HARVESTING TECHNICAL NOTE

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2019

Comparison of Felling Heads to Reduce Tree Breakage

Summary

Breakage during felling is a major contributor to the accumulation of slash on the cutover in harvesting operations. Current techniques, both manual and mechanical, have been identified as the main causes of felling breakage. This project compared two types of mechanised felling heads, a feller director ('dangle head') and a feller buncher ('fixed head'), to determine the difference in breakage when felling trees on moderate to steep slopes. Results showed that the relative break height of stems from the fixed head feller buncher was between 87 – 92% of mean tree height (MTH). Analysis of harvester wood flow management software (STICKS) data from the trial confirmed that the average merchantable stem length of trees felled by the 'fixed head' was significantly longer than stems felled by the 'dangle head'.

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INTRODUCTION

Erosion and debris flows from forestry operations is currently a live topic. Debris flows are a liquefied mixture of mud and woody debris from harvesting residues and wind damaged trees, (commonly called 'slash'). Severe weather events in the Nelson and Gisborne regions in 2018 caused localised debris flows to extend beyond the forest boundary on to neighbouring properties.

These larger scale debris flow events in Tasman Bay and Tolaga Bay (and the recent sediment issues in the Marlborough Sounds) have caused significant damage to downstream land use. Concerns have been raised about industry practice and the efficacy of management controls over plantation forestry, (Robertson 2018; Wright *et al.* 2019). Public perceptions are that these events are due to poor forest management practices (Rishworth 2018; Macfie 2018).

With manual felling, mature radiata trees usually break at between 60% and 75% of their mean tree height (MTH) when they hit the ground (Murphy 1984; Fraser *et al*. 1997). Studies in Kinleith Forest derived a relative break height of 68% of MTH for trees aged 20 – 28 years and 78% of MTH for 18 year old trees (Piebenga, 1989). The causes of this breakage are predominantly unknown, but where it has been identified, contributing factors are: tree height, diameter at breast height (DBH) and factors in the tree landing zone (Murphy & Gaskin, 1982). The broken pieces from these trees are frequently short, of small diameter, relatively low value, and costly to recover. As a consequence, they are often left on the cutover.

A recent study of stem breakage in one forestry company's operations showed that manual felling breakage was between 69 and 83% of MTH, while trees mechanically felled ranged from 70% to 86% (Prebble 2015). This study also identified crossing terrain undulations and crossing other stems as significant causes of breakage. Targeted studies of the Bell TF120 and Timbco T445 felling machines in 1996, in Kinleith forest found the relative break height was 80% of MTH (Lambert 1996).

It is estimated that between 10-15% of a tree's total standing volume, or 50-100 cubic metres (m^3) per hectare, is left behind on the cutover as branches, needles, and stem wood after harvesting operations. The volume varies with crop, terrain, harvest system and operator skill (Hall & McMahon 1997; Hall 1998; Hall 2007), but felling breakage is considered a major contributor to the accumulation of this slash.

Figure 1: TimberPro 765 feller buncher with Komatsu KS800 fixed wrist felling head

An industry workshop sponsored by FGR in August 2018 supported a project to investigate reducing stem breakage from felling as a priority for action in 2019 (FGR, 2018). This included investigating whether alternative mechanical felling technologies for steep terrain would give greater control over tree felling direction and reduce the amount of breakage.

The project included an evaluation of felling head design and harvesting machine configurations. It was perceived that the difference between the feller director and feller buncher would be better control from the feller buncher over the rate of fall (velocity), thus limiting the impact when the tree hits the ground. Recent publicity over the TimberPro TL765D with KF800 feller buncher (Figure 1) prompted FGR to take a closer look at the fixed wrist (fixed head) feller buncher concept (Ellegard 2019).

OBJECTIVES

The main objective of this project was to compare two different types of mechanical felling heads working alongside each other in similar conditions, by measuring the length and diameter of the felled stems. This would compare the amount of felling breakage occurring with the feller-director (“dangle head”), with that generated by the feller buncher (“fixed head”).

