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PROJECT REPORT

MECHANISED THINNING TRIALS IN KINLEITH FOREST:
The Waratah DFB in 5m Shortwood and Whole Tree Systems

LINDSAY VAUGHAN

Project Report

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New Zealand Logging Industry Research
Association (Inc.)
P.O. Box 147
ROTORUA
NEW ZEALAND

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The Waratah DFB in 5m Shortwood and Whole Tree Systems

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Prepared by:
Lindsay Vaughan
N.Z. Logging Industry Research
Association (Inc.)
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For information address the NZ Logging Industry Research Association (Inc), PO Box 147, Rotorua, New Zealand.

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ABSTRACT

Two mechanised systems were studied in Kinleith Forest in selection thinning operations. The shortwood system involved a Waratah delimber-feller-buncher (DFB) felling, processing and bunching thinnings into 5m lengths for extraction by forwarder. The whole-tree system involved a Waratah DFB delimbing to 6m, felling and bunching partially-delimbed thinnings. A cable skidder extracted the prestropped bundles and a Waratah heavy duty (HD) grapple processor completed the delimbing and cut the stems into a maximum length of 12m for trucking.

In the shortwood system, the Waratah was capable of processing 33 trees/pmh into 5m lengths, recovering 0.19m³ per tree. Processing time was affected by malformation and the number of pieces per tree. Forwarder productivity averaged 119 pieces/pmh in an average piece size of 0.10m³, with cycle times affected by travel distance, the number of pieces/payload and the number of bunches loaded.

Data from Australian studies indicate that much higher levels of productivity are being achieved. These differences are attributed to differences in operator experience, work methods, forwarder technology and stand conditions.

In the whole-tree system, the Waratah DFB handled 65 trees/pmh, recovering 0.22m³/tree. Cycle times increased once slopes exceeded 10° and boom assistance was needed for uphill travel once slopes exceeded 15°. The cable skidder extracted 76 trees/pmh with travel distance having the greatest effect on cycle times; payload size was determined by bunch size and considered sub-optimal. The Waratah HD grapple processor handled 105 trees/pmh, with double and multi-leadered trees substantially increasing processing time.

A comparison of the two systems is made, using the levels of productivity in the trial. The whole tree system (1 DFB, 1 skidder, 1 processor) offers savings over the shortwood system (2 DFBs, 1 forwarder) of around 40%. However, using Australian studies as a guide to the potential productivity of shortwood systems in New Zealand conditions and incorporating the benefits of improved work methods, an outrow thinning system into productivity levels of both systems and improved tree form, differences in production costs between the two systems become minor. This shortwood system involves processing at stump, an advantage for nutrient recycling, particularly on low fertility sites and avoids the accumulation of slash around landings.

A comparison is made with other studies of productivity levels for the Waratah DFB, the Waratah grapple processor and the forwarder.

A recommendation is made for a cost benefit study to be undertaken on the effects of outrow thinning on residual stand quality, on thinning costs and machine productivity, in a range of stands.

INTRODUCTION

The development of mechanised harvesting systems in Australia and New Zealand has been well documented. Recent studies have included a range of Australian systems (Raymond, 1988b), and machines and systems currently operating in New Zealand. These include the Harricana stroke delimber (Raymond, 1988a), the Waratah grapple processor (Duggan, 1988, 1989), the Bell feller-buncher (Moore, 1988) and the shortwood system at Aupouri forest involving the Waratah delimber-feller-buncher (DFB), the Waratah processor and forwarder extraction (Raymond, 1989, Raymond & Moore, 1989).

NZFP Forests Limited recently organised a series of thinning trials in Kinleith Forest with the Waratah DFB. This project report summarises the results of using the Waratah DFB as a processor in a shortwood system and as a feller-buncher in a whole-tree system. In this report, whole tree refers to tree-length stems and branches, but not roots.

THE TRIALS

Table 1 - Stand Information

	Kakarihi Road	Antelope Road
Age (years)	12	11
Stocking (s/ha)	900	950
DBHOB (cm)	19	18
Height (m)	18	16
Standing Volume (m^3/ha)	200	190
Area thinned (ha)	40	20
Residual stocking (s/ha)	320	290
Merchantable thinnings (s/ha)	400	450
Thinning malformation	40%	20%
Recovered volume per tree (m^3)		
- shortwood system	.19	-
- whole tree system	.21	.23
Recovered volume (m^3/ha)	80	100
Slope	0 to 25°	5 to 25°

THE STANDS

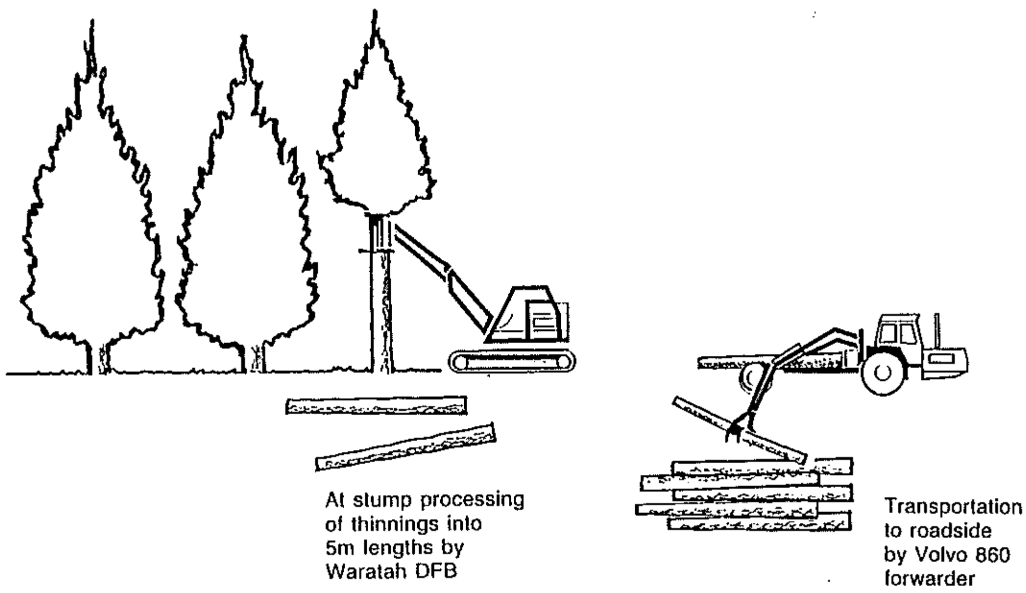
The trials were undertaken in two stands on the north side of the Rotorua-Whakamaru highway; one in Kakarihi Road approximately 5 km west of Atiamuri, the second in Antelope Road approximately 5 km east. Both stands were planted in the mid-1970s and had received similar silvicultural treatment - a waste thinning at age 6 to 900 stems/ha and pruning to 6 m on 250 stems/ha. These stands were scheduled to be production thinned to 350 stems/ha. Stand details are summarised in Table 1. The Kakarihi Road stands had been damaged by frost and had higher levels of malformation than the Antelope Road stands.

THE SYSTEMS

Two systems were evaluated - a shortwood (5 m) system and a whole-tree system. The shortwood system involved using the Waratah DFB to fell, delimb, cut into 5m lengths and bunch in a selection thinning operation. A forwarder was used to extract to roadside.

