# HARVESTING TECHNICAL NOTE

HTN03-08
2011

# Valmet 445 EXL Self-levelling Feller Buncher

## Summary

This report describes the felling and bunching phase of a grapple yarder operation in Victoria, Australia. Radiata pine (0.8$m^3$ tree size) was felled and bunched by a Valmet 445 EXL self-levelling feller buncher. Mechanised felling and bunching on steep slopes of 20$^o$ to 25$^o$, with good soil conditions (dry sedimentary soils) was highly productive with observed feller buncher productivity of 180 trees per productive machine hour (PMH). Felling and bunching costs for a single feller-buncher servicing two cable logging crews were in the order of \$2.40/$m^3$. Due to the production and safety advantages of self-levelling feller bunchers, these machines appear to be commonly used in Australia on steeper slopes. The variability of New Zealand terrain and soil types, which often provide poor traction even in dry conditions, coupled with large tree size and higher capital cost of this specialized equipment (as opposed to excavator conversions) results in these machines being less common in New Zealand.

**Tony Evanson, Scion**

FFR acknowledges the assistance of the Cooperative Research Centre for Forestry, Australia in this project.

## Introduction

Purpose-built level-swing tracked feller bunchers have been available for more than 30 years since the original Timbco Hydro-Buncher appeared in 1980, and have been used in both New Zealand and Australian clearfell harvesting operations for at least the last 15 years.

Well documented advantages of mechanised felling include: increased production rate compared to manual felling; providing the opportunity to bunch stems for higher extraction productivity; improved value recovery through reduced stump height and tree breakage; and reducing operator exposure to physical harm [1, 5, 11, 13].

Disadvantages include: stem size capability limits; higher initial capital investment; operational areas limited by rough terrain and loose soils and stability limitations on steep slopes. It is estimated (from industry sources) that there are currently some 21 level-swing feller-bunchers working in New Zealand. Of these, 14 are Komatsu Forest machines, including older model Timbco models. Five of these are working in thinning operations and the remainder in clearfell. Specifications of some current models of steep terrain level-swing feller-bunchers are shown in Table 1.

**Table 1**: **Examples of some steep terrain level-swing feller-bunchers/harvesters** **[adapted from Tiernan *et al* 2002]**

| Machine | Mass (kg) | Boom reach (m) | Max working[1] slope (degrees) |
|---|---|---|---|
| Valmet 911 (Snake) | 16,900 | 9.5 | 39 |
| Timbco 445C | 27,500 | 6.5 | 27 |
| Impex Konigstiger T30 | 28,000 | 15.0 | 35 |
| Tigercat L870C | 35,600 | 8.4 | 20 |
| John Deere 909K | 35,670 | 8.4 | 26 |
| Caterpillar 552 | 36,015 | 11.3 (harvester) | N/A |
| Valmet 475FXL | 37,195 | 7.3 | 22 |

[1]Maximum value for different possible machine orientations with respect to the terrain slope.

FFR has identified steep slope harvesting, and the felling phase in particular, as a key area of interest, and initiated research in 2008. Because of the continuing interest in mechanised felling and bunching, especially for cable extraction, the FFR Harvesting Theme initiated a specific study on a mechanised felling operation on steep terrain. This study was of a Valmet 445 EXL feller-buncher in Victoria, Australia (Figure 1).


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**Figure 1: The Valmet 445 EXL feller-buncher in operation.**

## Study Area

The evaluation took place in a forest owned and managed by Hancock Victorian Plantations (HVP), Compartment 110, Bolgers Rd, near Yarram, Victoria (Figure 2).

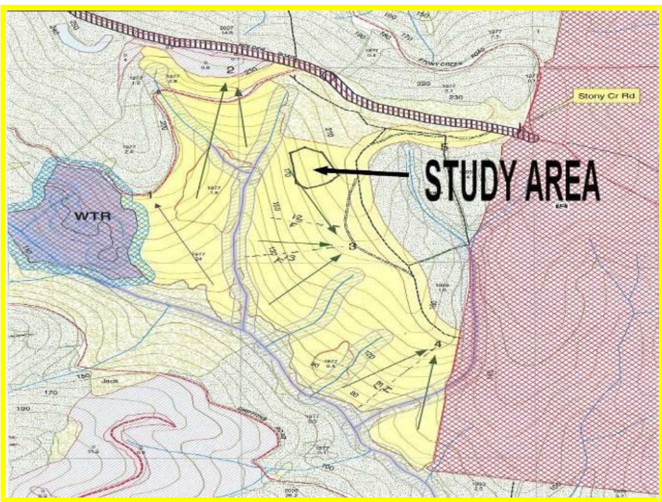


**Figure 2: Study area - Cpt 110 Bolgers Rd, Yarram,Vic.**

Stand characteristics of Compartment 110, Bolgers Rd are summarised in Table 2.

