PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: forestgrowersresearch@fgr.nz
Web: www.fgr.nz

Programme: Harvesting & Logistics

Task No: 1.6 **Report No. H062**

Productivity potential of the Harvestline Cable Yarder: Results of three case studies

Authors:
Hus Abeyratne and Rien Visser

Research Provider:
School of Forestry
University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch, New Zealand

Date: 13 Feb 2023

TABLE OF CONTENTS

EXECUTIVE SUMMARY 3
INTRODUCTION 2
METHODS 7
RESULTS 9
CONCLUSION 16
ACKNOWLEDGEMENTS 17
REFERENCES 17

Disclaimer

This report has been prepared by University of Canterbury School of Forestry for Forest Growers Research Limited (FGR) subject to the terms and conditions of a Services Agreement dated 21 November 2018.

The opinions and information provided in this report have been provided in good faith and on the basis that every endeavour has been made to be accurate and not misleading and to exercise reasonable care, skill and judgement in providing such opinions and information.

Under the terms of the Services Agreement, University of Canterbury School of Forestry's liability to FGR in relation to the services provided to produce this report is limited to the value of those services. Neither University of Canterbury School of Forestry nor any of its employees, contractors, agents or other persons acting on its behalf or under its control accept any responsibility to any person or organisation in respect of any information or opinion provided in this report in excess of that amount.

supported by forestgrowers commodity levy

EXECUTIVE SUMMARY

New Zealand steep slope harvesting mainly uses the larger-sized North American cable yarders. These are powerful, able to extract large turns, but are also expensive to operate. Smaller excavator-based yarders may provide an effective alternative, especially where average piece size is not excessively large, but also for woodlots where machine relocation cost becomes a more significant factor in total harvesting costs. The smaller size and absence of guy lines provides ease of setup, other machines can work closer to the yarder, and has the ability to carry out rapid line shifts.

Traditionally, excavator-based yarders have been viewed as a niche alternative, for example partnering with a ground-based system to extract timber on smaller steep areas on a harvest area that is primarily ground-based. Continuous improvement of the excavator yarder includes increased power and hence extraction speed, but also technology improvements to automate line movement. The Harvestline is an example of a modern, excavator-based yarder. EMS in Rotorua have built around 70 Harvestline machines over the last 20 years, which have been sold into both the domestic, and international markets.

The goal of this study was to establish a reference for the productivity potential of modern excavator yarders. Three operations were chosen for the time studies, whereby all three Harvestline yarders were relatively new machines, operated by crews who were respected for being highly efficient, operating a motorised grappled carriage (in each case an EMS Hawkeye), and in forest blocks with good productivity potential.

A manual time study was conducted at each site, and included a GPS attached to the grapple carriage to measure line speed. In total 1030 production cycles were recorded; 353 cycles in Mosgiel (average terrain slope 30deg, extraction distance 105m and piece size 1.7m^3), 431 cycles near Rotorua (30deg, 96m, and 1.9 m^3), and 246 cycles in Opotiki (35deg, 181m, and 2.3m^3).

The resulting average cycle times were 1.37 and 1.4 min for Mosgiel and Rotorua, yielding delay-free productivity of 73 and 77 m^3/PMH respectively. These values are very consistent, which can be expected given the similar site conditions. The Opotiki average cycle time was 2.45 minutes, attributed to the much longer extraction distance, but with large average piece size still achieved a delay-free productivity of 58 m^3/PMH. From the GPS, it was possible to establish average carriage speed, which was 4.0, 3.8 and 4.0 m/sec for the outhaul phases, and 3.8, 3.0 and 2.8 m/sec for inhaul (loaded) respectively. As expected, outhaul was consistent, but inhaul shows the slowing effect of average piece size.

This data indicated that a modern excavator-based yarder, working at a variety of distances, piece sizes and terrain, is a very capable machine. It was very productive out to about 250 m, and then the productivity started to drop, but that is also similar to other yarder options. While mechanically felled timber is typically pre-bunched and easier to grapple, the system also did very well in manually felled areas. All three operators interviewed liked the reliability, cabin layout of the machine, safety features and the commended the ease of operating the Hawkeye grapple.

INTRODUCTION

Cable yarding systems remain a common harvesting system for steep slopes, with just over 300 crews operating full time in New Zealand (Visser and Harrill, 2018). Much of New Zealand's plantation forests in are on steep terrain, but also the harvesting of smaller woodlots is becoming more prevalent (Raymond, 2010). Harvesting is one of the biggest costs in managing a forest and employing cable yarders in smaller woodlots can be expensive due to high costs associated with setting up the cable yarder and woodlots not having the required wood volume to justify the frequent shifts (Heinimann, et al. 2006; Raymond & Hill, 2018).

Excavator-based yarders, also called Yoaders in North America, are built using excavator bases, attaching an integral tower typically to the boom, and using two or three winches powered by the excavator (Torgersen & Lisland, 2002). Excavators are considered a robust and low-cost base given their relative abundance with use in construction, farming and forestry (Talbot, et al. 2014). Being smaller with a lower centre of gravity, excavator-based yarders can be more stable, use the boom to support it from tipping forward, and hence typically do not require guylines. Without guylines they work well under space constraints and allow for other machines to work in close proximity.

Because of the higher harvesting costs of cable yarder systems, the average logging rate being about $12 more than ground-based systems (Visser, 2022), they are a focus for operational efficiency gains (Gingras, 2013; Raymond, 2018). These challenges are not unique to New Zealand, with work on improving steep slope extracting systems reported in Scotland (Tuer, et al. 2013), South Africa (McEwan, et al. 2013) and Ireland (Devlin & Klvac, 2014).

While level of deflection is correctly referenced as the primary factor influencing productivity performance of a cable yarder, factors such as stand volume, stem size, extracting distance and terrain slope will also influence productivity (Devlin & Klvac, 2014). For the yarder system itself, correct choice of rigging configuration is important, and a grapple carriage provides the opportunity to work without choker-setters (Delvin & Klvac 2014; Harrill 2018). However, choker-setters can attach more trees, increasing production per cycle, but also bring down the utilisation of the machine and increase costs (Malietoa, 2014).