The whole-tree system involved the Waratah DFB delimbing to 6m on the unpruned trees, felling and bunching. A cable skidder was used to extract the pre-stropped bundles of whole-trees. A grapple skidder would be the preferred method of extracting bunched wood. A Waratah heavy duty (HD) processor was used to process the trees on the landing. These two systems are shown diagramatically in Figure 1.

Shortwood System



Tree Length System

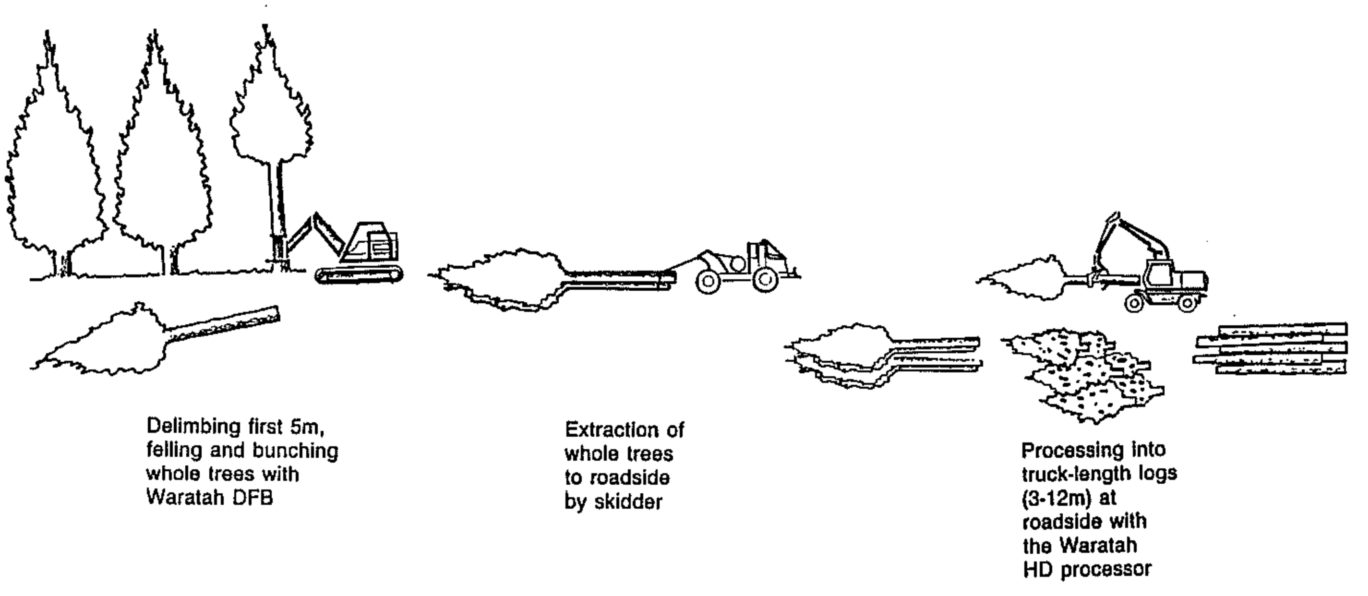


Figure 1 - Two harvesting systems evaluated.

Figure 2 - Waratah DFB

THE MACHINERY

The Feller-Buncher

The feller-buncher used in the trial was the Waratah DFB owned by contractor Pat Clarkin of United Logging Limited, Kaitaia and brought down from Aupouri forest for the trial. It featured a New Zealand-made Waratah Mark 5B felling head mounted on a 15 tonne 74 kW Komatsu PC 150 tracked excavator base. The head weighs 1500kg and consists of four wrap-around delimbing knives between the double-acting shears at the base and top of the head (Raymond, 1989).

The Forwarder

The forwarder was a 17-year old 6-wheeled Volvo 868 owned and operated by contractor Harold Conrad (Figure 3).

The Processor

The processor was a 2-year old Waratah HD grapple processor owned by contractor Keith Travers and features a Waratah HD processing head mounted on a Hitachi 073 wheeled excavator (Figure 4).

The Skidder

The skidder was a 6-month old Tree Farmer C5D (74 kW) owned by contractor Ted Jenkins, fitted with 5 m strops for pre-stropping bunches of whole trees.

Figure 3 - Volvo 868 Forwarder

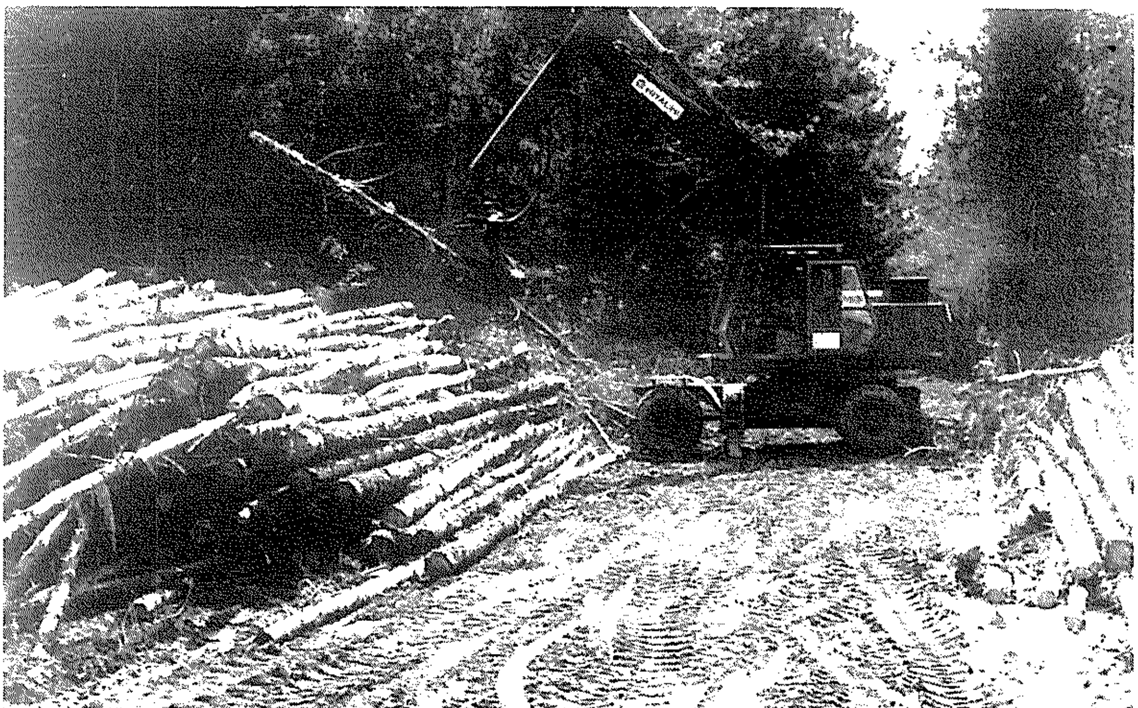


Figure 4 - Waratah HD Grapple Processor

STUDY METHOD

The stands were assessed using standard MARVL inventory techniques (Manley et al, 1987). Log size was calculated from measurements of the length, sedib and ledib (Ellis, 1982).