**Table 2: Stand characteristics of the study area**

| | |
|---|---|
| Stand Age | 33 years |
| Stocking | 1000 stems/hectare |
| Mean live tree DBH | 32 cm |
| Mean extracted piece size | 0.8 -1.0 $m^3$ |
| Soil type | Dry sandy loam |
| Maximum slopes | 25 degrees |
| Undergrowth | Nil present |

The harvest setting was composed of steep convex slopes leading to streams where machine access was either prohibited and/or restricted. The dry, sedimentary-based soils (Strzlecki Grey/Yellow/Brown Dermosols) enabled maximum traction. Slash, shrubs and other hindrance were non-existent.

Trees in the study area were colour-coded according to 5-cm DBH classes The distribution of felled trees is shown in Figure 3.

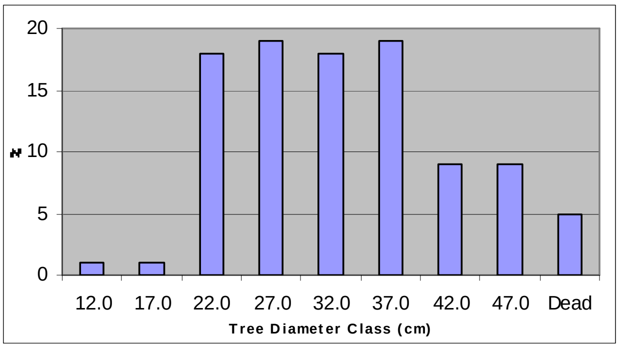


**Figure 3: Diameter distribution of felled trees**

## Machine Description and Operating Method

The harvesting system comprised a Madill 124 swing yarder and grapple, a Komatsu PC 300 with a Waratah 622 processing head, a Hitachi 280LC excavator loader, a tail hold excavator and a bulldozer. The tail hold operator spotted for the yarder operator. Most of the extracted trees had been bunched, the exception being trees too close to the riparian management zones, which were hand-felled.

The feller-buncher was a Valmet 445 EXL equipped with a Valmet 233 fixed felling head



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(Figure 4). Operating weight was approximately 30 tonnes and maximum boom reach was 6.53 m. The operator was experienced in the use of the machine.

**Figure 4: Valmet 233 saw felling head**.

The observed operating method was for the machine to work a felling swath directly up the slope (moving at right angles to the contour), laying bunches at right angles to the line of movement (Figure 5).

**Figure 5: The felling pattern showing bunch layout**.

Most of the time, trees were cut when moving uphill, and then slewed to the right (the best visibility for the operator). Trees felled tended to be in the uphill semicircle (from about 270 to 70$^o$) of the machine's working radius.

Because of the high production rate of the feller-buncher, it also felled and bunched for two other cable operations, a tower and a swing yarder.

## Study Method

Tree diameters at breast height (1.3 m) were measured in a 0.6-ha plot and marked using a colour coding system. Eight different colour codes were used, in 5-cm classes from 12 cm ($\pm$2.5 cm) to 42 cm ($\pm$2.5 cm). Ground slope was measured at several points, averaging 20$^o$ with 25$^o$ maximum slope.

A video camera was placed inside the cab aimed at the felling head (Figure 6). The head and the colour-coded tree were clearly visible.


**Figure 6: View from the cab-mounted camera.**

Time and motion study methods were used to evaluate the productivity of the felling and bunching phase of the operation. Video recordings were made and the machine's movements timed. A GPS travel recorder was placed inside the cab and also on the felling head itself to record the machine's travel.

Feller-buncher cycle time (the time to fell one tree) was divided into time elements:

- Move-to-tree, Re-position: Machine moving uphill in a straight line between successive tree felling and bunching activities, or machine movement laterally, adjusting the move-to-tree line.

