FUTURE FORESTS RESEARCH

HARVESTING TECHNICAL NOTE

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A Steep Slope Excavator Feller Buncher

Summary

This report describes a cable yarding operation where mechanically felled trees were bunched by a prototype steep slope excavator feller buncher for grapple yarder extraction. On steeper slopes, the excavator was assisted by an integrated winch installed in the excavator with the winch cable connected to a stump tail hold. The study showed that the prototype feller buncher felled and bunched 65 m^3/PMH in a 1.92 m^3 average tree size, An analysis of bunched and unbunched yarding cycles showed that mechanised felling and bunching has advantages in terms of yarder productivity. Results indicated an average 50% increase in the number of trees hauled per cycle with mechanically felled and bunched wood compared to hand felled or unbunched trees.

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Introduction

The harvesting of trees on steep terrain has always been problematic in terms of worker safety and system productivity. The felling phase is particularly so because manual faller mobility is restricted, and directional felling on slopes is difficult and time consuming.

Figure 1. The prototype Kelly-designed steep slope feller buncher

An FFR Research Strategy workshop in 2008 identified mechanised steep slope harvesting, and phases in particular, as a key research need (FFR, 2008). The primary reason for this focus related to the need to increase cable system productivity through mechanised felling and bunching (Figure 1). One part of this research was to investigate an operation in Nelson (Wood Contracting Nelson Ltd) where a cable-assisted excavator was in use. The operation featured an excavator-buncher cable-assisted by a rope attached to a winch drum mounted on a tractor. The use of the winch rope meant that the machine could move with assistance on most steep slopes (sheet rock being an exception).

There are technological and regulatory limits to machine operations on slopes. The Approved Code of Practice for Safety and Health in Forest Operations (Dept of Labour, 1999) states that feller bunchers and excavators should not operate on slopes exceeding 22^0 (40%).

One manufacturer does not recommend extended operations of excavators on steep slopes (>45^0) because of concerns over adequate engine lubrication in "wet" sump systems. Satellite-based engine monitoring services such as Hitachi's "e-service" are well placed to monitor engine lubrication via oil pressure alarms. The prototype cable-assisted machine has experienced no oil pressure alarms to-date. It is also recognised that the slope and aspect of the engine is constantly changing as the upper structure slews and the machine changes position relative to the slope, ensuring oil pickup from the sump.

While there is no statutory provision for the Department of Labour (DoL) to provide approval of operational trials to certify plant or equipment as "safe to use", the contractor consulted with

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DoL and satisfied the local health and safety inspector that the system could be used safely. The contractor and his development of the cable-assisted system also has the support of Hancock Forest Management NZ Ltd who manage the Tasman Bay Forests where the system is used.

A short term study of Ross Wood's operation in 2008 identified hauler productivity improvement as a result of grapple yarding bunched wood on relatively easy slopes and on slopes up to 30^0. An increase of 33% in hauled trees per cycle was reported with bunched trees of average 0.85 m^3 tree size (Evanson and Amishev, 2009).

In late 2008, further developments by another Nelson contractor (Nigel Kelly of Kelly Logging Company Ltd) with the assistance of A.W. Trinder Limited of Nelson (under similar open engagement with DoL) saw a new Hitachi excavator loader modified by installing a winch drum between the tracks to assist the mobility of the machine on steep terrain (Figure 1). This prototype steep slope excavator was fitted with a felling head to enable both felling and bunching of trees on steep slopes.

Kelly Logging Ltd is contracted to Nelson Forests Ltd (NFL), and this forest management company also assisted the development process by initiating a protocol (with contributions by a number of parties) covering the trialling of the steep slope excavator. The protocol included current NFL slope policy and was necessary because of the steep slopes (>26^0) worked by the machine. NFL have a comprehensive steep slope policy covering the operation of all machines, mainly shovel loggers (and including feller bunchers) working on slopes (<26^0) that includes consideration of:

- Operator skills and experience
- Soil types and terrain
- Machine and system set up
- Guarding and grousers
- Weather conditions
- Planning and sign off.

Kelly Logging Company and Trinder Engineers have engaged with NZFOA and its stakeholders to develop operational Best Practice Guidelines for the machine now under trial and its further developments.