Continuous time study was undertaken using the Husky Hunter running the SIWORK workstudy program. The elements for the different machines are listed in Tables 2, 6, 8, 10 and 11.

RESULTS AND DISCUSSION

SHORTWOOD SYSTEM

1. *Processing Shortwood*

The Waratah DFB was first used on the easy terrain in Kakarihi Road to process and bunch the shortwood at the stump. The basic work cycle involved the DFB moving to a tree, delimbing to approximately 6 m, severing the base, pivoting to the bunch site before cutting off the bottom 5 m section, then swinging back to the slash pile to delimb the second section and repeating the sequence. Element times, basic cycle time, tree size and productivity data are summarised in Table 2.

The basic cycle time was significantly affected by the high level of malformation recorded in this trial (24%). The effect of malformation is shown in Table 3 where cycle time increased by 38% when processing double leaders, caused by the additional time involved in handling the second leader (when of merchantable size). This involved an extra swing/delimb/swing sequence.

Table 2 - Waratah DFB cycle times and productivity - Shortwood System

Element	Mean time per tree (min)	95% confidence limits	No. of observations
Move and Select	.38	$\pm$.07	50
Process 5m lengths	1.36	$\pm$.19	50
Operational Delays	.08	$\pm$.07	7
Basic cycle time	1.82	$\pm$.20	50
Average piece size	.10m^3		
No. of pieces per tree	1.88		
Recovered volume per tree	.19m^3		
Hourly Productivity	33 trees/pmh 6.3m^3/pmh		
Daily Productivity (7 pmh/day)	231 trees/day 44m^3/day		

Table 3 - Effect of Tree Form on Basic Cycle Time - Waratah DFB - Shortwood System

	Single Leader	Double Leader
Basic Cycle Time (mins/tree)	1.66	2.30
Number of Observations	38	10
Number of pieces per tree	1.7	2.5

Table 4 - Effect of Number of Pieces on Basic Cycle Time - Waratah DFB - Shortwood System

	No. of Pieces per tree			
	1	2	3	4
Basic cycle time (mins/tree)	1.2	1.9	2.6	3.3
Number of Observations	18	21	10	1

Processing time was also affected by the number of pieces processed as seen in Table 4, for the additional time involved in each swing/delimb/swing sequence.

The time required to process 1, 2 and 3 pieces per tree were significantly different.

Basic cycle time in this stand could be estimated using a regression based on the number of pieces produced.

Cycle time $= 0.47 + 0.72 * n \quad (r^2 = 0.63)$
where n = no. of pieces per tree

This relationship is illustrated in Figure 5.

The benefit of processing a small top log (usually a third log) was examined by considering a typical size tree cut into three 5m pieces.

The effects on productivity are shown in Table 5 for processing one, two and three pieces for this tree.

With the additional time of 0.7 min for processing each additional piece, the marginal piece size can be calculated. Once the volume of the additional 5m section drops below .07m^3 productivity will start to decline. This corresponds to a stem diameter (inside bark) of around 10 cm.

The results are based on a brief study using an operator with limited experience in processing shortwood. The processing rate of 33 trees/pmh is well below the 74 trees/pmh recorded in a brief study in Victoria, Australia, with a Waratah Mark 5A DFB in a similar size stand (Raymond, 1988b). This operation was a first thinning operation in a heavily stocked stand. The

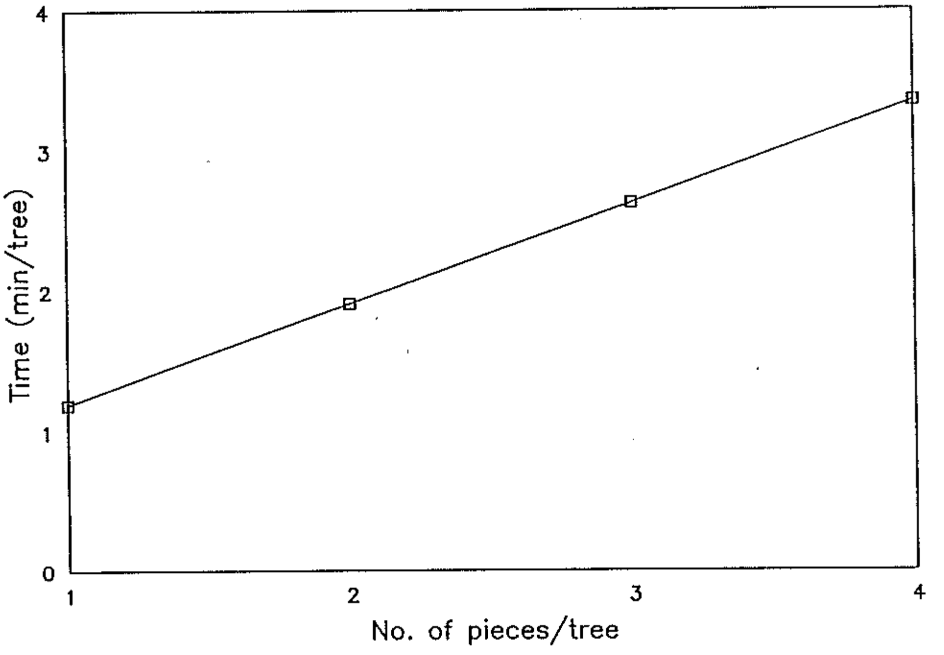


Figure 5 - Effect of Number of Pieces Processed on Cycle Time - Waratah DFB - Shortwood System

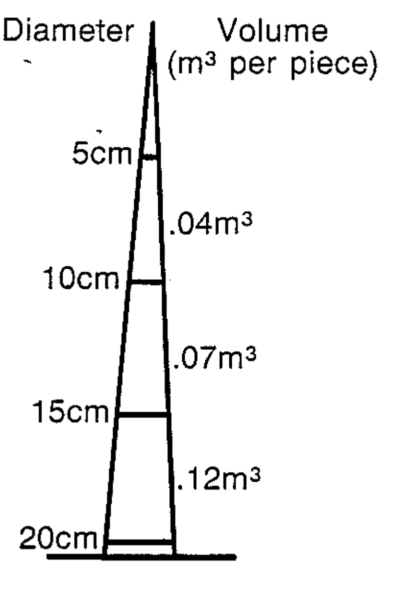


Figure 6 - Distribution of volume in 5m lengths

Table 5 - Effect of processing to different top diameters on Waratah DFB productivity

Top Diameter (cm)	No. of 5m pieces processed per tree	Recovered Volume per tree (m^3/tree)	Cycle Time (min/tree)	Productivity m^3/PMH
15	1	.12	1.2	6.0
10	2	.19	1.9	6.0
5	3	.23	2.6	5.3

Table 6 - Forwarder Cycle Times and Productivity - Shortwood System

Element	Mean time per Cycle (minutes)	95% CL	No. of Observations
Travel empty	3.5	0.5	13
Load	16.2	3.2	13
Move and position	2.7	1.0	13
Travel loaded	3.1	.7	13
Unload	7.7	1.3	13
Operational Delays	4.9	5.2	13
Basic Cycle Time	38.1	5.2	13
Total Distance travelled (two way)	303m		
No. pieces loaded	75		
Average piece size	0.10m^3		
Payload	7.5m^3		
Hourly productivity	119 pieces/pmh 11.9m^3/pmh		
Daily productivity (7pmh/day)	833 pieces/day 83m^3/day		

operator had two years experience in a systematic thinning operation which combined outrow and selection thinning.