METHODS

Study Site

The trial was planned to take place in a ground-based setting in Tasman Pine Forests Ltd.’s Waiwhero Forest in Nelson. The harvest area, Ridge Rd 438, was a block of 28 year old radiata pine on rolling terrain with a convex slope bounded by a dry stream around the bottom edge of the setting. Average slope was around 21º with steeper incised gullies of up to 23º around the stream edges. According to stand records, the mean tree height (MTH) was 38.0m.

Crew Description

The participating contractor was Mechanised Cable Harvesting Ltd (MCH), a combined cable/ground-based harvesting business with two operations based in Wakefield, Nelson. Due to their swing yarder being out of service, a ground-based block was selected for the trial. The area was being extracted uphill, using a bunching machine and a skidder. MCH has two different types of felling machine:

1. John Deere 909 self-leveller with a Satco 630 feller director (‘dangle head’)
2. TimberPro TL765 self-leveller with a Komatsu KF800 feller buncher (‘fixed head’).

Each machine has a dedicated operator with winch-assist capability available to them, but both chose not to use it in the trial setting.

Study Design

The original plan was to divide the block into two equal halves and over a period of 4 days, fell one half with the ‘dangle head’ and the other half with the ‘fixed head’. The following measurements were planned:

- The number of trees felled per hour.
- Activity sample of the elements in the felling cycle.
- A sample of stem dimensions after felling but before extraction, including large end diameter (LED), small end diameter (SED) and length.
- Dimensions of all trees after they were processed using data from the STICKS Harvester Woodflow Management System (Gibson & Herries, 2015).

Prior to commencement of the trial, operational constraints resulted in the area of the setting scheduled for the ‘dangle head’ being felled before the research team arrived. This meant that the STICKS data was the only information that could be collected from the ‘dangle head’ working in the trial block.

To capture some time study information on the performance of ‘dangle head’ machines, a similar unit, a John Deere 909 with a Waratah L95 feller director was studied. This machine, owned by Wood Contracting Nelson 2014 Ltd. was felling fire damaged pine in Tasman Pine Forest Ltd.’s Moutere Forest. As the operation was a salvage job, it was not possible to take detailed measurements of the trees or volume produced. Data collected included the number of trees felled per hour and an activity sample of the elements in the felling cycle.

To compensate for the limited data available from the Waiwhero trial, a supplementary study was arranged to observe the ‘fixed head’ feller buncher felling in a grapple carriage operation in Nelson Forests Ltd.’s Stanley Brook Forest. Stem size and terrain profiles were similar, but the TimberPro operator was using the winch assist in this operation. Cycle time and activity sampling data were collected but no STICKS data were available.

RESULTS

Felling Trial: Waiwhero Forest

Figure 2: The ground-based trial area after felling

Figure 2 shows the ground based trial area in Waiwhero Forest after felling. All of the bunched trees shown in the photo have been felled by the TimberPro TL765 (centre of photo). The extraction method of bunching with the Volvo excavator loader and extraction with the John Deere skidder can be seen to the left of the photo.

The TimberPro TL765 feller buncher was felling and bunching about one tree per minute in the Waiwhero forest trial. It should be noted that there was significant windthrow at the bottom of the setting and the operator was having to clear these trees to gain access to the standing trees, resulting in slower than usual felling times and increased time moving between trees. Unfortunately the same process using the 'dangle head' machine was not observed so direct comparisons between the two machines in similar conditions could not be drawn.

An activity sample taken of the TimberPro TL765 felling in the trial area, showed that 84% of the cycle time was spent actively felling trees, including the 'walk between trees' element (Figure 3). The remaining 16% of the time was spent clearing access to the trees, repositioning from the bottom to the top of the slope, and idle time. There was a significant amount of windthrow around the stream edges which meant that the machine had to spend more time clearing damaged stems to access the standing trees.