Study Area

FFR initiated a study on this operation, taking place in forest managed by Nelson Forests Ltd. Stand characteristics of the study block in Foxes Block, Nelson are summarized below:

Table 1: Stand characteristics of the study area

Stocking	201 stems per hectare
Extracted piece size	1.92 m^3
Average slope	21 degrees
Max haul distance	300 metres

The harvest setting was composed of a steep narrow gully and less steep upper slopes lying between two long spurs (Figure 2). Using a slope classification map, the average slope of three of the hauler corridors was estimated at 21^o, with 92% of the classification units being over 17 ^{o}.

A number of trees were windthrown and were scattered through the stand. In the area where the feller buncher was observed and cycles recorded, approximately 17% of the total number of trees bunched were windthrown. These trees appeared to be scattered, rather than concentrated, in that part of the setting.

Felling and Bunching Operation

During the study the feller buncher, a Hitachi ZX280 upper/ZX 330LC track base, operated on slopes closer to the hauler, secured by the winch when felling and bunching the steeper upper slopes.

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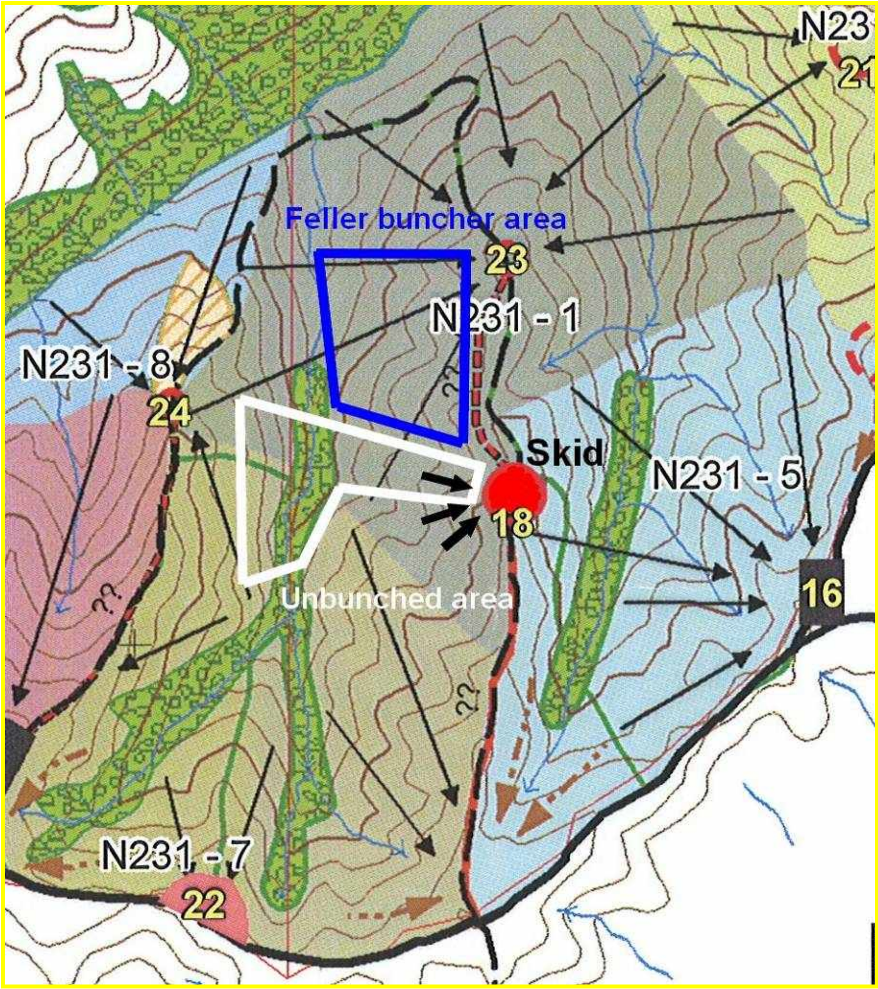

Figure 2. Haul directions to landing 18 and locations of bunched and unbunched trees.