Work methods differed, with the Australian operator delimbing at the base of the bunch which allowed the delimbed pieces to drop onto the bunch. In this study, the New Zealand operator delimbed nearby and each 5m piece was swung to the bunch. Each swing/delimb /swing sequence added 0.7 minutes to the cycle time.

Raymond (1990) noted a substantial improvement in Australian productivity, over a five year period with the Waratah DFB processing shortwood, from 46 trees/pmh to 67 trees/pmh. The contributing factors included mechanical improvements, improved tree form and operator experience.

On the basis of these results, the potential productivity of the Waratah in New Zealand conditions (lower stockings and heavier branching) is taken to be 60 trees/pmh.

2. *Extracting Shortwood*

The Volvo 868 forwarder operated in the Kakarihi Road area where the Waratah DFB first started work. It loaded 5m lengths from bunches of 5 to 30 pieces (average size 15 pieces), stacked them butt end forward, extracted them to the roadside and unloaded them into stockpiles. As an existing road network was already in place from the previous clearfelling extraction distances were shorter than is common for a forwarder; a recent study at Aupouri forest recorded average extraction distances in excess of 600m. The results from the two day Kakarihi Road study are summarised in Table 6.

Two of the travel elements ("travel empty" and "move and position") included a significant proportion of time spent manoeuvring by the forwarder to position the rear deck beside the bunches. This would be markedly reduced in an outrow system.

The bunches were laid out at right angles to the extraction track, requiring the logs to be rotated through 90° during loading. The higher stockings in parts of the block (325+ s/ha) made it difficult to avoid damaging adjoining trees. Aligning bunches along extraction tracks would reduce loading times, although it could increase cycle times for the DFB.

"Travel loaded" times were often affected by the need to follow a meandering track through the selection-thinned stand. The machine caused some minor damage at 2 to 4m above ground level on nearby trees, mostly from the rear bolsters which protruded about 0.5m beyond the wheels on each side (a result of the age of the forwarder). This damage often occurred when humps or hollows caused the machine to tip sideways. Little damage would be expected from a new machine with flush bolsters.

"Operational delays" included talking to the supervisor and despatch, restacking bundles to assist loading, removal of fallen trees and minor repairs.

The major variables influencing cycle time were number of pieces (affecting loading and unloading time), number of bunches (affecting move time) and total distance travelled. The best predictor of cycle time was:

$$t = 13.4 + 0.13*nop + 2.4*nob + 0.017*dis \qquad (r^2 = 0.76)$$

where

t = cycle time (mins)
nop = number of pieces loaded,
nob = number of bunches,
dis = total distance travelled (m)

Productivity was estimated at 119 pieces/hour (12m^3/hour) for .10m^3 piece size or 833 pieces/day (83m^3/d). Factors affecting productivity were the same as for total cycle time and the best predictor was:

$$P = 9.6 + 0.16*nop - 0.66*nob - 0.0077*dis \qquad (r^2 = 0.90)$$

where

P = productivity (m^3/hour)
nop = no of pieces loaded
nob = no of pieces per bunch
dis = total distance travelled (m)

Table 7 - Comparison of Forwarder Work Cycles - Shortwood System

Element	Volvo 868	Kockums 85-35
Travel Empty	3.5	3.2
Load	16.2	13.2
Move and Position	2.7	1.5
Travel Loaded	3.1	2.5
Unload	7.7	6.3
Cycle Time (excl. delays)	33.2	26.7
Average Payload	8.3t	9.0t
No. of pieces loaded	75	112
Total distance travelled	303	334
Productivity (t/hr)	15.0	20.2

These results are based on a limited sample and should only be applied to this machine in this trial. It is desirable to consider the potential productivity of a forwarder in an outrow situation with well-aligned bunches and clearly-defined tracks. Levels of 20 tonne/ hour were recorded by Raymond (1988b) in an Australian study of a Kockums 85-35 thinnings forwarder (15 tonne payload), although this excluded delays. A comparison of the two work cycles is shown in Table 7. The higher productivity is attributed to improvements in forwarder technology, the use of an outrow system, and an operator with two years of experience in this system.

WHOLE TREE SYSTEM

1. *Felling and Bunching Whole Trees*

The Waratah DFB operated on slopes ranging from flat to a maximum of 25°. On easy terrain, a selection thinning approach was used. For most of the time, it operated on undulating terrain using an outrow system. All trees in its path were delimbed to 6m then felled uphill into the stand before bunching on one side of the outrow for skidder extraction. Trees up to 7m on each side of the outrow were selectively thinned. The DFB would return travelling backwards down the outrow before moving across to the next row. Recovered volume per tree averaged .22m^3 after processing. In this piece size, productivity averaged 14.3m^3/hour (65 trees/hour). Tree size was similar in the Antelope Road area and there was no difference in cycle times.

Two different operators were involved in the trial, but no differences in cycle times were recorded when operating in similar topographic conditions. Cycle times and productivity are summarised in Table 8.

Topography had a major effect on the basic cycle time once slopes exceeded 15°, through its effect on the elements involved in travelling (move, travel loaded). This was studied in the Kakarihi Road area, as the DFB moved into progressively steeper terrain (Table 9). However, the range of slopes within each outrow masked the effect to some extent.

"Move" mainly involved travelling uphill. Once slopes exceeded about 15°, it was often necessary to use the boom for assistance. Excavator tracks

Table 8 - Waratah DFB Cycle Times and Productivity - Whole Tree System

Element	Mean Time per Cycle (minutes)	±95% CL	No. of Observations
Move and Select	.33	.03	455
Process	.17	.01	455
Travel loaded	.29	.02	455
Operational Delays	.13	.05	69
Basic Cycle Time	.92	.04	455
Recovered volume per tree	.22m^3		
Hourly Productivity	65 trees/pmh 14.3m^3/pmh		
Daily Productivity (7 pmh/day)	457 trees/day 100m^3/day		

Table 9 - Effect of Topography on Waratah DFB Cycle Times - Whole Tree System

Range of Slopes	5°-15°	5°-20°	5°-25°
		Element times (mins)	
Move	.36	.45	.54
Process	.12	.12	.13
Travel loaded and bunch	.28	.25	.37
Operational Delays	.08	.06	.22
Total	.84	.88	1.26
No. of Observations	48	60	60
Productivity (trees/pmh)	71	68	48
Productivity (trees/day)	500	480	330

were standard triple bar growser, designed for use on flat terrain. Single bar growser tracks would improve the machine's climbing ability but make turning more difficult. On steeper terrain, it was often necessary to check the access pathway, clear undergrowth and remove stumps, increasing operating delay times. On these steeper slopes, fewer trees could be reached for processing and more frequent moves were needed.

Wet weather also affected the machine's climbing ability; in dry weather, slopes exceeding 16° had been climbed without boom assistance. After rain, slopes above 12° required boom assistance. If a mechanised system was to operate on terrain which included slopes above 15°, a motor-manual option for harvesting steeper terrain would be needed.

