ULQ sites due to the larger amount of time Operational Delay time associated with treating log ends to reduce splitting.

Forwarder times, volumes and productivity

Elemental times, volumes and productivities for forwarding activities are presented in Tables 9 and 10 for the unpruned sites and the pruned site, respectively.

Table 9. Elemental forwarder times and volumes for the UHQ and ULQ study sites

Variable	UHQ Site			ULQ Site		
	Longs	Shorts	Mix	Longs	Shorts	Mix
Times (minutes per forwarder load)						
Clear brush	0.450	0.410	0.214	0.193	0.121	0.000
Travel empty	2.606	1.600	3.503	1.784	2.695	1.902
Loading	14.774	14.203	17.065	13.798	16.568	13.788
Travel while loading	1.074	1.082	1.670	2.120	2.032	2.219
Travel loaded	3.638	2.485	6.130	2.812	2.931	2.359
Unloading	7.037	7.233	8.159	9.020	9.736	7.412
Total delay free time	29.579	27.013	36.741	29.727	34.083	27.681
Operational delays	0.397	0.480	0.116	0.000	0.094	0.000
Personal delays	0.328	0.039	0.221	0.837	0.406	1.011
Mechanical delays	0.000	0.000	0.000	0.000	0.000	0.000
Loads, travel distances (m), load volumes (m^3) and productivity (m^3 per SMH)						
Loads	16	11	18	15	16	17
Travel empty distance	123	95	182	95	136	105
Travel loaded distance	142	111	213	105	121	86
Volume per short saw load	0.00	16.09	18.36	0.000	18.08	20.68
Volume per long saw load	26.80	0.00	24.90	23.73	0.000	20.20
Volume per pulp load	22.07	20.41	23.41	19.94	22.36	21.68
Average load volume	24.96	18.18	22.87	22.30	19.47	20.98
Productivity (m^3/SMH) *	36.4	26.9	30.1	30.7	24.2	30.4

* Average distances of 145 and 150 m have been assumed for the travel empty and travel loaded activities, respectively. A delay-free machine utilisation factor of 75% has also been assumed.

Some brief comments are also provided below.

- Loading and unloading activities occupied 70% to 80% of delay-free cycle time for the unpruned sites and 55% to 65% for the pruned site.
- Longer travel distances at the pruned site occupied a greater proportion of delay free cycle time than at the unpruned sites.
- At all sites, average forwarder load volumes, weighted by the log yield percentages determined from the harvester study, varied by treatment. Load volumes were greatest for the Longs treatment, in between for the Mix treatment, and lowest for the Shorts treatment.
- Issues with the GPS datalogger at the unpruned sites meant that measured travel distances could only be classed as indicative at the individual cycle level. Distances were, therefore, averaged for each treatment, giving only six data points, and plotted against travel time. More reliable travel distance data at the pruned site allowed development of regressions based on individual cycles. The following regressions were obtained for Travel Empty (TE) and Travel Loaded (TL) times.
    - TE UHQ and ULQ (minutes) = 0.021*Distance – 0.252 (R^2 = 0.96, n = 6)
    - TL UHQ and ULQ (minutes) = 0.031*Distance -0.631 (R^2 = 0.97, n = 6)

- TE PHQ (minutes) = 0.008*Distance + 1.990 ($R^2 = 0.26$, n = 118)
- TE PHQ (minutes) = 0.011*Distance + 2.731 ($R^2 = 0.50$, n = 121)

Calculated forwarder productivities were greatest for the Longs treatment at all three sites. Productivities for the Mix treatment were intermediate between Longs and Shorts treatments at both unpruned sites, but lowest of all treatments at the pruned site. Productivities were about 10% and 33% higher, on average, at the UHQ and PHQ sites, respectively, than at the ULQ site.