The method of felling is yet another important factor, and Holmes (2017) showed that manually felled logs result in the lowest productivity, as compared to bunched stems (Figure 1), and stems fed to the grapple directly by an excavator resulted in the highest productivity.

Figure 1: Mechanically felled trees, ready to be extracted by mechanised grapple.

The use of winch-assist systems is allowing ground-based systems to extend their operating range onto steep slopes (Visser and Stampfer 2015). However, the cable yarder is still the common machine option to carry out steep slope harvesting (Talbot, et al., 2015) and used worldwide due to safer operations and less soil disturbance (Kühmaier, et al., 2019). Winch-assist has also been extensively used to support cable logging, mainly by providing the opportunity to mechanise felling.

The 2018 yarder survey showed the biggest increase in yarder types was associated with the larger swing yarders – for example the Madill 124 or the T-Mar 650 Log Champ (Fig 2), but also excavator-based yarders (which in NZ apart from one Alpine Shovel Yarder is almost exclusively the Harvestline). A common problem for cost efficient cable logging is that forestry is moving into steeper yet smaller woodlots (Gingras, 2013; Raymond *et al.* 2016). Within this new context, large cable yarders become too costly to operate due to them being expensive and time consuming to move and set up, and the smaller volume of a woodlot not able to justify the costs.

Figure 2: The excavator based HarvestLine (left) is able to operate, in comparison the much larger full size swing yarder (T-Mar 650 shown on the right) requires a good level landing location to operate.

It is important to note that there are many smaller guyed and unguided yarders in existence (McMonchie, 1979; Liley 1989). To tackle issues such as smaller harvest areas, poor infrastructure, increased operating costs and declining profitability for forest operations, countries such as Scotland (Tuer, et al. 2013), Japan (Yoshimura & T, 2013), Ireland (Devlin & Klvac, 2014), America (Largo, et al. 2004), South Africa (i.e. Alpine yarder - Raymond & Hill, 2018),
and New Zealand (with i.e. Harvestline), have developed excavator-based yarders.

While excavator-based yarders have been operating a long time, there are few studies on them. Largo, et al. (2004) working in Idaho, showed that excavator-based yarders took significantly less time to move between different corridors and with modern winch systems had an average cycle time of about 4.35 minutes. In Scotland, Tuer, et al. (2013) working with a "standard" Daewoo 220 and an improved hauling-in mechanism on a Volvo 360, showed them working with a large range of load sizes successfully, being 0.2 – 10.9 t for the Daewoo and 0.5 – 6.0 t for the Volvo 360. Ellegard (2020) reported on a Harvestline working in the Kaingaroa forest on relatively flat ground, also capable of pulling stems up to 7.0 tonnes. They worked on flat ground due to the sensitivity of the soil on site.

The goal of this project was to establish the productivity potential a modern excavator-based yarder system in a New Zealand plantation forestry setting. Three case studies were chosen to get a good robust data set, and variability was reduced by only choosing experienced crews (as identified by the manufacturer), operating in a good setting (as identified by the forestry company). In all three locations a modern Harvestline was used operating a Hawkeye motorised grapple using a running skyline configuration.

The Harvestline is manufactured by Electrical and Mechanical Services Ltd (EMS), based in Rotorua. They have built approximately 70 machines that are working throughout the world. The Harvestline system includes the collapsible tower extension for the boom, the winch set, as well as the operating system. A client can either provide their own excavator (with a 30+ tonne base) or EMS will acquire the base machine.

METHODS

Productivity - Time Study

An elemental time study with a stopwatch was completed at each of the three locations. The yarding cycle was broken down into four elements:

Carriage out: carriage leaves the landing until it is above the stem(s) to be picked up and the carriage is starting to being lower directly on to them.
Grapple: mechanised grapple lowered onto, grappled the stem(s), and might be raised to break out the stems. Elements is complete when loaded grapple carriage starts to return to yarder.
Carriage in: loaded carriage moves toward the yarder until it is back over the landing area.
Unhook: stems placed on landing, potentially also slewed into a better position, and element ends as soon as the carriage starts moving out of the landing.

All other time not part of the productive cycle was recorded as delay and categories as operational (being delayed by other parts of the operation), mechanical (breakdown of any part of the yarder system), or personal (operator break).

Distance out for each cycle was measured using a range finder sighted to the carriage (if possible), and this was also cross-checked with known reference points along the terrain.

The number of pieces extracted each cycle was recorded and categorised as either a large diameter stem, small diameter stem or a (broken) top. At least 20 stems were measured (either manually or by the processor on site) to provide an estimate of average piece size. This was then also cross-checked against the company inventory information.

A GPS was attached to the carriage to gather details on carriage speed, and data downloaded at the end of each day and uploaded to ArcMap for visualisation and evaluation. Velocity was calculated for the ‘Carriage Out’ and ‘Carriage In’ part of each cycle. The KML files from the GPS device were converted into Excel files showing the X and Y coordinates at each time stamp (set at 3 sec intervals). The from the landing to the grapple point, the distance was calculated by:

$$Distance = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2}$$

The line speed is the distance divided by the time taken for the carriage to cover that distance as plotted by the GPS coordinates.

Figure 3: Example output of GPS unit tracking the carriage and overlay on GoogleEarth Image of forest area. The Harvestline landing area (red square) and mobile anchor line shifts (yellow triangles) area readily visible.

Site description

The following three Harvestline operations were studied and described in more detail below:

1. Roxburgh Contracting working for Wenita Forest Products in Waihola, south of Mosgiel.
2. Harper Logging working in the Kaingaroa Forest for Timberlands Ltd.
3. STR Logging working in a woodlot near Opotiki, managed by Dodd Forestry.