The feller buncher featured a Satco 630 directional felling head and Satco boom. The feller buncher was fitted with a winch located between the tracks which held 310 m of $^{7}/_{8}$-inch swaged wire rope. All engineering work had been carried out by Trinder Engineers of Richmond, Nelson. The winch was driven by the track drive motors on a 50/50 power-sharing basis. Weight of the winch unit was 3.5 tonnes. The track frame had been extended 500 mm to the rear and the track featured double grouser extensions, chamfered at the ends.

The winch controls were integrated with the track drive controls (touch screen display) so the operator could pre-select uphill or downhill winch/travel functions (or no winch used). The operator was secured in position by a full (four-point) restraint racing car-type harness,

The operating method was for the feller buncher to fell trees into the stand or downhill parallel to the stand edge, and bunch the trees, sometimes bunching head-first and sometimes butt-first using two distinct swings interspersed with a change of grip. Bunch size was sufficiently large to enable bunch formation from a single felling position. The trees were sometimes laid out at approximately right angles to the stand edge and sometimes almost directly downhill (Figure 3).

Figure 3. Yarder location, also showing some bunched trees aligned downhill..

The windthrown trees would either have the root balls cut off and be left in position for the next felling pass, or be bunched immediately after the root ball was cut.

A part of the setting was hand felled (Figure 4) so that extraction of bunched wood could be compared. The hand felled area was felled by a single faller using a mainly downhill felling pattern.

Figure 4: Hand-felled trees can be seen on the right below the hauler pad.

Extraction and Landing Operation

The hauler was a Thunderbird 6355 swing yarder using a grapple. Excavators were used for the functions of tail hold (Hitachi ZX330) and mobile guy line (Hitachi EX400).

Grappling of trees was assisted by the tail hold operator, who acted as “spotter” for the yarder. The haul lines moved progressively to the north during the study (Figure 4). The blue area indicates the area that was hand felled. Most of the steeper lower slopes on the far side of the gully were also hand felled.

Trees were hauled to the landing chute which was cleared by a Hitachi EX380 excavator loader with a long reach boom. Extracted trees were delimbed and processed by a Waratah 626 Big Wood harvester mounted on a Hitachi ZX380 excavator base. Trees were picked from a surge pile and, due to the numerous large branches, delimbed completely before processing into logs.

Fleeting was carried out by a Hitachi ZX240 excavator loader and a Volvo L90F wheeled loader. Logs were presented for fleeting in several distinct stacks. On occasion, a single log would be carried to a nearby stack.

Study Method

Time and motion study methods were used to evaluate the productivity of the felling, hauling and processing phases of the operation. Video recordings were made of these three phases. Felling and processing cycles were timed from video recordings, and the haul cycles were timed from direct observation.

As the prime purpose was to evaluate the feller buncher and the extraction of bunched wood, a number of hand felled and unbunched haul cycles were studied. Unbunched wood was mostly located on the steep opposing face of the gully and in the gully itself, and hand felled wood was located on the front slope before the hauler. Bunched wood was located outside these areas (Figure 4).

Results

Feller Buncher Productivity

The feller buncher was observed working with and without the use of the winch cable. Average bunch size, assessed from photographs (70 bunches) was four trees per bunch, varying from a minimum of two trees to a maximum of six trees. The work cycle comprised groups of time elements that were repeated, often in the same order. The windthrow element included time to turn the tree, cut the root ball off, clear the root ball and bunch the tree.

Table 2 shows average feller buncher cycle time (the average time to fell one tree). The feller buncher was operating on flat terrain without the use of the winch cable. During this part of the study (winch unused), 49 tree felling cycles were recorded. Total fell and bunch cycle time averaged 90.9 sec or 1.52 minutes, resulting in hourly productivity of 39.5 trees/Productive Machine Hour (PMH) or 75.8 m^3/PMH.

Table 2. Feller buncher cycle time on flat terrain

Element	Average time/cycle (sec)	% total
Move	15.2	17
Position head	7.2	8
Fell	18.4	20
Slew	4.0	4
Bunch	27.1	30
Windthrow	12.8	14
Clear slash	3.2	4
Other	3.0	3
Total Cycle time	90.9 sec	100

While operating with the use of the winch cable (on maximum slopes of 35^0), 55 felling cycles were recorded. Feller buncher cycle time averaged 106.8 sec, or 1.78 min (Table 3). This equated to 33.7 trees/PMH or 64.7 m^3/PMH.