Malformation below 5m above ground level was uncommon (less than 3%). When it occured, cycle times (per tree) doubled with the need to handle each stem separately although the effect on productivity was reduced because of the additional volume available from double leaders of this type. Malformation above this level did not affect felling and bunching times. A small proportion of the thinnings were unmerchantable and were waste thinned. This data has been excluded from the calculations.

Two work methods were used. One involved working away from the landing along an access track, felling into standing trees and bunching on the edge of this track. The second involved starting at the back of the block and felling back into the thinned area. This was an easier alternative for the processor but more difficult for the skidder which lacked a clearly defined extraction track and required a lot more weaving and the occasional removal of a crop tree. Any productivity differences between the two methods were masked by topographic variation.

2. *Extracting Whole Trees*

The cable skidder extracted the bunches of whole trees to the landing. Topography included uphill, flat and some downhill extraction. All bunches were pre-stropped and hooked on by the breaker-out. The skidder operator unhooked on the landing and fleeted the whole trees for processing. Cycle times and productivity are shown in Table 10.

Uphill pulling was restricted to short slopes of up to 15° and usually involved winching. Large payloads involved winching over short distances on the easier terrain. The average payload of 1.7m^3 (approx 1.9*t*) is considered sub-optimum for this size of machine operating on easy terrain.

Travel times (empty and loaded) were primarily influenced by distance and could be predicted from the two regression equations:

travel empty time =
$0.08 + 0.0051 * distance \quad (r^2 = 0.81)$

travel loaded time =
$0.25 + 0.0099 * distance \quad (r^2 = 0.70)$

The prediction for travelling loaded could be improved slightly by including payload, in terms of the number of pieces.

travel loaded time = $0.98 + 0.0092 *$
distance + $0.17 *$
no. of pieces $\quad (r^2 = 0.77)$

Operational delays were primarily re lated to the need to compress the bunch with the blade or to lift the bottom logs to assist the breakerout to strop on.

The bunches were well laid out for skidder extraction and positioned to avoid tree damage. One feature of whole tree extraction was the very low level of damage on crop trees, a combination of careful extraction and the cushioning effect of the branches on the trees in the bunch. This stood out in one area which involved extracting bunches to the road and turning the bunch through 90° before travelling along the road to the landing. Of some 20 "turn" trees, only one had had a significant area of bark removed.

Table 10 - Cable Skidder Cycle Times and Productivity - Whole Tree System

Element	Mean Time per Cycle (minutes)	±95% CL	No. of Observations
Travel empty	.84	.13	57
Position	.25	.04	43
Hook on	.28	.04	57
Breakout	.27	.06	57
Travel loaded	1.71	.27	57
Winch	.28	.10	26
Unhook	.37	.03	57
Fleet	1.21	.11	57
Operational delays	.91	.58	43
Total	6.12	.51	57
Average skid distance	148m		
No. of trees per cycle	7.8		
Recovered volume per tree	0.22m³		
Average payload	1.7m³		
Hourly Productivity	76 trees/pmh 16.7m³/pmh		
Daily Productivity	530 trees/day 117m³/day		

To allow processing of the bunches with the Waratah HD processor, it was necessary to align the bunches of whole trees on the landings with the butts facing the same direction. On landings with entrances at each end, the skidder was required to turn all bunches pulled from one end through 180°.

3. *Processing Whole Trees*

The processor operated on the landing, picking up the whole trees butt first, delimbing and cutting into trucking lengths (maximum length of 12m) and stockpiling these for easy loadout. Longer pieces (up to 18m) were cut to give a long and a short (minimum length of 6m). The tops were placed in the slash heap with other branches and removed by blading at regular intervals.

The processor work cycle is summarised in Table 11. No allowance for slash removal is included in this table as this was carried out by the processor, the skidder, and an independent loader at different times.

Some thinnings (21%) had their heads broken off during fleeting with the skidder, resulting in shorter logs without tops. This accounts for the fewer observations of cut stem and clear tops elements.

Double leader trees significantly increased processing time because of the need for the processor to cut and process large leaders separately. Trees with malformed stems (kinks or nodal swellings) also required additional processing time. In some situations, it was quicker for the operator to manually process these trees with a chainsaw. A comparison of processing times for different types of tree is shown in Table 12 and illustrated in Figure 6.

Comparing element times for shorts with those for single leaders, shorts took longer to pick up (because of their smaller size), less time to process (being shorter) and did not require the stem to be cut or the top to be cleared.

Compared with single leaders, element times for double leaders increased substantially as large leaders required

Table 11 - Waratah HD Processor Work Cycle Times and Productivity - Whole Tree System

Element	*Mean Time per Cycle (minutes)*	*±95% CL*	*No. of Observations*
Position head	*.14*	*.01*	*247*
Process	*.29*	*.02*	*247*
Cut stem	*.06*	*.01*	*195*
Clear tops	*.06*	*.01*	*190*
Operational delays	*.02*	*.02*	*9*
Basic Cycle Time	*.57*	*.03*	*247*
Recovered Volume per tree	*.22m³*		
Hourly Productivity	*105 trees/pmh* *23.1m³/pmh*		
Daily Productivity (7 pmh/day)	*735 trees/day* *162m³/day*		

Table 12 - Effect of Stem Form on Processing Time - Waratah HD Processor - Whole Tree System

Element	Shorts	Single Leader	Double Leader	Malformed Stem
Position head	.17	.12	.17	.29
Process	.19	.23	.48	.48
Cut stem	0	.04	.12	.10
Clear top	0	.07	.08	.06
Operational delays	.01	.01	.04	.04
Total	.38	.47	.88	.97
No. of Observations	8	184	41	11

Note: Adding the rounded element times may give values that differ slightly from the totals shown.

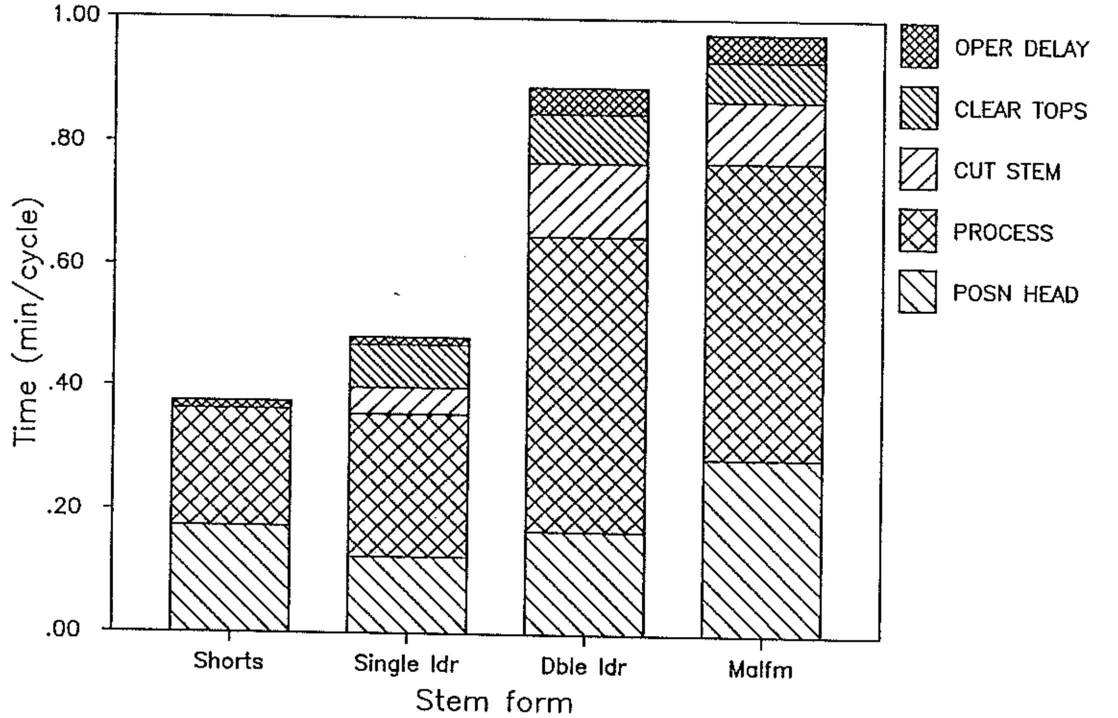


Figure 7 - Effect of Stem Form on Whole-Tree Processing Time for Waratah HD Processor