Table 10. Elemental forwarder times and volumes for the PHQ study site

Variable	PHQ Site		
	Longs	Shorts	Mix
Times (minutes per forwarder load)			
Clear brush	0.137	0.029	0.000
Travel empty	3.328	4.208	4.198
Loading	10.617	10.278	11.257
Travel while loading	1.588	3.465	2.521
Travel loaded	5.613	6.084	6.150
Unloading	8.747	8.465	9.515
Total delay free time	30.030	32.529	33.641
Operational delays	11.682	15.077	22.287
Personal delays	5.372	6.394	6.489
Mechanical delays	5.686	0.557	0.666
Loads, travel distances (m), load volumes (m^3) and productivity (m^3 per SMH)			
Loads	47	29	52
Travel empty distance	172	271	306
Travel loaded distance	195	342	298
Volume per short saw log load	0.00	21.33	18.18
Volume per long saw log load	27.80	0.00	31.17
Volume per veneer log load	26.86	26.72	28.89
Volume per pulp load	32.83	34.83	33.86
Average load volume	31.18	30.04	30.43
Productivity (m^3/SMH) *	38.5	38.0	36.1

* Average distances of 245 and 270 m have been assumed for the travel empty and travel loaded activities, respectively. A delay-free machine utilisation factor of 65% has also been assumed.

Loading times, volumes and productivity

Elemental times, weights and productivities for loading activities are presented in Tables 11 and 12 for the unpruned sites and the pruned site, respectively.

Table 11. Elemental loading times and volumes for the UHQ and ULQ study sites

Variable	UHQ Site			ULQ Site		
	Longs	Shorts	Mix	Longs	Shorts	Mix
Times (minutes per truck load)						
Pre-loading	2.18	4.57	5.18	6.09	8.17	7.58
Loading time	32.02	34.77	34.34	22.95	24.05	24.76
Post-loading	6.55	5.55	6.32	6.63	6.91	7.07
Total load time	40.75	44.89	45.84	35.67	39.13	39.41
Loads, load weights (t) and productivity (t per SMH)						
Loads	16	18	23	24	21	17
Net weight per short saw log load	0.00	34.77	-	0.000	30.29	30.35
Net weight per long saw log load	31.95	0.00	29.70	31.59	0.000	31.70
Net weight per pulp load	37.94	37.87	37.59	30.58	30.91	30.95
Average load weight	37.19	36.83	36.38	31.07	30.66	30.78
Productivity (t/SMH)	43.6	39.2	38.0	41.7	37.5	37.4
Productivity (m^3/SMH) *	42.3	38.0	36.8	40.4	36.4	36.2

* Based on a 1.03 t/m^3 conversion factor

Some brief comments are also provided below.

- Average total load times varied between 35 and 46 minutes.
- Pre-loading and post-loading activities accounted for a quarter to a third of this time at the unpruned sites. The time for these activities could not be determined at the pruned site.
- Average load weights were greater at the UHQ site where 3-bunk trailers were predominantly (92%) used, than at the ULQ and PHQ sites where 2-bunk trailers were predominantly used (78% and 86%, respectively).

Loading productivity was higher at the UHQ site than at the ULQ and PHQ sites. At both unpruned sites loading productivity was 10% to 13% lower with the Mix treatment than the Longs treatment. At the pruned site, however, loading productivity was higher for the Mix treatment than for the Longs treatment, primarily due to faster total loading times. The reason for the faster loading times is unknown.

Table 12. **Elemental loading times and volumes for the PHQ study site**

Variable	PHQ Site		
	Longs	Shorts	Mix
Times (minutes per truck load)			
Pre-loading*	-	-	-
Loading time	44.90	40.17	37.00
Post-loading*	-	-	-
Total load time	44.90	40.17	37.00
Loads, load volumes (t) and productivity (t per SMH)			
Loads	45	24	40
Weight per short log load	0.00	33.04	32.19
Weight per long log load	30.17	0.00	27.28
Weight per veneer log load	30.42	31.30	26.46
Weight per pulp log load	30.35	31.74	29.71
Average load weight	30.31	31.80	29.08
Productivity (t/SMH) *	33.3	35.7	31.5
Productivity (m^3/SMH) **	30.2	32.5	28.6

* Pre-loading and Post-loading times were unable to be determined from the loading forms for the PHQ study.

** Based on a 1.1 t/m^3 conversion factor and a machine utilisation factor of 75%.

Trucking times, weights and productivity

Elemental times for trucking activities are presented in Table 13. There is no distinction between treatments for the times shown in Table 13. In Tables 14 and 15, the effect of different treatments is enumerated in line with the relative proportions of log grades delivered.