Table 3. Feller buncher cycle time on a slope where the winch was used.

Element	Average time/cycle (sec)	%
Move	30.1	28
Position head	7.9	7
Fell	15.2	14
Slew	3.2	3
Bunch	35.8	35
Windthrow	5.7	5
Clear slash	6.5	6
Other	2.4	2
Total Cycle time	106.8 sec	100

Feller buncher – cable set up times and machine travel

The time to secure the winch cable to a stump was recorded on two occasions. The two recorded set up times were 2.9 and 4.2 min (average 3.5 min). Travel speeds for the winched machine were estimated at 0.21 m/sec (0.75 km/hr) up slope, and 0.92 m/sec (3.3 km/hr) down slope.

Hauler Productivity

Observed haul cycles (time for each haul) were divided into two types:

- Bunched: trees felled and bunched by machine
- Unbunched: including trees felled by hand for the purposes of the study.

Over the study period, 222 haul cycles were observed, comprising 160 bunched and 35 unbunched, 13 root balls extracted, and 14 cycles extracted from a steep gully.

Bunched haul distance ranged from 27 to 256 m and unbunched (hand felled) hauls ranged from 90 to 195 m. Some trees were extracted from a steep gully, out of sight of study personnel, and

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some involved grappling of root balls; these cycles were excluded from the analysis.

The haul cycle comprised the following time elements: Raise grapple, Outhaul, Grapple Load, and Inhaul. Grapple Load was the time taken from grapple strike to start of Inhaul. Drop time was minimal and included in Inhaul time. Average “Raise grapple” time for all cycles was 0.23 min.

The mean number of whole trees (butts) and heads (non-butt pieces) extracted was compared for the different types of haul cycle (Table 4).

Table 4. Comparison of number of trees/haul for different tree locations/configurations.

Cycle type	No. cycles	Mean no. butts per cycle	Mean no. heads per cycle
Unbunched	35	1.06 (a)	0.09
Bunched	160	1.61 (b)	0.19
*Different letters indicate significant difference at p>0.05.			

The number of trees grappled from bunches was significantly higher than for unbunched (hand felled) trees. In bunched tree cycles, 31% of hauls had two trees and 15% had three trees per cycle. In unbunched (hand felled) cycles, only 6% of hauls had two trees and no hauls had three trees. On average, twice as many heads (non-butt pieces) were extracted per cycle for bunched cycles compared to unbunched cycles. Bunching of small pieces made extraction of these small pieces easier.

Grapple Load times were compared for the different kinds of cycle (Table 5).

Table 5. Comparison of Grapple Load time for different haul cycle types.

Cycle type	No. cycles	Mean Grapple time/cycle, min	Average haul distance (m)
Unbunched	35	0.57 (b)	143
Bunched	160	0.64 (b)	146
*Different letters indicate significant difference at p>0.05.			

There was no significant difference found between mean grapple times for bunched and unbunched (hand felled trees).

Hauler productivity could not be confidently compared for bunched and unbunched (hand felled) cycles, because of the small sample size of hand felled cycles. There was no significant difference between key haul cycle elements.

Table 6. Standardised cycle time elements used in the productivity comparison of bunched and unbunched trees.

Element	Mean time per cycle (min)
Raise Grapple	0.23
Outhaul (130 m)	0.41
Grapple Load	0.63
Inhaul (130 m)	0.74
Other	0.05
Tail hold shift	0.36
Guy line shift	0.08
Total Cycle time	2.50 min

With key haul cycle elements held constant and number of butt logs per cycle varied with presentation, an indicative comparison of hauler productivity for hand felled and bunched trees was made. Standardised cycle time elements are shown in Table 6.