Mosgiel – Roxburgh Contracting Ltd

Waihola Forest is managed by Wenita Forest Products and is 20 minutes south of Mosgiel, in Otago. The stand was pruned *Pinus radiata.* with an average piece size of 1.7 tonnes. While normally fully mechanised, the stems extracted were predominantly motor-manually felled due to the self-levelling feller being out for repair.

The Harvestline base machine was a Sumitomo SH460 HD (46t) and the tail hold used was a smaller CAT machine. The average slope was 30 degrees, and the tail hold was located 210m from the yarder, which was pulling over broken terrain. Figure 4 shows the general layout, with the tree butts nicely presented to the extraction direction making for efficient grappling for the operator.

Figure 4: Left - Harvestline working across the gulley with good deflection, and Right- Harvestline with operator Blair.

One difficulty that arose from this corridor was that the wire ropes snagged on other stems and stumps at the top of the ridge (circled - Figure 5). This caused the cables to jump up after they were freed, having the potential for some damage to the cables. Once stems had been pulled up, there was a tendency for some of these pulled stems to slide back down due to the Harvestline operating right at the edge of the ridge and slash on the slope. However, these stems would only slide about 5-10 metres off to the side of the yarding corridor and the operator could easily swing the yarder in either direction to pull these logs back up.

Figure 5: The extracting corridor as seen from the road (left, on which the tail hold was located (right). Another important aspect seen here is the broken terrain, through which logs were pulled over.

Rotorua – Harper Logging

Kaingaroa Forest is managed by Timberlands Ltd. and the site was 40 minutes southeast of Rotorua. The stand was pruned *Pinus radiata*. with an average piece size of 1.9 tonnes. Felling was motor-manual, and the crew was also pulling out slash from the gully.

The Harvestline base machine was a Doosan DX 380 LC (38 tonne machine). The average slope was 30 degrees, and the tail hold was situated 150 metres from the yarder on the opposite ridge. Extraction was carried out from right to left (arrow – Figure 6).

Figure 5: Left showing the direction of work across the slope and right the Harvestline with operator Hemi.

Figure 7 shows the second setting. Extraction moved from left to right (arrow). The operator, Hemi, was working from the immediate front and then gradually clearing stems out to the tail hold. One distinct advantage seen was that logs did not snag on other logs, and it was an easier extraction.

Figure 7: Rotorua setting, note the presentation of stems.

Opotiki - STR Logging Waiotahi

This study was done in a woodlot of 1,000 hectares area, managed by Dodd Forestry Ltd, located approximately 15 minutes south of Opotiki. The stand was pruned *Pinus radiata,* felled motor-manually, and the average piece size was 2.3 tonnes.

The Harvestline base machine was a Komatsu PC 400 LC (40t) with a custom cab by EMS Rotorua. A bulldozer was used as a tail hold situated 440 metres away from the Harvestline (Figure 8 - red star). For the last two corridors a stump was used as tail hold where the dozer could not get access. Average terrain slope was 35 degrees and the tail hold located 440 metres from the yarder. The following figures show the site and landing as seen from the ridge on which the Harvestline was located, from the access road and from the cab.

Figure 8: Harvest area from the perspective of the HarvestLine location, with the red star showing the location of the tailhold. Right the Harvestline with operator Fletcher.

Figure 9 show the landing where space was limited. Due to this unique landing layout, grapple excavators were used to shovel logs down to the processor next to the road.

Figure 9: Opotiki operation as seen from the access road.

RESULTS

A total of 1030 cycles were recorded at the three different Harvestline sites:

- Mosgiel: 353 cycles (over three days) with the following averages - piece size of 1.7 tonnes, cycle time of 1 minute 22 seconds, extraction distance of 105 metres and delay-free productivity of 86 t/PMH.
- Rotorua: 431 cycles (over 3 days) with the following averages - cycle time of 1 minute 24 seconds, extraction distance of 96 metres and delay-free productivity of 76.7 t/PMH.
- Opotki: 246 cycles (over two days) with the following averages - piece size of 2.3 tonnes, cycle time of 2 minutes and 27 seconds, extraction distance of 181 metres, and delay-free productivity of 58 t/PMH.

Table 1 shows the range of data at each site (including mean, 5th and 95th percentile values), including distance, cycle time (also broken down by individual elements), as well as the productivity per cycle.

Table 2: Cycle time and Productivity values for each of the three case studies.

	Ave (5th and 95th %)		
	Mosgiel	**Rotorua**	**Opotiki**
Distance (m)	104 (35-180)	89 (40-140)	180 (53-283)
Cycle time (s)	82 (37-132)	82 (49-128)	148 (63-243)
Each element within the cycle			
Carriage Out (s)	25 (10-40)	24 (11-40)	44 (22-65)
Grapple (s)	24 (10-55)	23 (8-54)	32 (10-75)
Carriage In (s)	29 (7 – 53)	31 (15-50)	68 (20-123)
Stem Drop (s)	4 (2-7)	4 (2-6)	4 (2-10)
Productivity per cycle (t/PMH)	86 (35–167)	83 (0-165)	67 (32-132)

Basic trends can already be seen in Table 1, such as the higher average cycle time and hence lower productivity in Mosgiel being driven by the higher extraction distance. Both the time to grapple the stems, as well as the time to drop the stems at the landing, were very consistent across all three case studies. This supports the premise that all three crews were very professional and efficient.

Using the GPS data, it is also possible to establish the average velocity for both Carriage Out and In. As expected in all three case studies Carriage Out (not loaded) is faster than Carriage In. Carriage In also has a greater range in speeds as it will depend on the turn volume. There is still a considerable range in Carriage Out velocities, and at least some of this can be explained by the operator looking at the video screen identifying stems to grapple. The grapple speed for Carriage In for Optiki was lower, despite it having a longer run to maintain optimal speed. This can in part be explained by the larger piece size, but also the operator being careful not to get too much line-rub between the haul back (tail rope) and mainline in the running skyline configuration.

Table 2: Velocities calculated.