Table 13. Elemental trucking times for the UHQ, ULQ and PHQ study sites

Variable	UHQ Site	ULQ Site	PHQ site
Times (minutes per truck load)			
Travel to forest	14.28	31.34	59.72
Pre-loading*	5.30	11.77	-
Loading short saw logs	-	38.73	53.00
Loading long saw logs	30.00	24.08	49.67
Loading veneer logs	-	-	36.36
Loading pulp logs	25.10	23.29	38.69
Post-loading**	7.64	6.83	-
Travel to mill	12.89	34.76	69.12
Pre-unloading***	18.18	15.38	-
Unloading short saw logs	17.67	20.40	51.13
Unloading long saw logs	23.50	14.75	42.53
Unloading veneer logs	-	-	40.64
Unloading pulp logs	5.27	6.00	34.96
Post-unloading***	11.29	10.33	-
Number of loads and distances (km)			
Number of loads	54	62	109
Travel empty distance	12.0	27.9	62.0
Travel loaded distance	8.4	24.3	64.4

* Includes time waiting for other trucks to be loaded. On average 0.14, 0.29 and 0.19 trucks were waiting to be loaded at the UHQ, ULQ and PHQ sites, respectively. Insufficient data was recorded at the PHQ site to report times for this activity.

** Includes time waiting for other trucks to be unloaded. On average 2.58, 1.43, and 1.41 trucks were waiting to be unloaded at the UHQ, ULQ and PHQ sites, respectively. Insufficient data was recorded at the PHQ site to report times for this activity.

*** Insufficient data was recorded at the PHQ site to report times for these activities.

- Unloading times for saw logs from both unpruned sites were considerably higher than they were for pulp logs. This was because the saw logs were unloaded with a smaller machine. Under normal operations it would be expected that a large machine would be used to unload saw logs and loading times would be less than shown.
- Unloading times for sawlogs at the pruned site were also higher than they were for sawlogs or for veneer logs.
- Differences between sites were partially due to the predominance of 3-bunk trailers or 2-bunk trailers that were used to deliver wood to the mill.
- Average return trip travel times ranged between 27 and 129 minutes. Not unexpectedly, distance from the forest to the mill was the major factor affecting travel times.

Table 14. Calculation of trucking productivity for the UHQ and ULQ study sites for an assumed one-way travel distance of 80 km

Variable	UHQ Site			ULQ Site		
	Longs	Shorts	Mix	Longs	Shorts	Mix
Times (minutes per truck load)						
Travel to forest @ 75 kph	64.00	64.00	64.00	64.00	64.00	64.00
Pre-load, Load, Post-load	49.61	46.31	49.49	42.23	49.15	46.34
Travel to mill @ 65kph	73.85	73.85	73.85	73.85	73.85	73.85
Pre-unload, Unload, Post-unload*	33.54	33.35	33.82	31.70	31.70	31.70
Minor delays	1.28	1.28	1.28	5.74	5.74	5.74
Total time	222.57	219.09	222.73	217.52	224.43	221.62
Average load weights (t) and productivity (t per SMH)						
Average load weight	37.19	36.83	36.38	31.07	30.66	30.78
Productivity (t/SMH)	9.26	9.31	8.79	7.91	7.57	7.69
Productivity (m^3/SMH)	8.99	9.04	9.05	7.68	7.35	7.47

* Assumes that unloading of saw logs is carried out by a large machine, similar to what was used for unloading pulp logs in the study.

Table 15. Calculation of trucking productivity for the PHQ study site for an assumed one-way travel distance of 80 km

Variable	PHQ Site		
	Longs	Shorts	Mix
Times (minutes per truck load)			
Travel to forest @ 75 kph	64.00	64.00	64.00
Pre-load, Load, Post-load	41.42	40.05	41.77
Travel to mill @ 65kph	73.85	73.85	73.85
Pre-unload, Unload, Post-unload*	38.27	38.85	38.96
Minor delays	-	-	-
Total time	217.53	216.75	218.58
Average load weights (t) and productivity (t per SMH)			
Average load weight	30.31	31.80	29.08
Productivity (t/SMH)	8.36	8.80	7.98
Productivity (m^3/SMH)	7.60	8.00	7.25

Calculated trucking productivities from the PHQ and UHQ sites were larger than from the ULQ site. This was largely due to the bigger truck payloads resulting from using more 3-bunk trailers at the UHQ site than the ULQ site. Differences in calculated productivity between treatments were less than 5% for the unpruned sites and 10% for the pruned site.

Grade yields and gross revenues

Grade yields, based on VALMAX inventory assessments and actual study measurements, are presented in Table 16. Note that load weights for some truck trips were missing or unable to be allocated with confidence to the correct treatment for the unpruned sites. Best estimates of actual grade percentages are, therefore, based on the recorded harvester yields for unpruned sites.