- Swing-to-fell: Machine slewing and extending the boom to position the felling head to fell a tree.
- Cut: Saw operation to fell the tree.
- Swing-to-bunch: Slewing the felled tree and lowering to the ground or onto a bunch.
- Second cut, Cut stump: A second extension of the saw to sever a tree not felled after the first cut, or a cut to lower the height of a stump.
- Fell and bunch dead trees: Slewing, cutting and bunching or disposing of a dead tree.
- Adjust bunch: Move trees in a bunch to reduce spread of the butts.
- Operational Delay: Activities apart from the productive cycle, excluding social or mechanical delays.
- Travel: Machine movement (downhill) from the end of a felling swath to the start of the next.

## Results

### Feller Buncher Productivity

The feller buncher was timed for all felling cycles from two successive felling swaths. In total 275 marked trees and 8 unmarked trees were felled.

Table 3 shows average feller buncher cycle time. Total cycle time averaged 20.05 sec/tree, resulting in hourly productivity of 180 trees/PMH or 144 $m^3$/PMH (mean tree size of 0.8 $m^3$).

### Dead Trees, Stumps, Second Cuts

Five percent of the 283 trees in the trial area were dead. Small standing dead trees were sometimes pushed over (to waste) with the feller buncher boom. Larger dead trees were felled but sometimes disintegrated as they were bunched. Around 4% of trees (mostly larger diameter specimens), required a second cut. A few stumps (1%) were recut if the first cut was not clean.

**Table 3. Feller-buncher cycle time summary (time to fell and bunch one tree)**

| Element | No. of Observ. (n=267) | Mean Time per tree (sec) | % of Cycle time |
|---|---|---|---|
| Move-to-tree, or Re-position | 132 | 2.3 | 11.5 |
| Swing-to-fell | 267 | 6.0 | 30.0 |
| Cut | 267 | 3.3 | 16.4 |
| Swing-to-bunch | 267 | 6.3 | 31.4 |
| Second cut, or Cut stump | 14 | 0.15 | 0.7 |
| Fell & bunch dead | 8 | 0.3 | 1.5 |
| Adjust bunch | 11 | 0.3 | 1.5 |
| Op Delays | 16 | 0.4 | 2.0 |
| Travel | 2 | 1.0 | 5.0 |
| Total | 267 | 20.05 | 100.0 |

### Effect of Tree Diameter Class on Cut Time

The effect of tree diameter class on cut time was analysed (Table 4).

**Table 4**: **Average cut times for diameter classes**

| Tree diameter class | Mean Cut time (sec) | Significant difference* |
|---|---|---|
| 17 | 1.67 | a |
| 22 | 1.78 | a |
| 27 | 2.29 | b |
| 32 | 3.21 | c |
| 37 | 3.81 | d |
| 42 | 4.77 | e |
| 47+ | 6.36 | f |

**(Values with the same letter are not significantly different at p>0.05)*

Several of the mean cut times for the DBH diameter classes were significantly different, indicating a relationship between tree diameter and cut time.
A regression equation was developed to predict cut time based on tree diameter class. An exponential curve was fitted to the data (Figure 7) to enable prediction of the time to cut a tree:

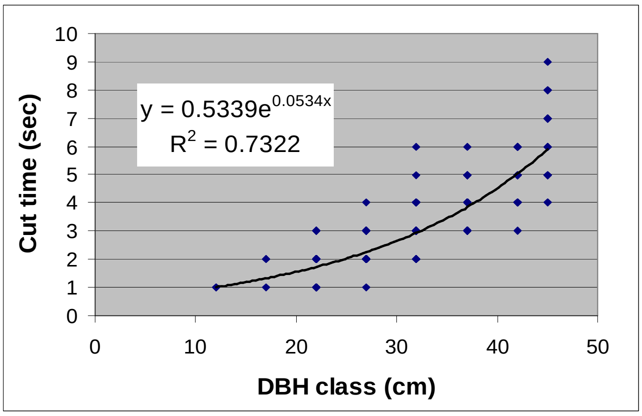


**Figure 7: Graph of cut time vs. tree diameter class**

Cut Time (sec) = $0.5339e^{0.0534x}$ where x is diameter (cm).

### Swing-to-bunch Times on Tree Diameter

For the individual 5-cm diameter classes there was no significant difference between swing loaded and bunch time (swing-to-bunch) and tree diameter. However by combining data into larger classes (17-27 cm, 32-37 cm and 42-45 cm), mean values were produced that were significantly different (Table 5).