Carriage Out (m/sec)	
Mosgiel	4.0 (1.2 – 6.0)
Rotorua	3.8 (0.3 – 7.2)
Opotiki	4.0 (0.6 – 6.0)
Carriage In (m/sec)	
Mosgiel	3.8 (0.9 - 6.3)
Rotorua	3.0 (0.3 – 6.1)
Opotiki	2.8 (0.5 – 4.0)

With an elemental time study, it is also possible to analyse in more detail both the overall cycle time, as well as the individual elements that make up each cycle for a more in-depth understanding.

Cycle Time

All three sites had relatively good deflection, and all ran the same rigging configuration, it was expected that extraction distance would be the primary factor influencing cycle time. Each point in Figure 10 is a single extraction cycle. It shows both the overall effect of extraction distance on cycle time, as well as the variability between individual cycles.

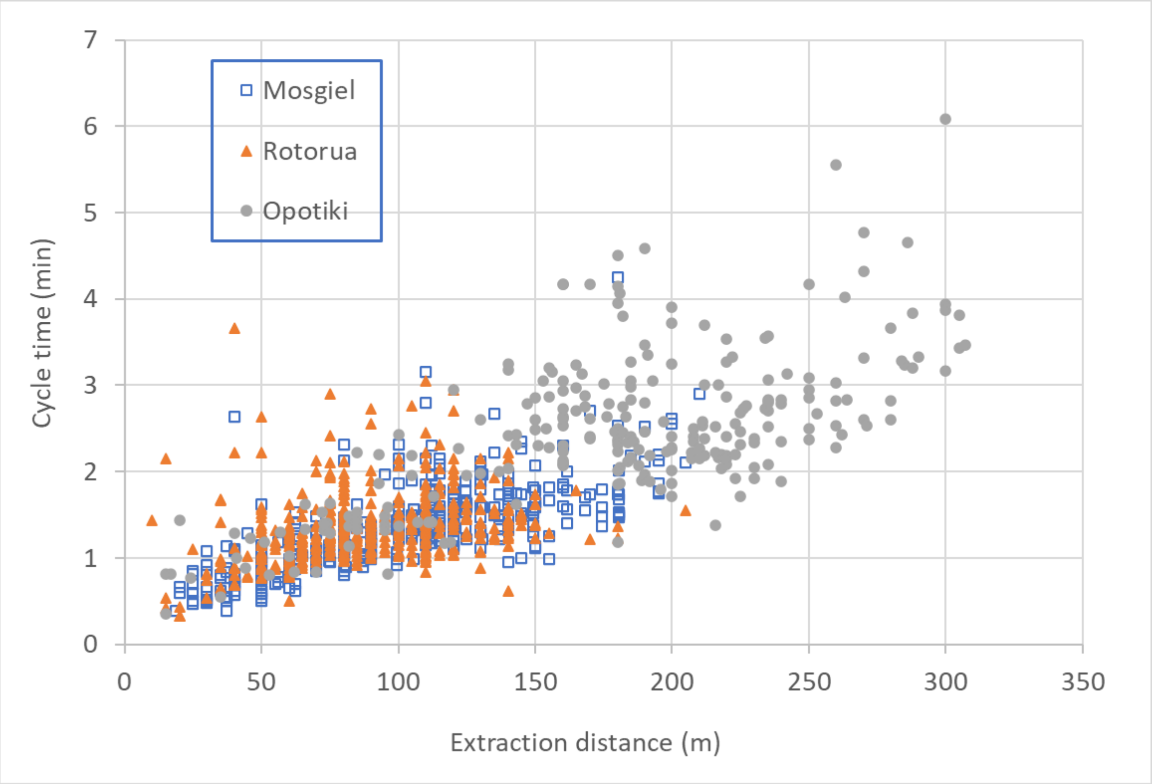

Figure 10: Cycle time for all three case studies as it relates to extraction distance.

All three case studies had data between 20 and 200 metres, and the regression equation (Eq. 1) is a good fit across all three sites giving us confidence that is a realistic interpretation for these case studies.

Eq. 1: Average Cycle time (min) = 0.48 + 0.0086 x Dist (m)

While average cycle time for an extraction distance less than 100 metres is less than a one and a half minutes, there are 18 cycles that had cycle time greater than 2 minutes. Typical examples for longer than expected cycles will include failing to grapple the stem(s) at first attempt, needing to adjust the location of the carriage to grab the stem(s) effectively, or taking the time to grapple an additional stem.

Beyond 200 metres, which was only at the Opotiki site, cycle time had greater variability and was also higher on average than the regression shown in Equation 1. It shows the difficulty of travelling out a greater distance with a grapple, with both operator visibility and also movement in the skyline making it more difficult to manage the carriage precisely.

While extraction distance was the primary driver, statistical analyses also showed payload to have an effect on cycle time, but not the number of stems pulled. Including this parameter, it is possible to derive the following equation:

Equation 1: Average Cycle time (sec) = 26 + 2.9 x Payload (t) + 0.6 x Dist. (m)

Carriage Out

Carriage out is expected to be the most consistent and best correlated parameter to extraction distance. There is consistency between all three case studies in terms of average speed, but also visible is a relatively high level of variability (compared to a skyline rigging configuration). For example, sending the carriage out 150 metres can be as quick as 25 seconds (i.e. velocity of 6m/sec), but there are plenty of cycles where it took more than 50 seconds. Some of this variability is readily explained in the nature of operating a running skyline configuration, with the operator adjusting carriage height as it is sent out.