Table 16. Grade yields and gross revenues for the UHQ, ULQ and PHQ study sites

Assessment method	Log grade*	UHQ Site			ULQ Site			PHQ Site		
		Longs	Shorts	Mix	Longs	Shorts	Mix	Longs	Shorts	Mix
Grade yields (%) of merchantable volume										
VALMAX inventory	S	0	29	29	0	24	20	0	19	2
	L	4	0	0	4	0	4	27	0	27
	V	0	0	0	0	0	0	11	17	10
	P	96	71	71	96	76	76	62	64	62
Actual	S	0	32	19	0	47	31	0	14	11
	L	38	0	28	43	0	11	29	0	17
	V	0	0	0	0	0	0	20	28	16
	P	62	68	53	57	53	58	51	58	56
Gross revenue ($ per ha) **										
VALMAX inventory		34,268	34,595	34,604	19,999	20,138	20,145	56,514	42,066	56,463
Actual		33,325	33,365	33,149	19,781	19,689	19,697	59,449	43,376	52,313

* S = Short saw logs, L = Long saw logs, V = Veneer logs, P = Pulp logs

** Total volume per hectare and log prices were held constant, for each site, in the calculations of gross revenues. Grade yield percentages were the only variables that were changed. Since random length pulp logs were included in all treatments there is no reason to assume that total volume per hectare would differ between treatments, other than that caused by stand variability between treatments at each site.

A number of things can be seen from Table 16.

- Other than the Shorts treatment at the UHQ site, the harvester operators at both unpruned sites tended to cut substantially more saw log material than was predicted by the inventory measurements. As noted earlier, it appeared that sweep specifications for saw logs were not strictly adhered to by the harvester operators. Measurements of logs, for average log volume determination, also found that some saw log small end diameters fell below the minimum threshold of 200 mm.
- At the pruned site actual recovery of saw log material was similar to what was predicted by the inventory measurements, except in Shorts treatment where actual recovery was about 5% lower than predicted. Export veneer log recovery at the pruned site was substantially above what was predicted for all treatments.
- Not unexpectedly, there were large differences in gross revenue between sites; the largest gross revenues were associated with the PHQ site and the smallest with the ULQ site. Differences are due to a combination of stand attributes (e.g., volume per hectare, tree size, stand management history) and log specifications and prices.
- Despite the differences between predicted and actual grade yields there was little difference between gross revenues (-7% to +5%) for the same site and for the same treatment.

- There was little difference in gross revenues between treatments for both unpruned sites with differences ranging from 0.0% to 0.9%. Larger differences (up to 37%), however, can be seen for the pruned site for the Shorts and Mix treatments, where cutting of short sawlogs substantially lowered gross revenues. It should be noted, however, that this was largely due to a combination of reduced saw log volumes and valuing short saw logs at pulp log prices.

Effect of short logs on mill yard log handling

Figure 8 shows the effect of increasing levels of short log volume on log handling costs at a marine port operation. It can be expected that relative increases in costs would be similar for a mill yard. At a port, logs are unloaded, put into storage, and later moved to shipside for loading. At a mill yard, activities are similar except that logs are moved from storage to mill infeed areas for processing.