**Table 5: Mean values of swing-to-bunch time**

| DBH class | Mean swing-to-bunch time (sec) | Significant difference* |
|---|---|---|
| 17-27 | 5.73 | a |
| 32-37 | 6.42 | b |
| 42-45 | 7.29 | c |

**(Values with the same letter are not significant at p>0.05)*

As expected, larger trees required more time to swing-to-bunch.

### Bunch Size

In total 66 bunching cycles were timed. Average bunch size was 4.3 trees ranging from 2 to 6 trees. The operator tried to keep bunch volume constant by including a larger number of small trees, or fewer large trees in each bunch.

### Move-to-tree and Travel time

Moving time during felling and bunching activity in each felling swath is summarised in Table 6.

**Table 6: Move-to-tree time**

| Activity | Average value |
|---|---|
| Move-to-tree, Re-position time per tree | 2.3 sec |
| Moves per bunch | 1.7 moves |
| Trees cut between each move element | 2.5 trees |
| Move-to-tree, Re-position time per bunch | 9.3 sec |

Travel time per tree to return to start of the felling swath averaged 1.0 sec/cycle (two observations of 145 and 112 seconds). Total machine movement time (including move-to-tree, re-position and travel elements) averaged 3.3 sec per cycle, or 16.5% of total cycle time.

The GPS travel recorder attached to the inside cab window experienced poor reception, consequently poor positional data were obtained. The GPS receiver placement on the relatively protected part of the felling head produced improved data The area covered during felling the day following the study can be seen in Figure 8.

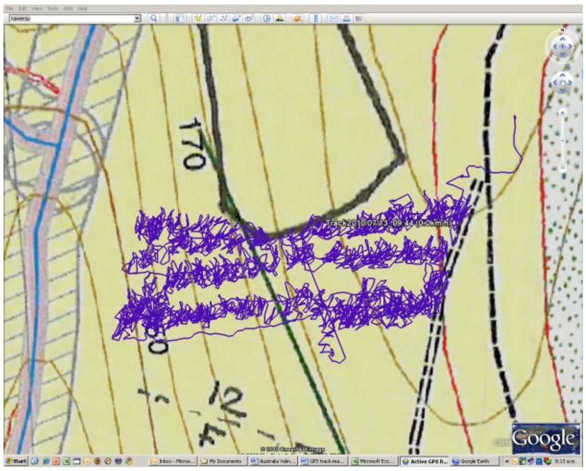


**Figure 8: GPS track of the feller buncher on the second day of the study (outside the trial area).**

The GPS data were used to measure downhill travel speed. Average move-to-tree speed uphill, during felling and bunching, was estimated at 0.47 m/sec (1.7 km/hr). Travel speed downhill was estimated at 0.61 m/sec (2.2 km/hr). In comparison, a study of a steep country



excavator feller-buncher in similarly dry conditions but on Moutere gravels in New Zealand, showed estimated speeds moving uphill of 0.21 m/sec, 0.75 km/hr, and travel downhill of 0.92 m/sec, 3.3 km/hr [5].

**Cost Estimates**

Felling and bunching costs were estimated using calculated productivity and representative costs from the INFORME forestry equipment survey[6]. Based on the feller buncher operating for 7.0 productive hours per day, the daily cost was estimated at $1650 and the cost of felling and bunching was $1.64/m$^3$. Due to its high daily productivity the feller buncher would need to operate for two or more cable logging crews. The productivity and cost of various scenarios is examined in Table 7 with felling for a single yarder, alternate felling for two adjacent cable yarders in the same harvest area (HA), and felling for two or three cable yarders in different harvest areas each day.

**Table 7: Feller buncher in multiple harvest areas.**

| | Single HA-1 yarder | Single HA-2 yarders | Two HA's-2 yarders | Three HA's-3 yarders |
|---|---|---|---|---|
| Average yarder production (6.75 PMH/day) | 432 | 432 | 432 | 336 |
| Total production m$^3$/day | 432 | 864 | 864 | 1008 |
| Average feller buncher PMH/day | 3.0 | 6.0 | 6.0 | 7.0 |
| Feller buncher cost/m$^3$ | $3.82 | $1.91 | $2.40 | $2.06 |

Assumptions: The cable yarders are assumed to work at an average rate of 64 m$^3$/PMH in bunched trees. Where the feller buncher is transported to different harvest areas the transporter cost/trip (30 km one way) is $425 and one hour forty minutes is lost to loading, travel and unloading per trip.

In the last scenario examined (felling in three separate blocks) the feller buncher must fell 6 days per week due to the limits on productive hours per day (10.5 PMH) in order to keep three haulers working (for 6 days) and to remain economically viable.