In standing skyline operations using chokers, Carriage Out can be a lot more consistent with the carriage simply coming to a stop before the slack-pulling adjustments are made. In terms of a regression equation for Carriage Out time:

Equation 2. Carriage out (sec) = 7 + 0.195 x ExtrDist (m)

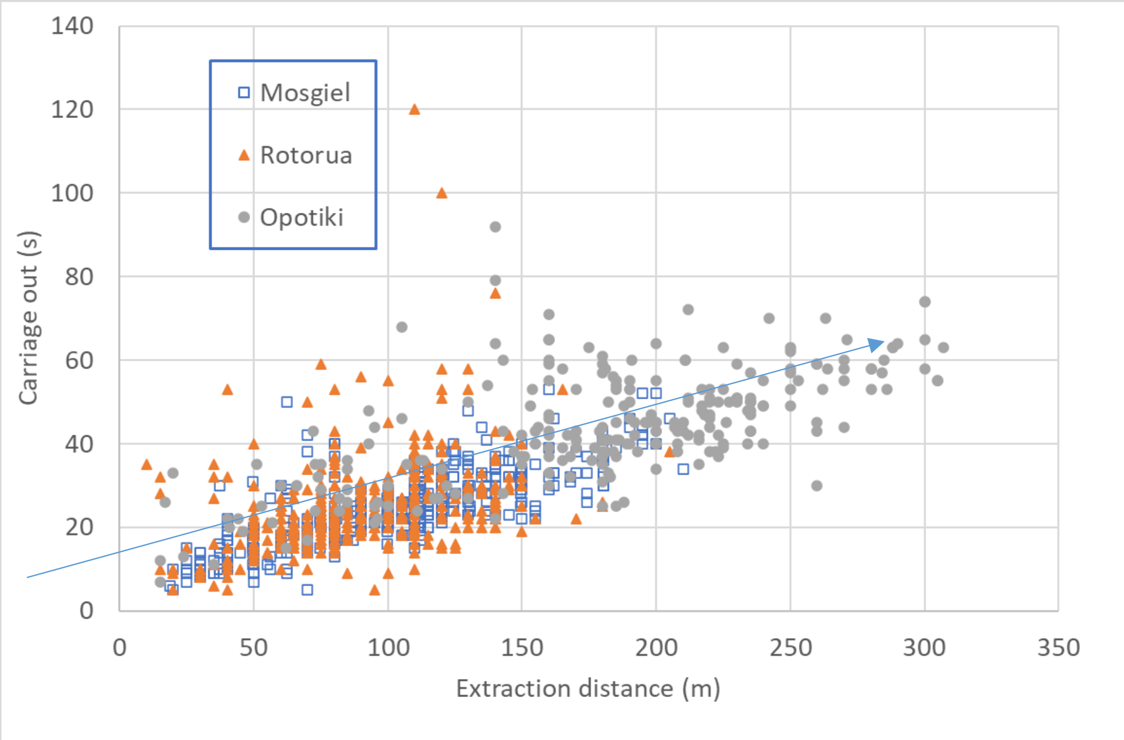

Figure 11: Time taken for the Carriage Out relative to extraction distance for all three case studies.

Grapple

While there is a minor tendency for the time to grapple the stems to increase with distance, there is not a significant trend (Figure 12). In about half the cycles it took less than 20 seconds to complete the grapple task, but with challenges such as managing the movement of the carriage or picking up multiple stems, almost a quarter of the cycles were more than double (i.e. 40+ seconds).

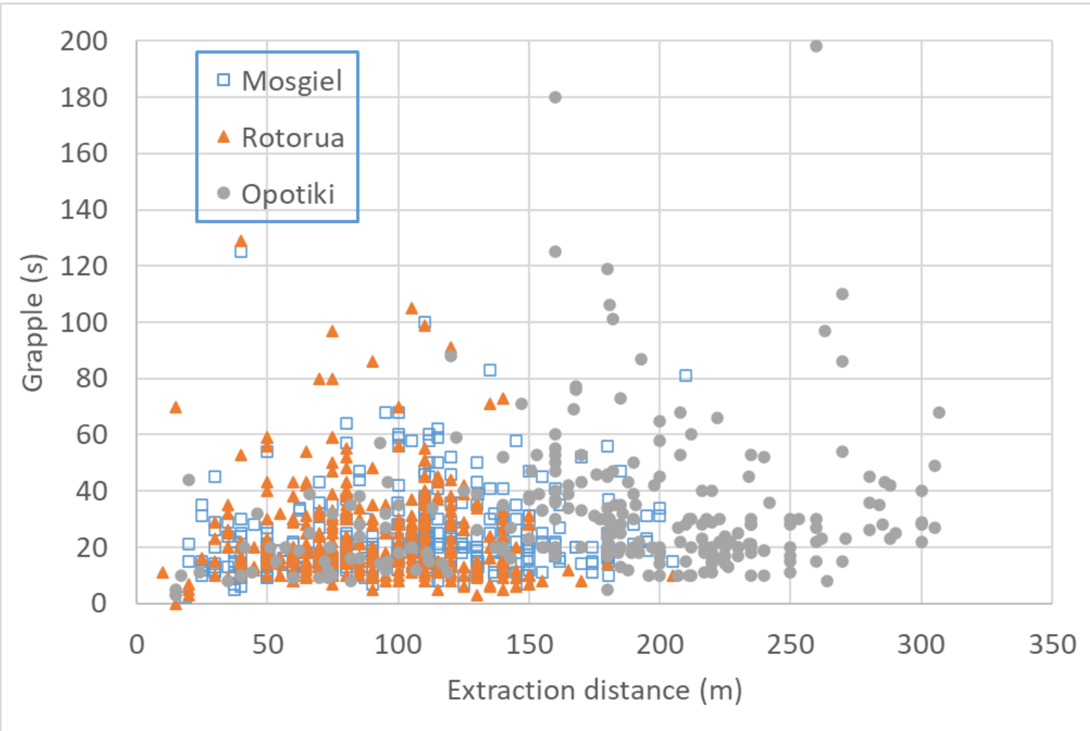

Figure 12: Grapple time relative to the extraction distance for all three case studies.

Also visible in Figure 12 is that the variability in grapple time is greater in the middle of the span, and this will be linked to grappling stems out of gullies. Grappling out of gullies requires more time to lower the grapple, but also time to break out the stems. In Rotorua the Harvestline picked up a lot of slash from the gullies and sometimes had to move broken tops before picking up the stems.