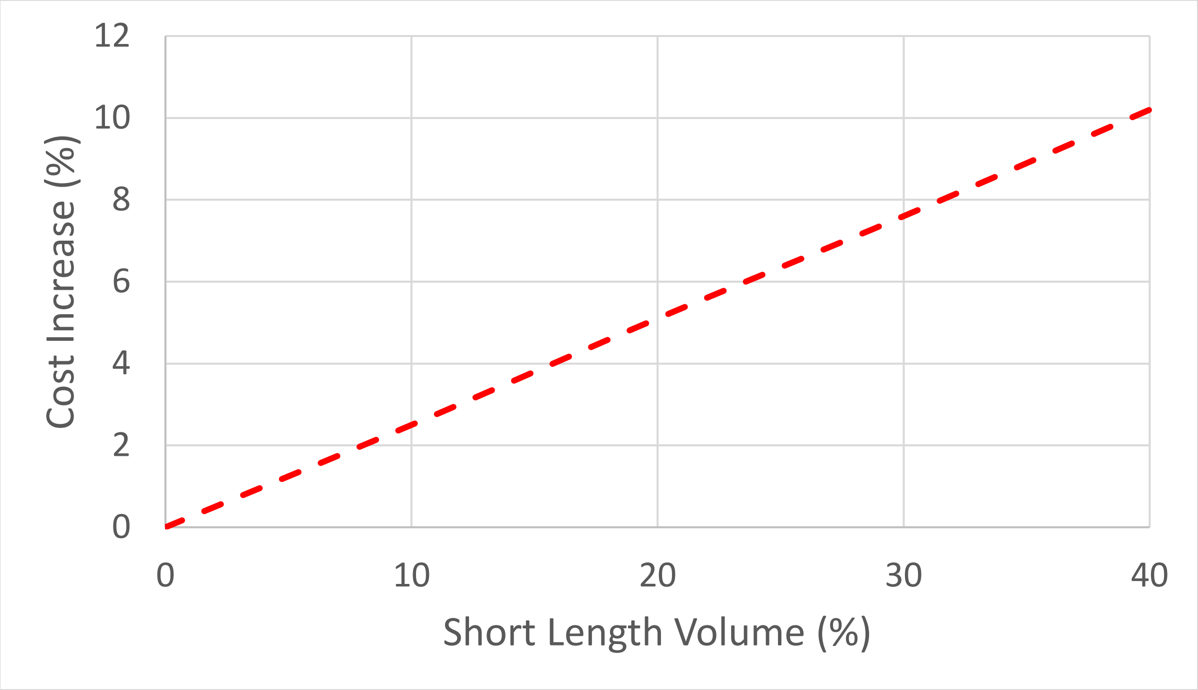

Figure 8. Effect of short length log volumes on marine port log handling costs.

Most of the inventory-predicted and actual pulp log material at all three sites was in lengths over 4 metres. Compared with the Longs treatment, increases in short saw log volume ranging from 19% to 47% for the unpruned sites and 2% to 19% for the pruned site are shown in Table 16. Figure 8 would indicate cost increases in mill yard handling of 5 to 8% for the Mix treatment and 8 to 12% for the Shorts treatment, resulting from these levels of short log volume increases for the pruned sites. Expected cost increases in mill yard handling would be lower than 5 to 8%, however, for the pruned site; i.e., 0% to 3% for the Mix treatment and 4% to 5% for the Shorts treatment.

Net revenue and cost summaries

Net revenues and costs, based on actual and inventory grade yield percentages (presented in Table 16) are shown in Tables 17 and 18 respectively.

Table 17. Revenues and cost calculations for the UHQ, ULQ and PHQ study sites based on actual grade yield percentages

Site	Treatment	Activity	Hourly cost ($)	Productivity (m^3/SMH)	Revenue or cost ($/ha)	Change in net revenue compared with Longs treatment (%)
UHQ	Longs	Gross Revenue	-	-	33,325	0
		Harvesting	226	19.55	5,219	
		Forwarding	198	36.45	2,453	
		Loading	135	42.34	1,440	
		Trucking	148	8.99	7,443	
		Net Revenue	-	-	16,770	
	Shorts	Gross Revenue	-	-	33,365	-8
		Harvesting	226	18.83	5,419	
		Forwarding	198	26.88	3,326	
		Loading	135	38.07	1,601	
		Trucking	152	9.04	7,591	
		Net Revenue	-	-	15,428	
	Mix	Gross Revenue	-	-	33,149	-12
		Harvesting	226	16.82	6,066	
		Forwarding	198	30.07	2,973	
		Loading	135	36.82	1,655	
		Trucking	149	8.79	7,664	
		Net Revenue	-	-	14,790	
ULQ	Longs	Gross Revenue	-	-	19,781	0
		Harvesting	226	14.04	4,293	
		Forwarding	198	30.73	1,718	
		Loading	135	40.40	891	
		Trucking	142	7.68	4,931	
		Net Revenue	-	-	7,947	
	Shorts	Gross Revenue	-	-	19,689	-10
		Harvesting	226	14.80	4,068	
		Forwarding	198	24.24	2,176	
		Loading	135	36.35	989	
		Trucking	146	7.35	5,306	
		Net Revenue	-	-	7,149	
	Mix	Gross Revenue	-	-	19,697	-12
		Harvesting	226	12.46	4,832	
		Forwarding	198	30.42	1,734	
		Loading	135	36.23	993	
		Trucking	145	7.47	5,164	
		Net Revenue	-	-	6,973	

Table 17. (continued) Revenues and cost calculations for the UHQ, ULQ and PHQ study sites based on actual grade yield percentages