This analysis supports the concept of a feller-buncher working in a single harvest area and felling for two extraction machines.

## Discussion

The performance of feller-bunchers can be affected by a number of factors, including:

- tree size;
- stocking;
- slope;
- soil type and condition;
- wind strength and direction; and
- felling head design.

**Tree Size**

Previous studies have identified tree size as a major issue with tracked feller-buncher performance[7]. Both tree volume and DBH affect cutting time and the ability to swing and bunch or drop the tree. Depending on the felling head used, some trees were larger than the machine could cut or control (some operators carried and used a chainsaw for manual felling).

Previous studies in medium to large tree size clearfelling operations in both New Zealand and Australia compared the productivity rates of self-levelling feller bunchers. The New Zealand study evaluated a Timbco 445 equipped with a Timbco bar saw head in one central North Island forest. In estimated tree size of 2.5 m$^3$, productivity ranged from 59 to 81 trees per hour. Slopes in pumice soils varied from 5$^o$ to more than 20$^o$. Move time (including re-position and travel time) was the largest single element in the productive cycle, ranging from 31 to 42% of the total cycle time[9].

In the study in Australia of a Timbco T430 with Timbco bar saw felling and bunching 2.2 $m^3$ trees estimated productivity was 54 trees/PMH. Slopes worked were gentle to rolling. Move time made up 47% of the total cycle time [3].

In one recent study, in untypical New Zealand conditions of high stocking (736sph) and small tree size, a Valmet 445 EXL was equipped with a Satco 630 felling head. Productivity was 100 trees/PMH in 1.0 $m^3$ tree size. Slopes travelled averaged $11^o$, and move time in this stocking comprised 16% of the total cycle time[4].

This current study confirmed that both felling (cut time) and bunching (swing-to-bunch time) was significantly affected by DBH. Maximum tree size of around 50 cm DBH did not appear to present any problems for the machine, and the larger trees were felled and bunched using the same methods as the trees of average size (32-cm DBH).

## Effect of variable stocking on feller buncher productivity

Stocking affects machine performance – with more trees within the swath area (area within reach of the felling head, and without the base machine or carrier moving), the swing-to-tree time is reduced, as is the move-to-tree and re-position time per tree, so there is proportionally more time spent felling and bunching[10]. The best felling and bunching productivity for steep slope machines is achieved while moving uphill, perpendicular to the contour [8]. Trees have to be slewed and cleared out of the machine's way to enable forward movement. On completion of a felling swath uphill, the machine returns downhill to the start of the next run or swath.

In this study, the high stocking of 1000 stems/ha enabled a high ratio of trees to be felled per move-to-tree element (i.e. 2-3, average 2.5). Move-to-tree time was also affected by the required bunch size. The average bunch size was four trees (varying from two to six trees depending on tree size) to match the grapple capacity so that each haul the grapple could extract a complete bunch for maximum efficiency. This was important, especially in small tree sizes.

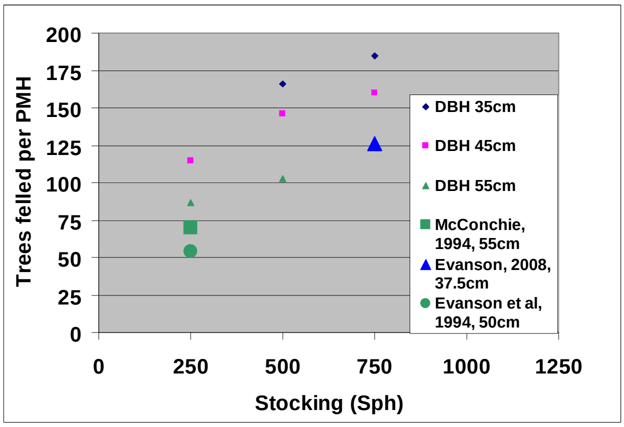


**Figure 9: Productivity for varying stocking and tree DBH.**

Extracted piece size in New Zealand forests is predominantly larger than that observed in this study, i.e. 1.8-2.4 $m^3$ [14]. An estimate was made of performance under similar terrain conditions in stands of 250 to 750sph and with average DBH values of 35 to 55 cm (Figure 9). These were compared with three historical studies [9, 3, 4]. Note that the cycle times for 55-cm DBH trees fall outside the range of the data provided in this study.

