HARVESTING TECHNICAL NOTE

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A New Method for Bunching Trees on Steep Terrain

Summary

This report describes a grapple yarding operation where both hand-felled and mechanically felled trees were shovelled and bunched by an excavator log loader for grapple yarder extraction. On steeper slopes, the excavator loader was secured by a cable attached to a winch on a mobile tail hold (bulldozer). The study showed that shovelling and bunching for grapple yarder extraction has a number of advantages in terms of yarder utilisation and increased harvesting system productivity. Results indicated a 33% increase in trees hauled per cycle with bunched wood compared to unbunched wood extracted with the use of a spotter or by the yarder operator alone.

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Introduction

Bunching of trees for subsequent extraction has been used extensively in ground-based operations to increase productivity in both thinning and clearfelling (Stokes and Lanford, 1985; Hartsough, 1990; Brown *et al*., 1996). Steeper terrain (slopes in excess of 35%, or 20^0) has traditionally been seen as the sole preserve of chainsaw felling, where bunching for payload is not possible. However, developments in the late 1990s have seen the production of steep terrain harvesters capable of operating safely on slopes between 35% and 55% (20^0 – 30^0).

Integration of tilting operator cabins and specially designed tracked machine chassis (Figure 1) has increased the operational capability of harvesters on steep terrain (Oswald and Frutig, 2001; Schöttle *et al*., 1997, 1998; Stampfer, 1999; Torgersen, 2001; Weixler, *et. al*., 1997, 1999).

European literature shows that bunching for yarder extraction has been concentrated primarily on thinning operations. Heinimann *et al*. (1998) reported felling and bunching of trees using a Skogsjan 687 harvester in a commercial thinning operation with a Syncrofalke yarder in the eastern Austrian Alps. Bunching with the harvester increased cable yarder productivity by 25%, and using a second choker setter improved yarding productivity by the same order as the bunching effect.

Figure 1: Valmet™ 911 "Snake" steep terrain harvester

Other countries have reported the use of tree bunching for yarder extraction. In Canada, a number of reports noted bunching of clearfelled trees for yarder extraction using a feller-buncher or feller-director. Peterson (1987) reported a 10% increase in trees yarded per productive machine hour (PMH), and 36% more trees yarded per haul in bunched versus unbunched wood (extracted piece size 1.5 m^3). Other studies of mechanically felled and bunched wood in cable yarding compared grapple yarding with hand-set chokers. Results showed high productivity of grapple yarded wood over short haul distances (MacDonald, 1988, 1990).

In Australia, a Valmet steep terrain feller-buncher was recently observed felling and bunching trees for downhill grapple yarder

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extraction. Small bunches were laid out in lines for downhill extraction (Heine, 2009).

Although feller-bunchers have been the preferred machine type for bunching in steep terrain elsewhere in the world, their use in New Zealand has been limited. Hemphill (1991) examined the potential for feller-bunchers in New Zealand cable yarder operations, and pointed out some of the constraints for this application:

- Large clearfell tree size (US operations were only economic with trees smaller than 1 m^3);
- High cost of capital relative to labour costs and difficulty with machine servicing in isolated regions;
- A large proportion of cable terrain being too steep for machines;
- Soils too wet or clayey, affecting bearing strength;
- Insufficient volume to sustain mechanised systems.

Hemphill (1991) also summarised the advantages favouring feller-buncher use in New Zealand as: the reduced labour requirement of mechanised felling; the safer work environment; and the systematic harvest planning employed in New Zealand, which assists application of these systems.

A major area of focus of the Future Forests Research harvesting theme is reducing the cost of steep country harvesting operations in New Zealand. One way to achieve this is by increasing harvesting productivity through the mechanisation of steep terrain operations. Previous work, examining the international literature regarding felling and bunching on steep terrain, showed it was well established overseas (Amishev *et al*. 2009).

Excavator-based bunching of trees for yarder extraction in clearfell operations is a relatively new development in New Zealand. This report describes a study of a grapple yarding operation in Nelson where an innovative contractor has developed an excavator-based bunching system for logging small tree sizes on moderate to steep terrain (Figure 2).

Figure 2: Bunched wood ready for grapple yarder extraction.

Study Area

Stand characteristics of the study block in Moutere South Forest in the Nelson region are summarised in Table 1.

Table 1. Stand characteristics of the study area.

Age	26 – 30 years
Top height	29.9m
Stocking	497 stems/ha
Stand Volume	422 m^3/ha
Piece size	0.85m^3

The block was managed by Hancock Forest Management (NZ) Ltd, and was composed of spurs about 250–300 m long and 100–150 m wide separated by native forest in the adjacent gullies. A ridge-top road was located at the top of the spurs, along which landings were located. There was a stream running at the bottom of the block, away from which trees had to be extracted to minimise stand damage. (Figure 3). The terrain was generally steep and broken and soil type was Moutere gravel. Some tracks existed from previous operations, and these were used by the bunching machines during the operation, but the block had not been contour-

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tracked, which was a common ground-based harvesting method used in the past.