Site	Treatment	Activity	Hourly cost ($)	Productivity (m^3/SMH)	Revenue or cost ($/ha)	Change in net revenue compared with Longs treatment (%)
PHQ	Longs	Gross Revenue	-	-	59,449	0
		Harvesting	226	29.09	4,645	
		Forwarding	198	38.52	3,073	
		Loading	135	30.23	2,670	
		Trucking	148	7.60	11,642	
		Net Revenue	-	-	37,419	
	Shorts	Gross Revenue	-	-	43,376	-42
		Harvesting	226	27.65	4,882	
		Forwarding	198	37.99	3,113	
		Loading	135	32.49	2,482	
		Trucking	152	8.00	11,347	
		Net Revenue	-	-	21,553	
	Mix	Gross Revenue	-	-	52,313	-23
		Harvesting	226	27.21	4,960	
		Forwarding	198	36.14	3,272	
		Loading	135	28.60	2,819	
		Trucking	152	7.25	12,521	
		Net Revenue	-	-	28,740	

Table 18. Revenues and cost calculations for the UHQ, ULQ and PHQ study sites based on inventory grade yield percentages

Site	Treatment	Activity	Hourly cost ($)	Productivity (m^3/SMH)	Revenue or cost ($/ha)	Change in net revenue compared with Longs treatment (%)
UHQ	Longs	Gross Revenue	-	-	34,268	0
		Harvesting	226	19.55	5,219	
		Forwarding	198	34.24	2,611	
		Loading	135	45.16	1,350	
		Trucking	146	8.90	7,402	
		Net Revenue	-	-	17,686	
	Shorts	Gross Revenue	-	-	34,595	-6
		Harvesting	226	18.83	5,419	
		Forwarding	198	28.32	3,157	
		Loading	135	33.95	1,795	
		Trucking	152	9.12	7,525	
		Net Revenue	-	-	16,699	
	Mix	Gross Revenue	-	-	34,604	-8
		Harvesting	226	16.82	6,066	
		Forwarding	198	31.06	2,878	
		Loading	135	33.49	1,820	
		Trucking	152	9.12	7,525	
		Net Revenue	-	-	16,315	
ULQ	Longs	Gross Revenue	-	-	19,999	0
		Harvesting	226	14.04	4,293	
		Forwarding	198	27.68	1,908	
		Loading	135	37.47	961	
		Trucking	142	7.64	4,957	
		Net Revenue	-	-	7,880	
	Shorts	Gross Revenue	-	-	20,138	0
		Harvesting	226	14.80	4,068	
		Forwarding	198	26.64	1,980	
		Loading	135	32.57	1,104	
		Trucking	144	7.47	5,144	
		Net Revenue	-	-	7,841	
	Mix	Gross Revenue	-	-	20,145	-5
		Harvesting	226	12.46	4,832	
		Forwarding	198	31.06	1,698	
		Loading	135	34.16	1,053	
		Trucking	144	7.51	5,104	
		Net Revenue	-	-	7,458	

Table 18. (continued) Revenues and cost calculations for the UHQ, ULQ and PHQ study sites based on inventory grade yield percentages

Site	Treatment	Activity	Hourly cost ($)	Productivity (m^3/SMH)	Revenue or cost ($/ha)	Change in net revenue compared with Longs treatment (%)
PHQ	Longs	Gross Revenue	-	-	56,514	0
		Harvesting	226	29.09	4,645	
		Forwarding	198	39.34	3,009	
		Loading	135	30.25	2,668	
		Trucking	148	7.63	11,957	
		Net Revenue	-	-	34,595	
	Shorts	Gross Revenue	-	-	42,066	-42
		Harvesting	226	27.65	4,882	
		Forwarding	198	38.07	3,106	
		Loading	135	31.76	2,539	
		Trucking	152	7.99	11,362	
		Net Revenue	-	-	20,178	
	Mix	Gross Revenue	-	-	56,463	-4
		Harvesting	226	27.21	4,960	
		Forwarding	198	37.62	3,143	
		Loading	135	28.88	2,792	
		Trucking	152	7.23	12,556	
		Net Revenue	-	-	33,012	

Compared with the Longs treatment, net revenues from the Mix treatment were 5% to 12% lower for both unpruned sites and 4% to 23% lower for the pruned site. The size of the relative difference depended on the site, the changes in grade yield percentages, and, at the pruned site, the impact of end-splitting[4] in short saw logs on gross revenue.