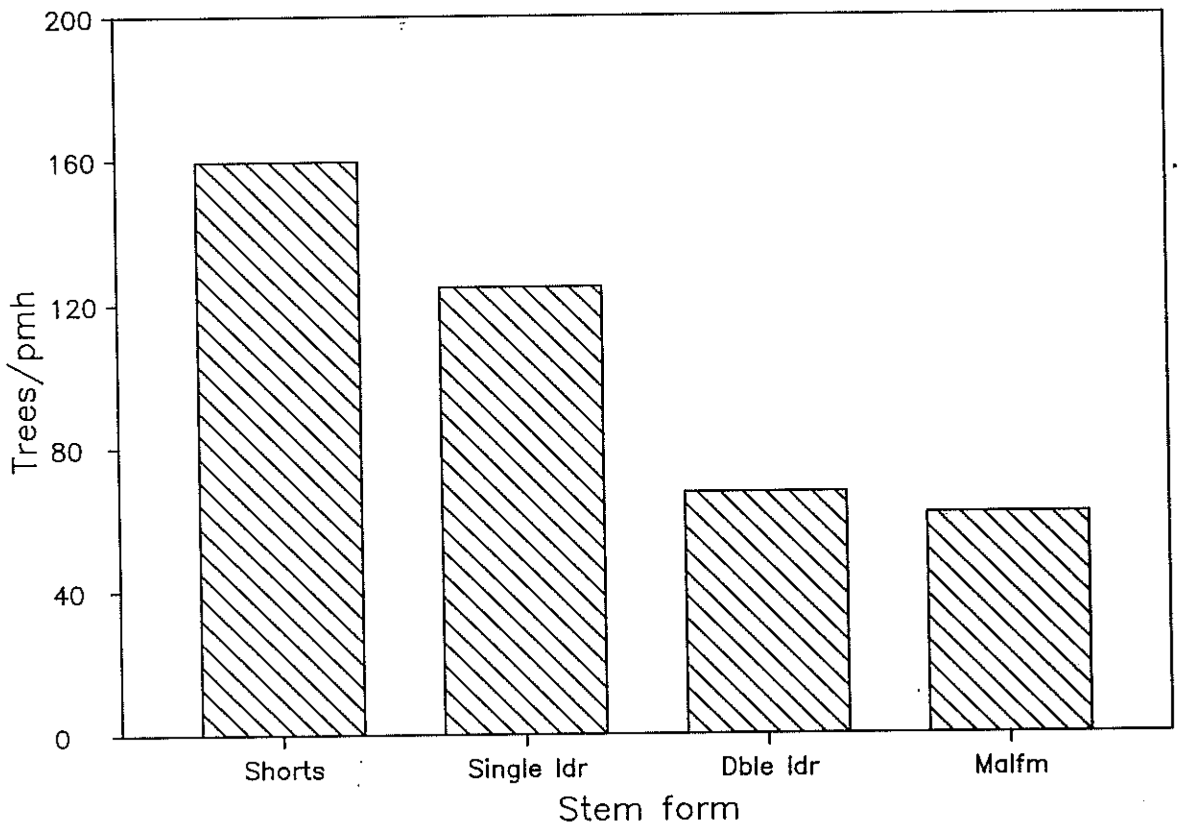


Figure 8 - Effect of Stem Form on Waratah Processor Productivity

processing separately. Differences in element times and total cycle time are significant.

Element times for malformed stems were substantially higher than for single leaders, but generally similar to double leaders. Compared with single leaders, their form made them more difficult to pick up, harder to process and it took longer to cut out the malformed section and clear this away. The differences in element times and total cycle times are significant.

The effect on productivity are shown above in Figure 8.

COSTING

Daily owning and operating costs were based on 1989 prices for new machinery and calculated using the format in the LIRA Costing Handbook (Wells, 1981). A rate of 16.5% was used to calculate interest on all capital investment. A summary of the costing data is shown in Table 13.

The capital costs of the Waratah processor head and excavator base are 1989 costs and are higher than those used by Duggan (1988). This is the major factor for the difference in daily costs. Daily costs are based on 7 pmh/day.

COMPARING SYSTEMS

A productivity summary of the machines is shown in Table 14.

This can be used as a basis for comparing two systems; a whole-tree system based on one machine of each type with daily production determined by the lowest-producing machine (the DFB) and a shortwood system of two DFBs and one forwarder. Costs are summarised in Table 15.

Table 13 - Summary of Costing Data for Trial Machinery

	Waratah HD Processor (head) on Komatsu PC150 base	Waratah DFB Head and boom on Komatsu PC150 base	Forwarder (FMG 1440)	C5D Skidder
Capital Cost ($000)	313	366	360	129
Economic Life (years)	5	5	5	5
Resale (as % of capital cost)	25	25	25	25
Repairs and Maintenance (as % of depreciation)	120	120	120	80
Ownership Costs ($/hr)	43	50	49	21
Operating Costs ($/hr)	36	40	42	20
Hourly Cost ($/hr)	79	90	91	41
Daily Cost ($/day)	552	630	639	283

Note: The use of rounded hourly costs may give daily costs that differ slightly from those shown.

Table 14 - Summary of Machine Productivity

	System: Shortwood		Whole Tree		
	Waratah DFB	Forwarder	Waratah DFB	Skidder	Waratah Processor
Productivity					
Pieces/pmh	63	119	–	–	–
Trees/pmh	33	63	65	76	105
m^3/pmh	6.3	11.9	14.3	16.7	23.1
m^3/day	44	83	100	117	162

Note: Recovered volumes are based on 0.19m^3 for shortwood and 0.22m^3 for whole tree.

Table 15 - Comparison of Production Costs for Two Systems

	Shortwood System		Whole-Tree System		
	Waratah DFB	Forwarder	Waratah DFB	Skidder	Waratah Processor
No. of machines	2	1	1	1	1
Daily cost of machines	1260	639	630	283	552
Operator	300	150	150	150	150
Travel & supplies	106	53	53	53	53
Sub total	1666	842	833	486	755
Overheads (2%)	33	17	17	10	15
Sub total	1699	859	850	496	770
Profit (10%)	170	86	85	50	77
Total	1869	945	935	545	847
Systems total	2814		2327		
Daily production (m^3)	83		100		
Costs ($/$m^3$)	33.9		23.3		

The difference in costs is $6.40, with the whole-tree system being about 20% less than the shortwood system.