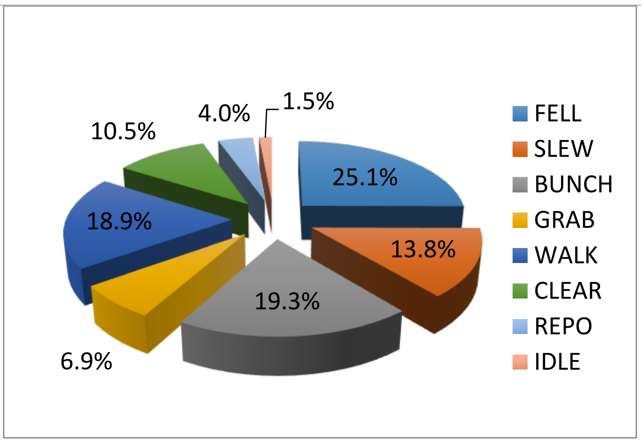

Figure 3: Activity sample of TimberPro 765 fixed head: Waiwhero Forest

The fell component of the cycle (25%) included operation of the chainsaw to cut the tree, and holding the tree in the grapple during felling. It did not include the grab function (7%). Of particular interest in Figure 3 is the time spent slewing (14%) with the tree held vertical and bunching the stem for extraction (19%). The operator of the TimberPro was very particular about the presentation of wood for the next phase of the operation so he went to some effort to ensure bunches were correctly aligned. Time spent clearing around the tree (10%) is representative of the windthrow in the lower portion of the setting.

A small sample of 19 stems that had been felled in different directions was measured in the area felled with the 'fixed head', to determine any indicative differences in stem breakage. Of the stems measured, 58% had been fallen uphill, 21% had been fallen across slope and 21% had been fallen downhill (Table 1).

Table 1: Measured stem dimensions after felling but before extraction

Felling Direction	N	LED cm	SED cm	Length m	% of MTH
Uphill	11	46.0	10.6	33.7	89
Across Slope	4	40.0	8.0	34.8	92
Downhill	4	42.8	16.5	28.9	76
Total	19	44.1	11.3	32.9	87

Based on the MTH of 38m derived from the stand data, the relative break height of trees in the trial area was 89% when felling uphill, 92% when felling across slope and 76% when felling downhill. Table 1 indicates that

stems felled across slope and uphill were longer and broke at a smaller SED than those stems felled downhill, meaning less breakage. While felling cross slope and uphill is difficult and hazardous for manual fallers, the same constraints do not apply to mechanical felling. Note that the sample size of stems measured was relatively small, so these results are indicative only.

From the STICKS data, a total of 1,381 stems (1,751.7 m^3), were harvested in the Waiwhero forest trial, with 791 felled using the 'dangle head'; and 590 felled with the 'fixed head'. The piece size in the 'dangle head' area was slightly smaller at 1.138m^3 compared to 1.426m^3 in the 'fixed head' area. The average DBH over bark (DBHOB) of the stems in the 'dangle head' area was also marginally smaller at 354mm, compared to 362 mm in the 'fixed head' area.

The STICKS data from the stems processed in the Waiwhero forest trial area were analysed by small end diameter distribution (described as Top Diameter Class in Figure 4).