## Effect of Slope

Slope affects machine performance by reducing move and travel speeds. Ground conditions in conjunction with slope affect tractive ability [7]. Hard, dry conditions enable traction on steeper slopes than do friable or wet soils. Similarly, obstacles such as old hardwood "snags" or boulders and/or undergrowth restrict or slow movement. It should be noted that most manufacturers of steep-slope felling machines refer only to the levelling cab orientation, and not slope capability of the machine. In New Zealand, the Approved Code of Practice for Safety and Health in Forest Operations guideline for such machines, is a slope of $22^{\mathbf{0}}$ [2].

The slopes encountered in this current study (20-$25^o$) were at the upper limit of acceptability



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according to the Approved Code of Practice. One forest manager indicated that steeper slopes were sometimes worked by feller bunchers, at the discretion of the operator, with appropriate hazard controls in place.

**Soil Conditions**

Along with the degree of ground slope, a key issue for steep country machines is soil type and moisture level, which affect the machine's traction and stability.

The Allied Tree Harvester (ATH 28), a large self-levelling tracked machine (now out of production), operated well on slopes up to $35^{o}$ in suitable soils [7]. In wet, clay soils Hemphill suggested a 22-$24^{o}$ limit.

In the New Zealand study of the Timbco 445 feller-buncher in the Central North Island, McConchie (1994) noted that in the pumice-based soils, for slopes of up to $15^{o}$, there was no difficulty in movement. For slopes 16-$20^{o}$, the operator had to often reposition the machine and change the line of movement to move ahead. Slopes exceeding $20^{o}$ regularly presented difficulty.

**Effect of Wind**

Wind strength and direction may overcome the machine's ability to direct the tree. This mainly applies to larger trees, and at extremes of the boom's reach. Wind conditions in this study did not affect the machine's performance.

**Felling Head Design**

Felling head design affects the feller buncher's performance in felling trees at the limits of its cutting capacity. Feller-director heads (such as the Satco 630) or chainsaw harvester heads (such as the Waratah) can allow a scarf cut, then a back cut on large or leaning trees. Fixed felling heads, either shear or chainsaw, will not allow a scarf cut (unless the machine can be repositioned), or a re-grip of the tree, once felled. Hemphill (1991) noted that for some operations, feller-bunchers in North America would not be used if more than 10% of the trees exceeded the head's cutting capacity for a single pass.

In this study there may have been gains in productivity in the use of the Valmet 233 head's accumulator arm when felling smaller trees. A bunching shear head might also have been an option, reducing cut time. The 233 bar saw had the advantage of flexibility to be used with both small trees as well as the largest trees it encountered.

**Feller Buncher Operating Cost**

Associated with the high capital cost, purpose-built feller bunchers, especially steep terrain level-swing machines, have one of the highest daily cost structures[6], with only large swing yarders having a higher cost per day. Coupled with this is the fact that purpose-built feller bunchers (with felling head only) have only one use and often cannot be used for other tasks such as loading or shovel logging, without risk of damage to the saw head.

This makes it essential that these machines are operated at their maximum capacity. Other factors, including tree size beyond their capacity, excessive slope, variability of terrain and soil conditions often contribute to the relatively limited use of these machines (as opposed to excavator conversions) in cable logging in New Zealand.

## Conclusions

The results of this study indicated that in good conditions (relatively small clearfell tree size – average 0.8 $m^3$ – and dry, sedimentary-based soils that enabled good traction on slopes of 20 to $25^{o}$), a high production rate can be achieved by a tracked self-levelling feller buncher.

Mechanical felling and bunching operations are particularly advantageous if working in smaller tree sizes because extraction efficiency can be improved through bunching for optimal haul sizes.



Daily production was estimated as higher than the capacity of a single cable extraction machine on a single shift (144 m$^3$ /PMH). If there is the capability to share the feller buncher capacity among two haulers, either in the same harvest area or adjacent areas, this will improve the operating cost per cubic metre and may increase the use of steep-slope feller bunchers in cable logging. Calculations showed an estimated felling and bunching cost of \$2.40/m$^3$ for alternate felling in two cable harvest areas.

It is recommended that FFR research into mechanised felling be directed towards acquiring more information on the performance of steep-terrain feller bunchers working in larger piece size (1.8-2.6 m$^3$) than studied here, and under typical NZ slope and soil conditions. The advantages to extraction efficiency, and overall cable system productivity will become more apparent to the New Zealand cable logging sector.

## Acknowledgements

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