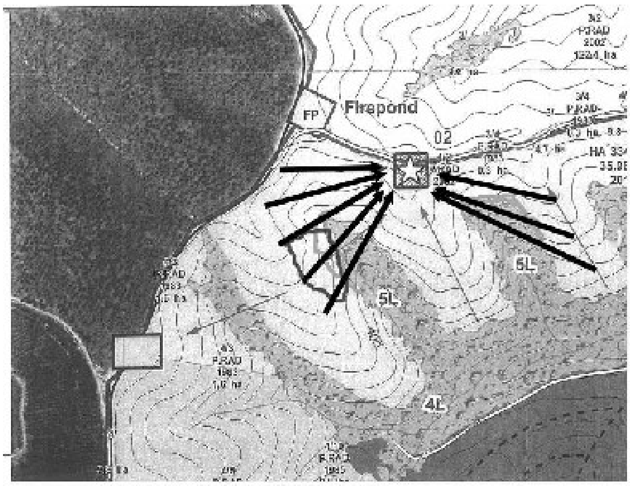

Figure 3: Study location with haul directions. Area logged using cable-secured excavator is outlined.

The extraction phase of the system comprised the use of an excavator log loader to bunch stems and present them to the grapple yarder. In situations where terrain became too steep for operating the free-moving excavator safely, it was secured by a pre-tensioned cable to a bulldozer-anchor (Figure 4). In this way the cable-secured excavator was able to operate on terrain that would have been previously inaccessible to such machines.

Figure 4: Cable-secured excavator and winch unit.

Felling and bunching operation

Some of the study area was felled by a Timberjack 2628 feller buncher equipped with a chainsaw head. In the area observed, trees had been felled downhill with minimal breakage. Steep gully heads had been hand-felled. The tops of the spurs were cleared first by the bunching machines to provide access for the mobile tail hold.

Two excavators, a Komatsu PC220 and a Volvo EC290, were used to bunch the trees for extraction by the yarder, a Pacific 1188 swing yarder equipped with a grapple. Bunching was often supplemented by shovelling, where large bunches were successively swung by the excavator over relatively shorter extraction distances towards the landing or roadside.

Since only one machine was required to bunch/present trees for breakout, the other machine continued bunching/shovelling. On the cutover, several different tree and bunch layouts were observed:
- Machine felled, unbunched trees.
- Machine felled, shovelled, large bunches.
- Machine felled, bunched, small bunches.
- Hand felled, unbunched trees.

The excavators were both modified with cable attachment points for either a Ropemaster sheave, or direct connection by shackle. The operators' seats were racing car-style full harness seats. The Komatsu D85 tractor-winch (an ex-roller crusher) to which an excavator could be attached, was equipped with a fairlead on top of the blade which generated good downward pressure on the 22mm swaged cable (breaking strength 45 tonnes).

The tractor winch was operated by a remote-control system designed by Salcom Technologies, a Christchurch company supplying telecommunications to the industry (http://www.salcom.co.nz/).

For winching in, the operator had to select one of three winch speeds (effectively, tractor engine throttle speeds). For pulling out cable (a fourth selection), the torque converter of the tractor supplied braking power. On loss of power (the tractor idles when the system is in use) a powerful brake could be applied to lock the cable in position.

Extraction operation

The main breakout method involved using the bunching excavator to present a bunch of tree butts to the yarder grapple for extraction (Figure 5). The excavator operator called advice over a radio link to the yarder operator for locating the grapple at the right spot for a secure grip. Other breakout methods used a spotter to aid the location of the grapple, or the yarder operator spotted his own haul.

Figure 5: Buncher presenting for grapple extraction.

Processing operation

The processor, located on the landing with the yarder, was a Hitachi EX330 Zaxis equipped with a Waratah 624 Super harvester head. The processor cleared the chute and processed 18 grades from a single position. The processor did not stockpile extracted trees (no surge pile), indicating processor productivity was higher than that of the yarder. The landing was also shared by a Hitachi EX225 excavator loader which fleeted the processed logs and cleared slash. There was insufficient room for the 14 different stacks required, so a Hitachi ZW180 wheeled loader was used to fleet shorter logs in 4-tonne loads some 200 m to another landing, and load trucks. A Bell Ultra Logger was stationed at the second landing for fleeting. A Hitachi EX300 was used as a mobile tail hold and a Komatsu PC400 was used as a mobile tether for the yarder's three guy lines.

Study Method

Time and motion study methods were used to evaluate the productivity of the extraction and processing phases of the operation. The haul cycles of the yarder were observed over two days, with haul distances measured by laser range-finder. Video recordings were made for later analysis. This consisted of division of the haul cycle into time elements. The relationships between these elements and other observed factors were then analysed.