Inhaul and Outhaul times (min) for unbunched and bunched cycles were combined and have been standardised for a haul distance of 130 m using the following inhaul and outhaul regression equations:

Outhaul = 0.228 + 0.00143*Distance (r^2 = 0.41)

Inhaul = 0.263 + 0.00366*Distance (r^2=0.48)

The r^2 values are not high, indicating that the equations explain less than half the variation in times. This may be for several reasons:

- The operator may have been inconsistent in controlling the grapple inhaul/outhaul speed.
- On outhaul, the grapple would initially move out fast, then slow as it approached the

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break out site as the spotter gave instructions.

- Break points for the start of Inhaul element and the end of Outhaul element were sometimes difficult to distinguish.
- Haul distance was calculated using trigonometry from laser rangefinder distance/depression angle to the grapple, and bearings to tail hold and yarder. This method may only approximate actual haul distance.

Given that inhaul and outhaul times for the different methods are assumed to be similar, and there being no significant difference between grapple times, a comparison can be made of unbunched cycles and bunched cycles.

For unbunched cycles, estimated hauler productivity was 25.4 trees/hr or 48.8 m^3/PMH. For bunched cycles productivity was estimated at 38.6 trees/hr or 74.1 m^3/PMH. This result showed that bunching improved hauler payload and thus hauler productivity by 51% versus unbunched extraction.

Processor Productivity

A total of 43 log processing cycles (time to process one tree) were timed. Delay-free cycle time averaged 1.9 min for whole trees (butts), producing 4.3 logs per tree, and 0.9 min for tops.

Average delay-free productivity for both butts and tops was calculated at 30.1 trees/hr, or 57.7 m^3/PMH (assuming tops comprised 10% of total pieces processed).

Cost Estimates

System costs were estimated using calculated productivity and representative costs from the INFORME forestry equipment survey (Forme, 2009). Assumptions included 9.0 scheduled working hours for all machines.

Estimated daily system production for a mechanised felling and bunching system was 444 m^3/day. System balance for this scenario required 6.0 PMH for the Yarder (74 m^3/PMH), 7.0 feller buncher PMH per day (64 m^3/PMH) and 7.6 Processor PMH per day (58 m^3/PMH). The Processor PMH which limits the system production, is appropriate for 9.0 scheduled hours at 85% machine utilisation.

Estimated system cost for a mechanised felling and bunching system based on daily production of 444 m^3/day was \$22.26/m^3.

A comparable estimated daily system production for manual felling and yarding unbunched wood was calculated at 353 m^3/day. System balance for this scenario required 7.2 Yarder PMH/day (49 m^3/PMH), and 6.1 Processor PMH (58 m^3/PMH). The yarder PMH which limits the system production, is appropriate for 9.0 scheduled hours at 80% machine utilisation.

Estimated system cost for manual felling and yarding unbunched wood based on daily production of 353 m^3/day is \$25.19/m^3.

In high production hauler operations there is frequently an imbalance in productivity rates between felling, extraction and processing. In this operation the productivity of the feller buncher on steep terrain (64 m^3/PMH) was outpaced by the extraction productivity in bunched wood (74 m^3/PMH). The system productivity could be balanced by the feller buncher felling in easier terrain for part of the day at higher productivity (76 m^3/PMH), or by working the feller buncher for 7.0 PMH per day.

Conclusions

This study of an innovative harvesting operation using a steep slope excavator feller buncher to bunch trees for grapple yarder extraction showed that although terrain slopes were not excessively steep, a significant area exceeded the recommended operational guidelines for standard excavators. Similar to an earlier study

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of cable-assisted bunching (Evanson and Amishev, 2009) this contractor used the winch mode only when dictated by steep terrain. By virtue of the specialised harvesting machine used, the system bunched trees safely for grapple yarder extraction at a high production rate.

The high productivity of the harvesting system was achieved through grappling an increased number of trees per haul cycle from bunched trees (two or more trees, more frequently). There was no difference observed between elemental grapple times for bunched and unbunched trees.

The conclusion was therefore that the increase in productivity from bunched cycles was driven from increased hauler payload (+50%) rather than from reduced cycle time.

Further FFR research will explore other ways in which steep slope felling machines can be used to increase both system productivity and log quality.

Acknowledgements

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The costs stated in this report have been derived using estimates obtained from Informe Harvesting 2009, where appropriate supplemented with cost data from other sources. They are an indicative estimate and do not necessarily represent the actual costs for this operation.

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