Another approach is to produce a balanced of system for whole-tree processing, involving three Waratah DFBs, three skidders and two processors. This would need to operate out of phase to minimise interference between machine types and require more intensive management. Productivity levels could be considered optimistic. These systems are compared in Table 16.

On this basis, the whole tree system represents savings of $13.50 per m^3, about 40% less than the shortwood system.

A further comparison can be made, incorporating a number of improvements and assumptions and the results of the Australian studies, to indicate the potential of these systems.

Shortwood

- A third row outrow system, allowing faster forwarder travel times.
- Bunch alignment parallel to row direction, allowing faster forwarder load times.
- Flat to easy terrain, allowing the Waratah DFB to achieve high levels of productivity while processing shortwood.
- Experienced operator.
- Improved work method.
- Current forwarder technology.

Table 16 - Comparison of Production Costs for Two Balanced Systems

	Shortwood System		Whole Tree System		
	Waratah DFB	Forwarder	Waratah DFB	Skidder	Processor
No. of machines	2	1	3	3	2
Daily Cost of					
Machines	1260	639	1890	849	1104
Operator	300	150	450	450	300
Travel and Supplies	106	53	159	159	106
Subtotal	1666	842	2499	1458	1510
Overheads (2%)	35	17	50	29	30
Subtotal	1699	859	2549	1487	1540
Profit (10%)	170	86	255	419	154
Total	1869	945	2804	1636	1694
Systems Total	2814			6134	
Daily Production (m^3)	83			300	
Cost $/$m^3$	33.9			20.4	

Table 17 - Comparison of Potential Machine Productivity

	Shortwood System		Whole Tree System		
	Waratah DFB	Forwarder	Waratah DFB	Skidder	Waratah Processor
Productivity (existing)					
(pieces/pmh)	63	119			
(trees/pmh)	33	63	65	76	105
(m^3/tree)	0.19	0.19	0.22	0.22	0.22
(m^3/pmh)	6.3	11.9	14.3	16.7	23.1
Productivity (potential)					
(pieces/pmh)	114	200			
(trees/pmh)	60	105	80	95	120
(m^3/tree)	0.22	0.22	0.25	0.25	0.25
(m^3/pmh)	14.5	23.1	20.0	23.7	30.0
Productivity increase (%)	130	94	40	42	30
Factors affecting increase	1,2,3,6,7,8	1,3,4,7,8,9	1,3,6	1,3,5,6	1,2

Factors

1. *Increased piece size (15%) with seed orchard stock*
2. *Reduction in malformation*
3. *Outrow thinning system*
4. *Bunches aligned along outrow*
5. *Grapple skidder*
6. *Easy terrain*
7. *Experienced operator*
8. *Improved work method*
9. *Current forward technology*

Table 18 - Potential Production Costs

	Shortwood System 1	2	3	Whole Tree System 4	5
Daily cost ($)	1880	2814	4694	2327	6134
Daily production (m^3)	102	162	305	140	420
Cost ($\$/m^3$)	18.4	17.3	15.4	16.6	14.6

Note: Systems are:
1. *1 DFB 1 forwarder*
2. *2 DFB 1 forwarder*
3. *3 DFB 2 forwarders*
4. *1 DFB 1 skidder 1 processor*
5. *3 DFB 3 skidders 2 processors*

2. Whole-tree System

   1. Optimum bunch size for skidder extraction (averaging 90% of optimum payload)
   2. Grapple skidder to speed extraction.

Both systems would operate in genetically improved stands, reducing the level of significant malformation to 10% of thinnings, improving processing productivity of both the Waratah DFB (shortwood) and the Waratah HD processor (whole tree).

Given these assumptions, productivity could rise to the levels in Table 17.

These increased levels of productivity are used as a basis for setting daily production levels (based on 7 pmh/day) for three shortwood systems and two whole tree systems shown in Table 18. The shortwood options are 1 Waratah DFB and 1 forwarder (a common Australian system), 2 DFBs and 1 forwarder, and 3 DFBs and 2 forwarders (a better balanced system).

The two whole tree systems are 1 DFB, 1 skidder and 1 processor, and 3 DFBs, 3 skidders and 2 processors (a better balanced system). In all cases, system productivity is determined by the lowest producing machine.

As a result of the substantial improvements that may be achieved with shortwood systems in ideal circumstances, the costs of production of the shortwood systems approach those of the whole tree systems. The difference between the two balanced systems is only 5%, although the number of machines involved in each system (5 for the shortwood, 8 for the tree length) may be too many to be easily managed and the capital outlay (nearly $2 million) would deter most contractors, particularly in view of their vulnerability to industrial disruptions at the pulpmills. Only the Central North Island forests would have sufficient area to support these systems.

The difference between one of the smaller shortwood systems (2 DFBs, 1 forwarder) and the smaller (1 DFB, 1 skidder, 1 processor) is only 5%, and the size and capital costs of these systems are more manageable.

However, there are some advantages in the use of the shortwood system. The major one is the uniform distribution of slash throughout the stand, avoiding the build up of slash around landings with its increased fire risk and untidy appearance. The benefits of nutrient recycling on lower fertility sites with delimbing in the bush is another advantage.

Slash accumulation in the whole-tree system could be reduced by redistributing the slash with a loader or chipping the slash to accelerate breakdown.

Table 19 - Comparison of Machine Productivity

Machine	Operation	Product length (m)	Volume/tree (m^3)	Cycle time (mins/tree)	Productivity (trees/pmh)	Productivity (m^3/pmh)	Data Source
Waratah DFB	Felling and bunching whole trees	tree-length	0.22	0.92	65	14.3	1.
			0.11	0.72	84	9.2	4.
	Felling and processing shortwood	5m	0.19	1.82	33	6.3	1.
		5m	0.23	0.81	74	17.0	2.
		5m	0.21	0.90	67	14.1	5.
Waratah Processor	Processing whole trees	14m	0.22	0.57	105	23.1	1.
		14m	0.30	0.67	90	27.0	3.
	Processing shortwood	2.6m	0.17	0.91	66	11.2	4.
			(m^3/piece)	(mins/cycle)	(pieces/pmh)	(m^3/pmh)	
Forwarder	Extracting shortwood	5m	0.10	38.1	119	11.9	1.
		5m	0.08	26.7	252	20.0	2.
		2.6m	0.05	44.5	299	15.0	4.

Data Sources: 1. *Kinleith study*
2. *Australian study (Raymond 1988b)*
3. *Kinleith study (Duggan 1989)*
4. *Aupouri study (Raymond 1989)*
5. *Australia study (Raymond 1990)*

PRODUCTIVITY COMPARISON WITH OTHER STUDIES

A comparison of similar machines in similar systems is shown in Table 19.

Cycle times and productivity levels from the two studies on the Waratah DFB felling and bunching whole trees are not too dissimilar, given the differences in tree size, stand conditions and topography. Further studies are needed to examine the effect of different stockings, different tree size and its potential in an outrow system.