The Shorts treatment also had lower net revenues than the Longs treatment. The differences were less, though, than those of the Mix treatment for the unpruned sites, but larger for the pruned site. The percentage changes shown above for the unpruned sites were sensitive to the assumed difference (~4%) in price between sawlogs and pulp logs. If there was no price premium for sawlogs, albeit unlikely, the average changes in net revenue for the Mix and Shorts treatments would be about 2% lower than shown above.

Costs were generally higher for all activities for the Mix treatment than the Longs treatment. There was one exception; calculated forwarding costs for the ULQ site were lower for the Mix treatment than the Longs treatment, based on inventory-based grade yields. This was largely due to considerably lower forwarder unloading times found for this treatment and may have been an

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[4] As described in the Methods section, log prices for short saw logs were reduced to pulp log prices in our analyses for the PHQ site because of a high incidence of end-splitting. If we had assumed in our analyses that short saw log prices were the same as those for long saw logs, net revenues for the Mix treatment would have been lower than net revenues for the Longs treatment based on both inventory predictions of grade recovery and actual grade recovery.

anomaly in the study. If forwarder unloading times were similar to those found for the Longs and Shorts treatment the difference in net revenue would have been -7%, rather than -5%.

Figure 9 shows the contribution that different activities make to the difference in net revenue between two treatments for one of the sites (UHQ) and one of the grade yield assessment methods (Inventory). In this figure, harvesting and loading contributed the greatest negative differences to net revenue. There was a small gain in gross revenue value. For this example, the overall difference in net revenue was -8%.

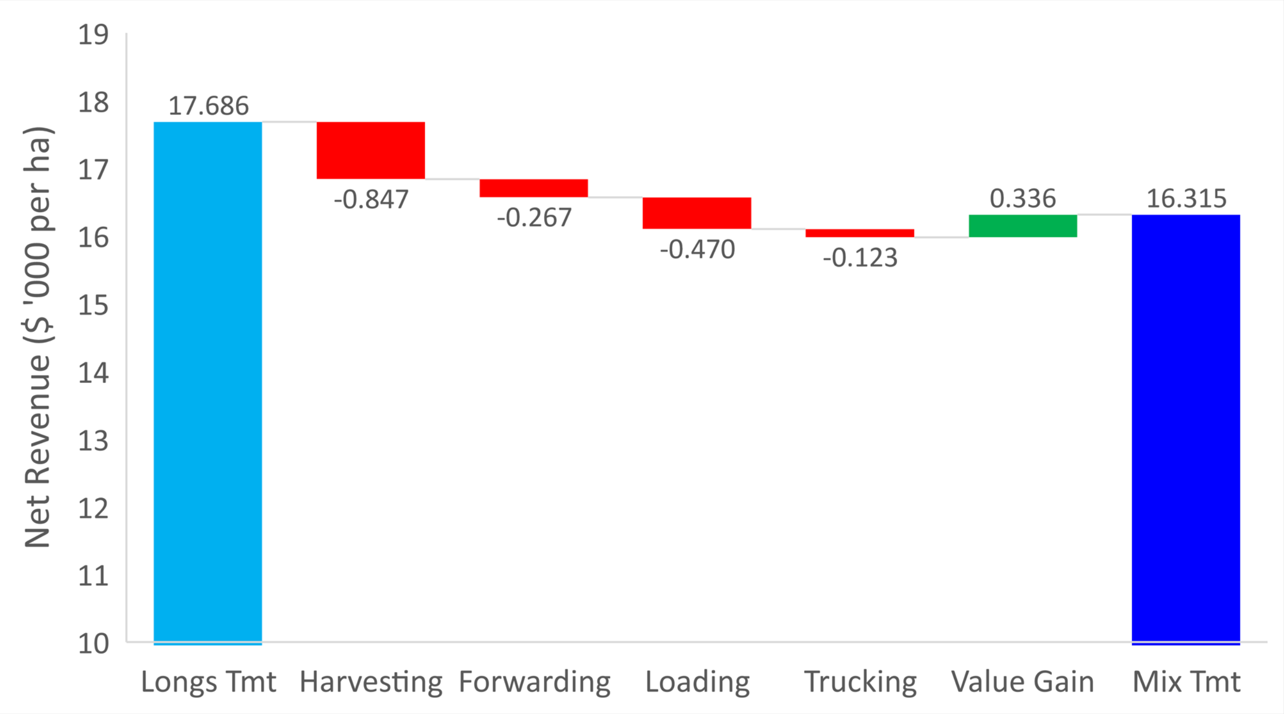

Figure 9. Waterfall chart showing the sources of differences in net revenue between the Longs treatment and the Mix treatment for the UHQ site (based on inventory assessment of grade yields)

Waste left at harvest site

Post-harvest waste assessments were undertaken at none of the trial sites. Comment can only be made on treatment effects on waste based on the VALMAX inventory assessments.