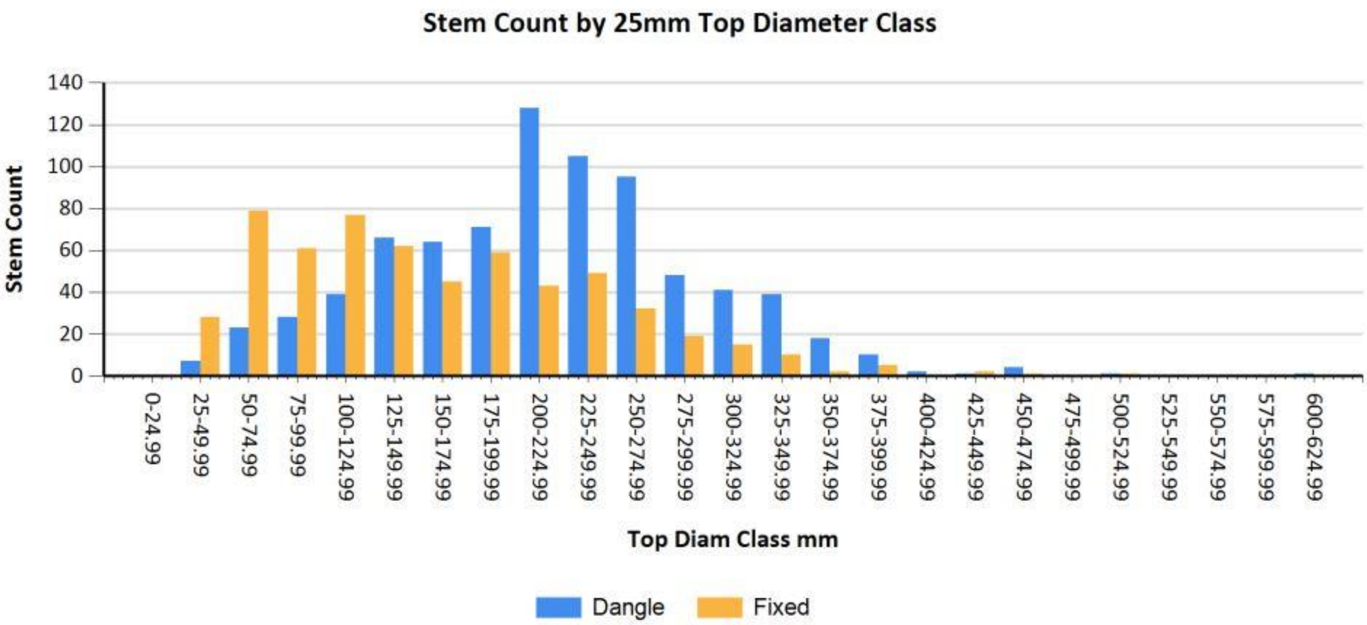

Figure 4: STICKS analysis of small end diameter class for Waiwhero trial area

The stems felled with the 'dangle head', (blue bars), showed a relatively normal SED distribution with the average small end diameter of 21.8cm. The diameter distribution of the trees felled with the 'fixed head', (orange bars), showed a large proportion of trees with smaller top diameters, averaging 15.8cm. Despite the larger piece size of the trees felled with the 'fixed head', the average small end diameter of the sample was 27% lower than that of the trees felled with the 'dangle head', indicating less breakage.

Analysis of the processed trees by stem length distribution is shown in Figure 5. This graph shows merchantable stem recovery (after processing), not full tree length.

Average merchantable stem length from the area felled by the 'dangle head' was 16.05 metres, while the average length of merchantable stems from the 'fixed head' area was 22.51 metres. Despite the slightly smaller average piece size in the 'dangle head' area, the trees felled with the 'fixed head' were significantly longer than those felled with the 'dangle head'.