The differences in the shortwood processing capability of the DFB are substantial. As noted previously, the two Australian studies involved experienced operators in outrow systems in heavily stocked stand with well-formed trees. Raymond (1990) had noted considerable differences (30%) between operators and major productivity gains over time.

The lower levels of production are understandable, given a selection thinning system, the operators limited experience with processing shortwood, the lower stockings, heavy branching, high levels of malformation and undulating terrain. Additional New Zealand studies are required to quantify the potential of the DFB in a shortwood system.

The results for the Waratah processor at Aupouri (study 4) show the influence of the requirement to cross-cut the wood into 2.6m lengths and stack, an increase of nearly 60% in processing time per tree. The increased piece size in study 2 (almost 50% larger) only increased processing time by 18%; suggesting that processing time over this range of piece size is governed by feed rate.

The poorer performance of the forwarder in this study is considered to be due to a selection thinning system, poorly-aligned bunches, an old forwarder and an operator with limited experience in thinnings.

Outrow systems has always been a controversial subject in New Zealand, because of the highly variable form of radiata pine and the importance of the form of final crop trees. A substantial opportunity cost may be incurred through the use of an outrow system, with the loss of some final crop trees in the outrow and their replacement with poorer quality trees. Seed orchard stock may reduce this opportunity cost by producing more uniform trees. There are substantial gains in productivity with the use of outrow systems for mechanised systems. They also reduce the likelihood of damage to final crop trees.

CONCLUSIONS

Two mechanised thinning systems, both using the Waratah DFB, were trialled in Kinleith Forest. The whole-tree system used the Waratah DFB to delimb in the first 5m, fell and bunch for skidder extraction to the landing for delimbing with the Waratah HD processor. The shortwood system used the Waratah DFB to fell, process the thinnings into 5m lengths and stack into bunches for extraction with the Volvo 868 forwarder.

The trial results suggest that whole tree systems are able to harvest thinnings at a substantially lower cost than shortwood systems. However, improvements in work methods, changes in thinnings systems and work methods, and increased operator experience could be expected to substantially raise levels of productivity. If these levels approach those achieved in Australia, then differences in thinning costs appear to be minor. This shortwood system offers the advantage of processing at stump, particularly important for nutrient recycling on low fertility sites, and avoids the accumulation of slash around landings.

Tree form had a major effect on processing productivity of the Waratah DFB and the Waratah HD processor. Higher productivity levels would be achieved in stands with lower malformation levels and bigger piece size.

It is recommended that a full cost benefit study of outrow thinning be undertaken in a range of stand types to examine the effect on residual stand quality and on thinning costs and machine productivity.

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The costs stated in this Report have been derived using the procedure shown in the LIRA Costing Handbook. They are only an indicative estimate and do not necessarily represent the actual costs for this operation.

ELEMENT DESCRIPTIONS

1. Waratah DFB (in shortwood system)

Move and select	The Waratah DFB moves from tree to tree, selecting thinnings for processing. Element starts once machine drops the top of the tree on the slash pile and finishes when the processing head touches the trunk. Record tree form.
Process 5m lengths	The Waratah DFB delimbs the tree to approximately 6m above ground level, severs the base, holds the tree upright, drops the lower 5m section through the delimbing knives, pivots to the bunch site, cuts bottom 5m section, swings back to the slash pile to delimb the next 5m section and repeats the sequence until processing is completed. Element starts when Waratah head touches truck and finishes when the machine drops the top of the tree into the slash pile. Record number of pieces processed.

2. Forwarder (in shortwood system)

Travel empty	Forwarder moves from landing to bunches of shortwood stacked in stand by Waratah DFB. Element starts with forwarder moving off landing and finishes when forwarder stops by first bunch for loading, or to back up to bunch site. Record distance travelled.
Load	Forwarder loads 5m shortwood from bunches in stand. Element starts when forwarder stops travelling empty and finishes when forwarder completes loading before moving to next bunch. Record number of pieces in bunch and number of bunches loaded.
Move and position	Forwarder moves after loading each bunch and positions itself for loading next bunch. Element starts when forwarder starts moving and finished when forwarder stops at next bunch site. Record distance travelled.
Travel loaded	Forwarder moves from last bunch to landing with payload. Element starts when forwarder moves from the last bunch and finishes when the forwarder stops on the landing to unload. Record distance travelled.
Unload	Forwarder unloads payload on landing. Element starts when forwarder stops on landing and finishes when forwarder completes unloading and starts moving back into stand. Record number of pieces unloaded.

3. Waratah DFB (whole-tree system)

Move and select	The Waratah DFB moves from tree to tree, selecting thinnings for felling. Element starts once machine completes processing the previous tree, drops the top of the tree on the ground and finishes when the processing head touches the trunk. Record tree form.

Process	The Waratah DFB delimbs the tree to approximately 6m above ground level, severs the base and pivots to place the stem in a bunch with the butts aligned for skidder extraction. The element starts as soon as the processing head touches the truck and finishes when the tree is placed in the bunch. Record number of trees in bunch.
Travel loaded	The Waratah DFB travels a short distance carrying a tree to place in the bunch. Element starts as soon as the machine moves with the tree and finishes as soon as the machine stops by the bunch.

4. Skidder (whole-tree system)

Travel empty	The skidder moves from the landing to the bunch site in the bush. The element starts when the skidder starts moving on the landing and stops when the skidder stops moving forward. Record distance travelled.
Position	The skidder usually backs up to the bunch of logs. The element starts when the skidder reverses and finishes when the skidder stops.
Hook on	The main rope of the skidder is pulled out and attached to the strop wrapped around the bunch of logs. The element starts once the skidder stops by the bunch and finishes as soon as the operator starts winching in the mainrope. Record number of pieces in bunch.
Breakout	The skidder winches in the bunch of logs until the ends are suspended under the fairlead. The element starts when the mainrope starts moving and finishes when the skidder starts moving after the load is suspended under the fairlead.
Travel loaded	The skidder moves from the bunch site to the landing with its payload. The element starts as the skidder moves away from the bunch site and stops when the skidder stops on the landing.
Winch	The skidder occasionally stops when travelling loaded to winch the bunch of logs up a steep section of the track. The element starts when the skidder stops moving forward and finishes when the skidder moves off again.
Unhook	The skidder stops on the landing and the operator dismounts to unhook the bunch of logs. The element starts as soon as the skidder stops on the landing and finishes when the skidder moves away.
Fleet	The skidder blades the bunch of logs into the existing stack. The element starts when the skidder moves after unhooking the bunch and finishes when the skidder moves forward after fleeting.

5. Waratah HD grapple processor (whole-tree system)

Position head	The processor pivots to the stack to pick up an unprocessed tree. The element starts when the processor starts turning after processing the last tree and dropping the top into the slash pile, and stops as the head touches the next unprocessed stem.
Process	The processor picks up the unprocessed tree and delimbs it. The element starts once the head touches the stem and finishes when delimbing is completed. Record tree form.
Cut stem	Stems exceeding 12m in length are cut by the chainsaw on the processor. The element starts once delimbing stops and finishes when the processor starts pivoting after cutting off the stem. Record number of pieces produced.
Clear tops	The processor pivots to place the tops of trees in a slash heap. The element starts when the processor pivots to drop the tree top in the slash pile and finishes when the head is dropped.