Figure 13: Grappling stems out of the gully takes extra time.

Carriage In

For all three case studies, Carriage In time is relatively linear with extraction distance and consistent for all three case studies up to 150 metres (Figure 14). Beyond that, especially for the Opotiki case study, a much higher level of variability can be seen. This was in part attributed to the lower level of deflection available at the longer distance, and hence the operator having to apply more power to help the stems drag along the terrain. The equation for the Carriage In time is:

Equation 3: Carriage In (sec) = 3 + 0.27 x Dist(m)

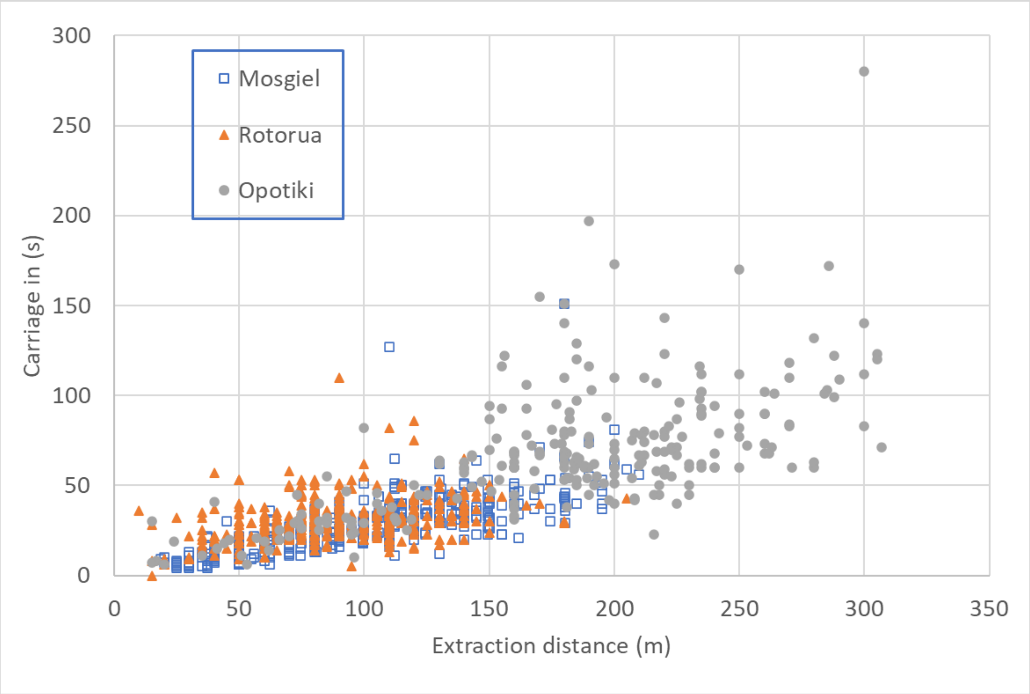

Figure 14: Carriage In time relative to extraction distance for all three case studies.

Productivity

By combining the cycle time and payload for each cycle, we can also plot out delay-free productivity per cycle and the average extraction distance for the entire study (Figure 15). Of note is the number of cycles with zero productivity because the cycle involved picking up and clearing the slash from the gully. A clear declining trend is visible and can be approximated by the linear equation:

Equation 5: Productivity (t/PMH) = 126 – 0.35 x Dist(m)

This equation is a good fit for estimating the productivity between extraction distances of 50-200 metres. Productivity at longer distances is higher than the linear regression estimates and a better fit natural logarithmic curve is given by Equation 6:

Equation 6: Productivity (t/PMH) = 278 – 42 x Ln(Dist)

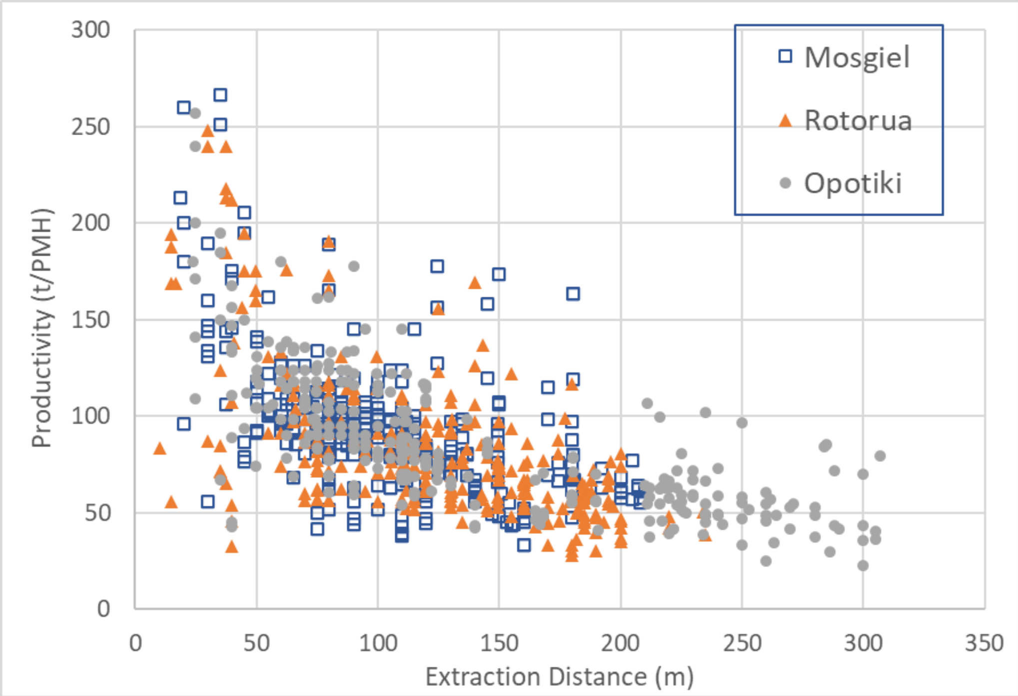

Figure 15: Productivity relative to extraction distance for all three case studies.