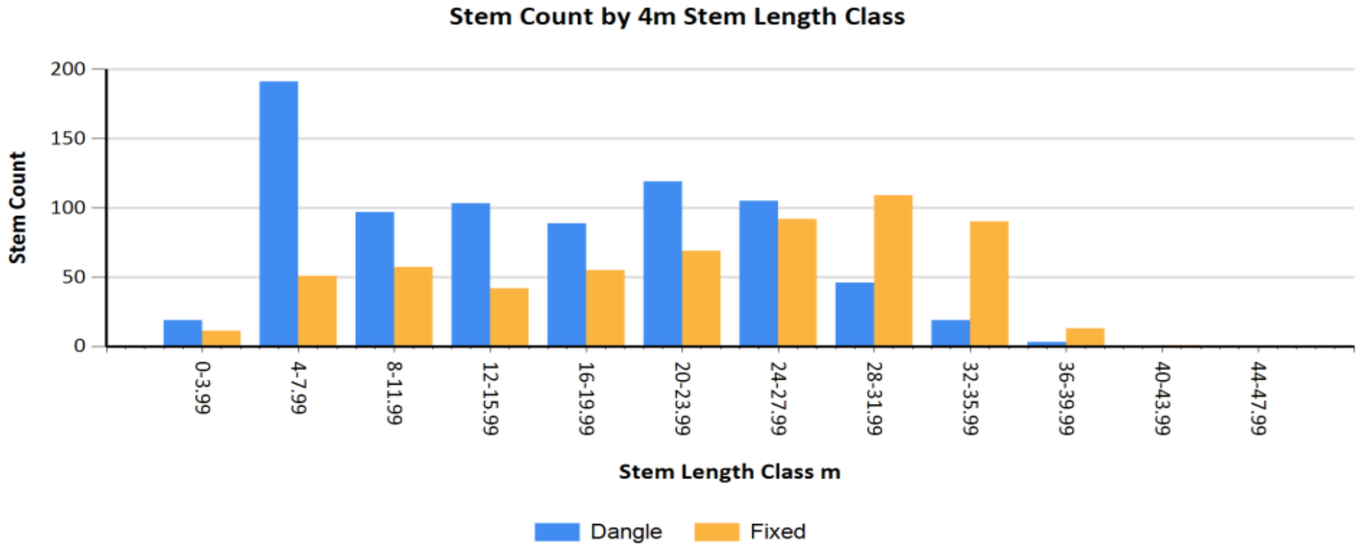

Figure 5: STICKS analysis of processed trees by stem length distribution class

While the objectives of the trial focused on breakage at the top end of the stem, occasional damage occurring at the butt end of the tree was also recorded when using the "fixed head" (Figure 6).

This damage was in the form of:

- Stems breaking off just above the grapple arms of the felling head. This only occurred to two or three trees and they tended to be smaller in butt diameter, but the issue could be significant if it occurred in high value pruned stands.

- Damage to the butt of the stem. This occurred just above the saw where serrated spikes designed to stop the tree sliding sideways bit into the cambium layer of the trunk. If felling in pruned stands, the damage may require a sloven to be cut off the log, reducing value recovery.

Modifications have subsequently been made to the serrated spikes on the KF800 head to reduce this damage.

Figure 6: Damage caused to the butt of trees felled with the KF800 felling head

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Results: Felling with a Dangle Head in Fire Damaged Trees.

To collect some data on felling using the ‘dangle head’, in similar terrain and tree conditions to the ‘fixed head’ trial, an adjacent harvesting operation was observed using a John Deere 909 with a Waratah L95 felling head, to fell and bunch trees for grapple yarder extraction. The piece size was similar to the Waiwhero trial and the JD909 was working without winch assist. A separate shovelling machine was being used to bunch the stems for the swing yarder.

Activity sampling data are summarised in Figure 7. Analysis of these data show that 90% of the John Deere’s felling cycle was actively felling trees. The remaining 10% was spent clearing debris to gain access to the trees.