Waste volume was expected to be 6.3% of total volume for the UHQ site. Of this waste, dead trees accounted for 4.1% (20.8 m^3 per ha) and processing waste accounted for the other 2.2% (10.9 m^3 per ha).

Waste volume was expected to be 4.9% of total volume for the ULQ site. Dead trees accounted for 2.7% (7.9 m^3 per ha) and processing waste accounted for the other 2.2% (6.1 m^3 per ha).

Waste volume was expected to be 2.4% of total volume for the PHQ site. Dead trees accounted for 0.9% (4.9 m^3 per ha) and processing waste accounted for the other 1.5% (9.2 m^3 per ha).

There were differences between sites in the percentage of total volume expected to be left as waste, but not between treatments.

DISCUSSION AND CONCLUSIONS

The main goal of the study was to determine if adding short saw logs to the current basket of log grades (long saw logs, export veneer logs, and pulp logs) would have a positive or negative impact on net revenues. The current basket of log grades was represented by the Longs treatment. Adding short saw logs to the current basket was represented by the Mix treatment. The Shorts treatment provided additional information but will not be commented on further, other than to say that net revenues lay between those of the Longs treatment and the Mix treatment for the unpruned sites and below both Longs and Mix treatment for the pruned site.

Based on the results from all three sites adding short saw logs to the current basket of logs would be expected to reduce net revenues; by 5% to 12% for the unpruned sites and by 4 to 23% for the pruned site. Adding short saw logs to the basket generally decreased productivity and increased costs for all activities – harvesting, forwarding, loading and trucking – by 5 to 10%.

Although the log size and harvesting method at the UHQ and ULQ sites were very different from those reported by Mousavi (2009), the difference (7%) that he found in harvesting and transport costs between short logs and long logs was similar to those found in this study (6% to 8%). The difference was not as great (-1% to -2%) at the PHQ site where slightly lower loading and transport costs out-weighed slightly higher harvesting and transport costs for the Shorts treatment compared with the Longs treatment.

The harvesting cost increases are perhaps higher than those (1 to 4%) reported by Gingras and Favreau (2002) in Canada from adding a new log type. Similarly, New Zealand cost data has indicated a 2% increase in harvesting costs per log sort above four sorts for ground-based terrain (Rien Visser, unpublished).

Modelling of mill yard or marine port log handling activity indicated that cost increases from handling a greater percentage of short saw logs would be similar to that which was found for harvesting and transport; i.e., up to 8%. A brief review of the literature also indicated that mill processing costs would be about 6% greater with a greater focus on processing short saw logs than long saw logs.

There was little to no improvement obtained in gross revenue by adding short logs to the basket for the unpruned sites. This was largely due to there being only a 4% difference in the log prices for saw logs compared with pulp logs. For the pruned site, there was a reduction in gross revenue by adding short logs to the basket. This was largely due to short saw logs being assigned the same value at this site as pulp logs because of the high incidence of end splitting in short saw logs.

One of the limitations of this study was that only shortwood (harvester plus forwarder) harvesting systems were included in the study. Long length (feller buncher, grapple skidder, and processor) harvesting systems were not included. This limitation was accepted when the study was designed since shortwood systems are perhaps the most common systems used in Australia, and adding another harvesting system would have doubled the costs of undertaking the research. The additional forwarding cost associated with sub-optimal loading of a forwarder with short logs, may had been reduced by using a long length extraction system.

It can be concluded from these results that relative increases in shortwood harvesting and transport costs, similar to those found in processing of logs at saw mills and handling of logs in mill yards, could be expected from adding short saw logs to the current basket of log grades (long saw logs, export veneer and pulp logs). In both unpruned and pruned hardwood plantation stands, these cost increases would not be expected to be covered by the additional revenue obtained from the additional saw log volume, particularly if there is little or no difference between short saw logs and pulp logs in log prices.

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