While these three case studies provide a valuable insight into the productivity effectiveness of modern excavator-based yarder, it is also of interest to compare again other productivity studies. An example set is shown in Table 4, whereby the first three rows are the studies in this report. All of these studies are referenced in the references section. Each study presented is unique, but overall it is easy to conclude the Harvestline was very competitive, even against the much larger swing yarders.

Table 4: Summary of a selected set of comparable yarder productivity studies

Yarder Type	Carriage Type	Line Length (m)	Piece (t)	Productivity (t/PMH)	Operation Type	Origin	Cycles (n)
Sumitomo SH460 HD Harvestline	***Mechanised Grapple***	***105***	***2.0***	***86***	***Clearcut***	***Mosgiel, NZ***	***353***
Doosan DX380 LC Harvestline	***Mechanised Grapple***	***96***	***1.9***	***77***	***Clearcut***	***Rotorua, NZ***	***431***
Komatsu PC 400 LC Harvestline	***Mechanised Grapple***	***181***	***2.3***	***58***	***Clearcut***	***Opotiki, NZ***	***246***
Alpine MDWS	Grapple	103	0.5	63	Clearcut	Malaysia	54,624
Madill 124	Grapple	100	0.8	58	Clearcut	Australia	184
Thunderbird 6355	Grapple	160	0.9	86	Clearcut	New Zealand	123
Thunderbird 255	Slings	233	1.5	39	Clearcut	New Zealand	165
Madill 122	Slings	267	0.7	44	Clearcut	USA	70
Timbco T425	Slings	80	0.6	15	Thinning	USA	218
CAT 315 L	Slings	80	1.4	30	Thinning	USA	237
Doosan DX 210W	Slings	120	0.3	11	Clearcut	Norway	149
Modified JCB	Slings	130	0.4	17	Clearcut	Ireland	90

Delays

In all short time studies, for example such as these over just two or three days, delays will simply reflect a snapshot of what happened during those days and not be representative of long-term trends.

In Mosgiel the utilisation rate was 57% over the three days. Two major delays occurred; a diesel pipe cracked on the carriage that took 2.5 hours to repair, and the tail hold was re-positioned for a second setting which took 1.5 hours. The tail hold excavator travelled approximately 1 kilometre on a gravel road around a stand to get to the new setting.

In Rotorua, utilisation was 50% over the three days. Repositioning the Harvestline took 1.25 hours which included using a drone to fly the straw line back over to the tail hold.

In Opotiki, utilisation was 64% over the two days, with two main delays being the tail hold shift to 440 metres and the mainline breaking. The tail hold shift took one hour and 10 minutes and the Hawkeye grapple was used to send strops/D-ring locks to the bulldozer. The main line break took 1.5 hours to repair with the broken end of the cable cut and spliced.

Other Study Observations

A modern cabin layout was found in all three operations, where the view from the operators' seat is excellent, monitors for the grapple well placed, a good view of the working drums, as well as a built-in tension monitor. The running skyline can readily be operated by floor pedals and a single joystick.

Figure 16: The operating cabin of the Harvestline used in Opotiki.

Overall size of the machine and the reliability were noted as other beneficial features. Due to being excavator-based, the Harvestline is not a big machine and hence able to access and operate from terrain not suited to larger yarders (Figure 17). Owner observations were that the Harvestlines were extremely reliable if maintained properly.


Figure 17: In Mosgiel, the Harvestline operator moved down off the main landing to improve deflection and cycle time. The excavator-grapple machine shovelled the extracted stems up to the landing.

The Hawkeye motorised grapple carriage system was common to all three case studies, and again they received positive reviews from the operators (Figure 17). They noted few break-downs, and a very good grip on the stems being extracted so very pieces lost during grappling and or extraction. The Hawkeye grapple has three 'night and day' cameras that face forward, down and back covering a vast large area that helps when extracting at longer distances.


Figure 17: The operating cabin of the Harvestline used in Opotiki.

CONCLUSION

This study tested three well-established, professional crews under good stand and terrain conditions, and showed that a modern excavator yarder working in a New Zealand plantation forest carrying is a very capable and productive system. Even at longer extraction distances, delays-free productivity was greater than 50 t/PMH, and many cycles were recorded in excess of 100 t/PMH at shorter distances. Anecdotally this can be corroborated by a typical day target in the order of 300 t/day, whereby 6 productive hours is about the maximum that can be expected from any yarder operation. While already competitive under normal operating conditions, it may further favour in smaller woodlots when relocation costs and set-up efforts need to be considered. The absence of guylines make it both quick to set up and move around.

ACKNOWLEDGEMENTS

We would like to thank Chris Hancock and EMS Rotorua for their support in setting up the study.
A special thank goes out to Alec Cassie of Wenita Forest Products, Blair and the crew of Roxburgh Contracting, Lawrence and the crew of Harper Logging and Steve and Fletcher and the crew of STR Logging for their cooperation, expert assistance and making it possible to obtain the data in a safe and efficient way.

REFERENCES

Acuna, M., Skinnell, J., Evanson, T., & Mitchell, R. (2011). Bunching With a Self-levelling Feller-buncher on Steep Terrain for Efficient Yarder Extraction. *Croatian Journal of Forest Engineering*, 521-531.

Bentley, T. A., Parker, R. J., & Ashby, L. (2005). Understanding Felling Safety in the New Zealand Forest Industry. *Applied Ergonomics* , 165-175.

Bentley, T. A., Parker, R. J., & Ashby, L. (2005). Understanding Felling Safety in the New Zealand Forest Industry. *Applied Ergonomics*, 165-175.

Devlin, G., & Klvac, R. (2014). How Technology Can Improve the Efficiency of Excavator-Based Cable Harvesting for Potential Biomass Extraction - A Woody Productivity Resource and Cost Analysis for Ireland. *Energies*, *7*(12), 8375-8395.