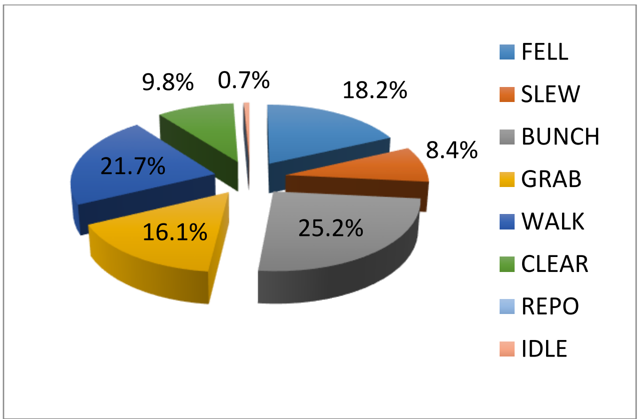

Figure 7: Activity sample of John Deere 909 with Waratah L95 dangle head

At 18% of the total cycle, the proportion of fell time was lower than with the fixed head (25%), as was the time spent slewing with the tree upright, in the grapple arms (8% vs. 14%). Bunch time (moving the stems into bunches once they were on the ground) was a greater proportion of the cycle at 25% vs. 19%. This operator felled trees in both directions (uphill and downhill), so there was no repositioning element in his felling cycle. While the TimberPro could also fell trees in both directions, the operator preferred working uphill from below the standing trees.

During the period of observation, the John Deere 909 felled 105 stems per hour, but it should be noted that, being a salvage situation, the amount of breakage occurring was not considered to be an issue and a separate bunching machine was present to assemble the stems into drags for the yarder.

Results: Felling with the Fixed Head in a Grapple Carriage Operation.

The additional data collection was undertaken in Nelson Forests Ltd.’s Stanley Brook Forest where MCH Ltd were operating a Thunderbird TMY 70 hauler with a Falcon Claw grapple carriage. The TimberPro TL765 operator was using the winch-assist when felling and bunching for the grapple carriage (which was his preference).

The method used was to walk to the bottom of the setting and work back up the slope, felling trees in the process. The felling direction was mostly downhill although extraction at the top of the setting was initially across slope until the mobile tail hold was able to move further down the ridge.

Stem alignment was slightly off-set from the winch line and the operator swung trees either side of the connecting chain as he assembled the trees into bunches. The TimberPro operator was attempting to bunch stems into grapple sized drags for the carriage. His anecdotal comments were that if he had more accurate information on the size of the stem being harvested, he could improve the productivity of the hauler cycle by assembling the correct sized drag.

Activity sampling data from the felling for the grapple carriage are summarised in Figure 8.

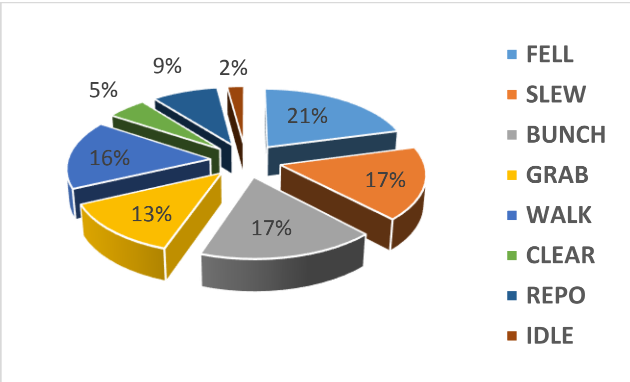

Figure 8: Activity sample of TimberPro TL765 felling cycle in the cable extraction area

The felling component of the cycle at 84% in the cable area was the same as that in the Waiwhero trial. Although there was less clearing of windthrow to gain access to the trees (5% vs 10%), there was more time spent repositioning to start a new strip (9% vs 4%). The slew component was slightly higher than the Waiwhero trial (17% vs 14%) and this could be a

reflection of the operator slewing trees either side of the winch rope as he was working up the slope.

Productivity when the machine was winch assisted was 70 trees felled per hour. The operator commented that having the winch line attached increased machine stability, particularly when slewing and placing the stems. Other comments were that some of the bigger stems (over 60cm in diameter) could be felled with a single cut, which would have been a challenge with the 'dangle head'.

A small sample of stump heights were measured in the two adjoining blocks where both types of head had been used (Table 2).

Table 2: Sample of stump heights measured

Felling Head	N	Average Height	Range cm	Slope
Dangle	13	18.4cm	2 – 29	32º
Fixed	13	16.7cm	9 – 30	28º
Difference	0	1.7cm	-	4º

Results showed that there was little difference between stump heights in the area felled with the dangle head compared to the area felled by the fixed head.