The measured time elements were:

- Raise grapple
- Outhaul and grapple
- Inhaul
- Lower grapple
- Operational, mechanical, personal delays
- Clear chute and process

Observed non-time elements were:

- Haul distance, slope
- Number of trees per haul
- Number of logs processed
- Process location (track or slope)
- Bunch descriptor (small, large, hand felled, directionally felled)
- Breakout method (spotter, yarder spotted, buncher spotted, buncher grappled, cable buncher grappled)

Results

Feller-buncher productivity

A total of 44 feller-buncher cycles were timed (Table 2). Observed delay-free hourly productivity was calculated at 80.5 m^3/PMH (=94.7 cycles/hr * 0.85 m^3).

Table 2: Feller buncher cycle time elements

Element	Cycle time (sec)	St. Dev.
• Fell • Move • Clear	22.2 12.8 3.0	7.0
Total cycle time	38.0	

Yarder productivity

Over the two days of the study, 193 yarder cycles were recorded over haul distances ranging from 67 to 230 m, average haul distance 163 m (Table 3). Yarder swing times (raise and lower grapple) were timed from video observations. Inhaul and outhaul times were timed directly.

Table 3: Yarder cycle time elements

Element	Cycle time (sec)	St. Dev.
• Swing and raise grapple	23.0	
• Outhaul and grapple	55.1	20.0
• Inhaul	50.6	
• Swing and lower grapple	17.0	0.95
Delay-free total	145.7	
Delays:		
Operational	31.5	
Mechanical	2.2	
Personal	0.7	
Total cycle time	180.1	

For all cycles, average volume per cycle was 2.53 m^3 (2.98 trees/cycle * 0.85 m^3) extracted over an average haul distance of 163 m. Delay-free cycle time was 145.7 seconds or 2.43 minutes, which translated to average delay-free hourly productivity of 62.6 m^3/PMH (=24.7 cycles/hr * 2.53 m^3/cycle). Including observed delays for tail hold moves and yarder turns (16.0 sec/haul) resulted in an average cycle time of 2.70 minutes and hourly productivity of 56.3 m^3/PMH.

Prediction of Inhaul and Outhaul element times

For outhaul times, low correlations were found between outhaul time and haul distance. For the most common extraction method (grapple by buncher) over 115 observations, the following equation was derived:

Outhaul (sec) = 0.18*Distance+26.134 (r^2= 0.36)

For inhaul times, over 134 cycles were recorded with between three and five trees per haul. The following equation explains 47% of the variation in inhaul time:

Inhaul (sec) = 0.233* Distance + 6.189 (r^2= 0.47)

Grapple/breakout method

The different breakout methods resulted in different average number of trees hauled per cycle (Table 4). Most of the cycles involved breakout by excavator presentation (Buncher grappled). Twelve percent of all cycles were grappled using a spotter and only 7% by the yarder operator only. Of the spotted cycles, two thirds were from unbunched trees.

Table 4: Comparison of haul size per cycle by breakout method.

	N	Mean trees per grapple	1=significant difference at p>0.05)
Spotter	23	2.4	1
Yarder spotted	13	1.5	1
Buncher grappled	115	3.2	1
CSE buncher grappled	41	3.1	

The number of trees grappled per haul is a measure of the system's efficiency. When grappling trees from a track, an average 3.15 trees per haul were grappled; on the slope this averaged 2.65 trees. Most of the hauls (nearly 90%) from the track were from a very large bunch. Most of the on-slope hauls were from directionally felled trees.

In terms of grappling method, grappling with excavator assistance (presentation of bunches by excavator) was the most productive. This method enabled significantly more trees to be

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grappled per haul than using either a spotter (+33%) or yarder operator alone (113% increase). This is comparable to results found by Peterson (1987) who reported a study of yarder extraction of bunched vs. unbunched trees and found a 36% increase in trees yarded per haul. No significant difference (p>0.05) was observed between productivity of grappling from bunched/presented trees from large bunches and that from small bunches which were progressively accumulated ("bunch as you go").

Cable-secured excavator (CSE) bunching

Forty-one yarder cycles were recorded with bunches grappled by excavator while it was secured by cable. Half of these involved trees from a large bunch, with the excavator located on a track, and the rest occurred with the machine located on the slope, bunching machine-felled, unbunched trees. In each case, an average of over 3 stems per haul was extracted from both locations.

A spotter was sometimes used to grapple unbunched trees in a different area on the haul line while the excavator was occupied with bunching or moving. This enabled the excavator to finish its task; the following cycle would be a bunched/presented cycle. The spotter was responsible for shifting the tail hold excavator and the winch securing the excavator. On average, the number of stems per haul for CSE bunching/presentation showed no significant difference from that of the untethered excavator.