Ellegard, J. (20212020). Treading Lightly, Harvesting Heavily. *NZ Logger* , December, 18-27.

Gingras, J.-F. (2013). Update On Steep Slopes Operations Research At FPinnovations In Canada. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions,* June 2013, 15-17, Honne, Norway.

Harrill, H. (2014). Improving Cable Logging Operations for New Zealand's Steep Terrain Forest Plantations. Retrieved from University of Canterbury. https://ir.canterbury.ac.nz/bitstream/handle/10092/9923/thesis_fulltext.pdf?sequence=1&isAllowed=y.

EMS. (2022). *Harvestline* Retrieved from EMS: https://www.emsnewzealand.co.nz/harvestline

EMS. *(2022). Hawkeye* Retrieved from EMS : https://www.emsnewzealand.co.nz/hawkeye

Heinimann, H., Stampfer, K., Johannes, L., & Caminada, L. (2006). Perspective on Central European Cable Yarding Systems . The International Mountain Logging and 11th Pacific Northwest Skyline Symposium, Dec 10-12, 2001, Seattle, Washington, USA.

Hoffmann, S., Jaeger, D., Engler, B., & Pierschkalla, S. (2013). Demand for Mechanized Steep Terrain Logging Systems in Southern China Due to Changing Operational Conditions. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions*, 24-26, Honne, Norway.

Holmes, L. (2017). *Productivity Analysis of Fully Mechanised Cable Logging Operatrions in New Zealand.* Retrieved from Forest Engineering NZ : https://forestengineering.org/wp-content/uploads/2020/11/2017-Luke-Holmes-Diss-Rayonier-Yarder-Productivity.pdf

Kühmaier, M., Harrill, H., Ghaffariyan, M., Hofer, M., Stampfer, K., Brown, M., & Visser, R. (2019). Using Conjoint Analyses to Improve Cable Yarder Design Characteristics: An Austrian Yarder Case Study to Advance Cost-Effective Extraction. *Forests, 10*(2), 165 .

Largo, S., Han, H.-S., & Johnson, L. (2004). Productivity and Cost Evaluation for Non-guyline Yarders in Northern . *Machines and People, the Interface .* April 27-30, 2004. Hot Springs : Council on Forest Engineering .

Liley, W. B. (n.d.). *The Igland Hauler .* Logging Industry Research Association .

Malietoa, K. K. (2014). *An Investigation into the System Production Balanced within Three Mechanised Harvesting Case Studies.* Christchurch: New Zealand School of Forestry.

McEwan, A., Brink, M., & van Zyl, S. (2013). Guidelines for Difficult Terrain Ground-Based Harvesting Operations in South Africa. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions,* June 2013, (pp. 27-28). Honne, Norway.

Mconchie, M. (1979). *Lotus Experimental Skyline Hauler.* Logging Industry Research Association.

Ottaviani, A. G., & Talbot, B. (2013). Operator Performance Improvement Through Training in a Controlled Cable Yarding Operation. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions*, November 2013, 64-66, Honne, Norway.

Prebble, R. (1989). *Madill 122 Interlock Swing Yarder .* Rotorua : Logging Industry Research Association.

Raymond, K. (2010). Steep country harvesting - "Innovative Harvesting Solutions' A Step Change. *New Zealand Journal of Forestry*, *55(*3), 3-9.

Raymond, K. (2018). PGP Steepland Harvesting – a collaborative research and development programme. *NZ Journal of Forestry,* 63(3).

Raymond, K., & Hill, S. (2018). *Alpine Shovel Yarder in New Zealand*, October 2018, HTW-018, *.* Rotorua : Forest Growers Research .

Sakai, H., Sakurai, R., & Oikawa, R. C. (2013). Direction of Development of the Tower Yarder in Japan . *Proceedings of the International Conference on Forest Operations in Mountainous Conditions,* November 2013, 13-14, Honne, Norway.

Stampfer, K., Visser, R., & Kanzian, C. (2006). Cable corridor installation times for European yarders. *International Journal of Forest Engineering*, *17*(2), 71-77.

Talbot, B., & Stampfer, K. Visser, R., (2015). Machine Function Integration and its Effect on the Performance of a Timber Yarding and Processing Operation. *Biosystems Engineering*, *135*(2015), 10-20.

Talbot, B., Ottaviani Aalmo, G., & Stampfer, K. (2014). Productivity Analysis of an Un- Guyed Integrated Yarder Processor with Running Skyline. *Croatian Journal for Forest Engineering*, *35*(2), 201-210.

Talbot, B., Tarp, P., & Nitteberg, M. (2014). Selecting an Appropriate Excavator-based Yarder Concept for Norwegian Conditions Through the Analytic Hierarchy Process. *International Journal of Forest Engineering*, *25*(2), 113-123.

Torgersen, H., & Lisland, T. (2002). Excavator-Based Cable Logging and Processing System: A Norwegian Case Study. *International Journal of Forest Engineering*, *13*(1), 11-16.

Tuer, K., Saunders, C., & MacIntosh, G. (2013). Steep Ground Harvesting Project – Forestry Commission Scotland: Evaluation, Innovation and Development in Scottish Skyline Operations. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions,* June 2013, 21-23, Honne, Norway.

Visser, R., & Harrill, H. (2018). Survey of Yarders and Rigging Configurations: 2018. *Forest Growers Research,* HTN10-04.

Visser, R., McFadzean, S., & Hill, S. (2013). Productivity and Ergonomic Study of a Motorised Hydraulic Grapple Carriage. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions*, June 2013, 72-74, Honne, Norway.

Visser, R., Raymond, K., & Harrill, H. (2014). Mechanising steep terrain harvesting operations. *NZ Journal of Forestry,* November 2014, *59*(3).

Yoshimura, T., & T, N. (2013). Productivity Analysis of Thinning Operations Using a Swing Yarder on Steep Slopes in Western Japan. *Proceedings of the International Conference on Forest Operations in Mountainous Conditions, June 2013,* 35-36, Honne.