DISCUSSION

The activity sample data collected on the two types of head demonstrated the different operating techniques involved and the effect they had on the felling cycle. The elements in the felling cycle comprised: grab, fell, bunch and walk. Interestingly, the activity sample data collected on the two types of head showed that even with the different operating techniques involved, the felling cycles were similar proportions of the total cycle times. From the observations made, the performance in the Waiwhero trial area was influenced by the amount of windthrow around the lower reaches of the setting and the amount of clearing that had to be done to gain access to the standing trees.

The most compelling outcome from this study has been the results from the STICKS data, which clearly showed the difference in merchantable stem length achieved between the two types of felling head. This is a clear indication that felling breakage at the stump can be reduced by introducing a fixed head. The additional value recovered from extracting longer tree stems has not been balanced against the daily cost of the felling machine in this study.

The other indicative result from this study is that felling breakage can be reduced by changing the pattern in which the trees are felled, i.e. felling uphill and across slope as opposed to straight down the hill. The initial small sample studied did show potential for reducing tree breakage by cross slope felling using a feller buncher.

A comparison with earlier felling breakage studies is also interesting. Murphy (1984) found that the majority of felled trees broke at a relative mean break height of 83% of average tree height (37m). In this study where mean tree height was 38m, the small sample of cross-slope and uphill felled trees broke at 92% and 89% of mean top height, respectively.

Break height relative to total tree height in this study was comparable to those of other studies (Table 3).

Table 3: Summary of other tree breakage studies (Andrews 2015)

Author	Location	Breakage	Relative Break Height
Manley (1977)	*Kaingaroa Forest*	*99.30%*	*67% (age unknown)*
Murphy & Gaskin (1982)	*Whakarewarewa Forest*	*99%*	*70% (age 41)*
Murphy (1984)	*Tairua Forest*	*73%*	*83% (age 43)*
Twaddle (1987)	*Kaingaroa & Kinleith*	*% unknown*	*66% (age 31)*
Lambert (1996)	*Kinleith Forest*	*84 – 100%*	*76% (age 25-30)*
Fraser et al, (1997)	*New Zealand*	*69%*	*67% (age 29)*

Another aspect arising from this study was the benefit of having an integrated approach to the harvesting operation, ensuring that each phase enhances the efficiency of the next phase. The TimberPro operator took the time to ensure bunches of stems were correctly aligned for extraction and that bunch sizes were appropriate for the system being used and the terrain it was working on.

Without data on the bunching machine working behind the felling machine, the advantages of controlling the tree to the ground, minimising breakage, and correctly aligning the felled stems with the fixed head could not be quantified. Combining all of these functions into the felling process would eliminate the second machine, potentially reducing costs and improving value recovery.

RECOMMENDATIONS:

From the outcomes of this study, the following recommendations are made:

1. Further validate the indicative conclusions from analysis of STICKS data on steeper terrain. Set up a study to measure the effects of 'fixed head' felling on grapple yarder performance and system cost.

2. Provide the machine operator with tree size and volume information displayed live in the cab to assist in determining optimum bunch size.

3. Integrate payload predictions with machine GPS location so that accurate bunch sizes can be assembled as the trees are being felled.

4. Make GPS coordinates of bunched trees available to enable automation of the yarder outhaul function in the future.

5. Investigate "fell and delimb" options to determine whether delimbing during felling would reduce stem breakage and the volume of unmerchantable stem wood left on the cutover.

CONCLUSION

This study showed that use of the 'fixed head' will increase the stem length available, and enable correct alignment of the stem in bunches for the grapple carriage. This provides the opportunity to maximise yarder productivity and increase the value of products from the forest resource. While stem breakage during felling was not eliminated there is no doubt it was significantly reduced.

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