Processor productivity

A total of 123 processing cycles were timed and average delay-free cycle time was calculated at 35.6 seconds to process 3.03 logs per tree (Table 5).

Observed delay-free hourly productivity was calculated to be 86.0 m^3/PMH (101.1 cycles/hr * 0.85 m^3).

Table 5: Processor cycle time elements

Element	Cycle time (sec)	St. Dev.
• Process (Av. 3.03 logs)	33.0	15.7
• Clear slash	2.1	
• Clear logs	0.5	
Delay-free total	35.6	
Delays:		
Operational	11.4	
Mechanical	0.0	
Personal	0.9	
Total cycle time (min)	47.9	

Yarder delays

Operational delays due to the buncher averaged approximately 5 sec per haul, and commonly comprised situations where a presented bunch was not yet ready (still being accumulated by the buncher) at the point when the yarder grapple was poised for grappling. This value was approximately the same for extraction from progressively bunched or previously bunched (large bunches) trees.

Tail hold moves and yarder turns (including guy line moves) were the main contributors to yarder operational delays. A single major tail hold move comprised 50% of the total operational delay recorded. Short tail hold moves averaged only 1.4 minutes per observation. They occurred on average every 12 haul cycles and comprised only 10% of operational delays. Yarder turns comprised 13% of operational delays. Delays due to either processing or sorting comprised 4% of the total delay time.

Fewer tail hold moves were made when extracting from previously bunched large bunches (23 cycles/move) than in areas progressively bunched (8 cycles/move). A single major setting shift involved a tail hold move of approximately 700 m and took 104 minutes. This value was not included in the yarder's total cycle time. Social delays (meal breaks) were also excluded. A rope breakage which occurred on the last haul prior to the meal break was repaired during a meal break. On the second day of study, when one of the excavators was

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secured by cable, the tail hold attempted to move back up a spur and one of the yarder's working ropes became caught between the excavator's boom and stick. This incurred a delay of 17 minutes.

Processor delays

Processor operational delays were largely composed of waiting for work (i.e., no stems to process), 11.3 sec per stem or 24% of total cycle time). Interference from the sorting loader comprised only 0.05 sec per stem.

Estimates of costs

Costings were estimated using calculated productivity and representative costs from the INFORME forestry equipment survey (Forme, 2009). Estimated system cost based on daily production of 344 m^3/day (= 62.6 m^3/PMH * 5.5 PMH/day) is \$26.59/m^3.

An indicative comparison of cost estimates (given limited cycles from manually felled and unbunched areas) can be made between wood that was manually felled, and yarded using a spotter, and that from mechanically felled and bunched / presented timber from the cable-secured excavator (Table 6).

Table 6. Cost and productivity comparison of systems

System	Stems/ haul	Yarder m^3/PMH	Hauler PMH	Proc PMH	System Cost \$/m^3
Manual fell, unbunched, spotter yarded	2.0	42	5.5	2.75	34.68
Mech. fell and bunch, CSE presented	3.1	65	5.5	4.25	25.56
Manual fell, CSE bunched & presented	3.1	65	5.5	4.25	24.24

The comparison assumes that the main effect of mechanical felling is to facilitate bunching / shovelling and to replace 3 manual fallers. As previously discussed, the comparison shows the main effect of bunching / presenting is on the number of stems grappled per yarder cycle.

Conclusions

This study describes an innovative harvesting operation where system productivity was high despite a relatively small extracted piece size (0.85 m^3). The use of excavator bunching / presenting resulted in a significantly larger (+33%) haul size than conventional grapple yarding using a spotter (3.2 vs. 2.4 trees/haul). This translated to an estimated 23 m^3/PMH or 126 m^3/day extra production. Yarder cycle time when grappling from large bunches was not significantly more productive than that when grappling individual small bunches.

While one of the study objectives was to evaluate the cable-secured excavator in use, most of the observed cycles were recorded from the free-moving or untethered excavator. The contractor reported that since commencing operation in 2006, an estimated 70-75% of the areas logged by the crew were logged using free-moving excavator bunching and shovelling. The cable-secured method was reserved for areas judged too steep for normal methods, and used selectively, according to the situation.

As the use of excavator loaders for bunching on steep terrain (either cable-secured or free-moving depending on conditions) becomes more accepted in the industry, it is expected that yarder productivity will increase. In larger tree size, the same advantages of bunching in yarder operations should apply, such as increasing average haul size and reducing the number of rope and hauler shifts. Shovelling may aid access for yarder extraction to areas where there is a blind lead, or may even reduce the number of hauler setups (pads) required in a setting.

Further research will examine the extent of use of free-moving excavators on steep terrain, and bunching and shovelling productivity under differing terrain conditions.

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The costs stated in this report have been derived using estimates obtained from Informe Harvesting 2009 and 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.