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An evaluation of a ClimbMAX Steep Slope Harvester in Maungataniwha Forest, Hawkes Bay

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EXECUTIVE SUMMARY

The ClimbMAX steep slope harvester, manufactured by ClimbMAX Equipment Ltd was evaluated in a logging operation in Maungataniwha Forest in northern Hawkes Bay. The objectives were to measure productivity and site disturbance of the ClimbMAX harvester. Ergonomic factors and winch rope tensions of ClimbMAX machines were also examined.

In this study, the ClimbMAX felled and bunched trees for grapple extraction with a Madill 124 swing yarder. Measured productivity was 40m^3 per productive machine hour (PMH) in tree size of only 0.6 m^3 per tree. The tree size handled by the ClimbMAX was not representative of clearfell tree size in most New Zealand forests. Consequently the felling and bunching productivity is not indicative of its performance in other forest conditions.

Two adjacent study areas, each of one hectare in area were selected to compare soil disturbance of a ClimbMAX harvester-felled area and a manually-felled area. Trees on both sites were extracted by grapple yarder. Site factors for the adjacent sites included steep slopes and low bearing capacity soil. Crop factors included a high stocking of 745sph and small tree size (0.6m^3). The site disturbance assessment showed more soil was disturbed in the ClimbMAX-felled block, with total deep disturbance of 14% of the trial area compared to 8% in the manually-felled block. Most of the deep disturbance was due to the exposure of subsoil (topsoil removed and mineral soil mixed). Rutting, caused by the machine tracks or from logs dragged along the ground during extraction, showed similar results, 3.3% and 2.6% for the ClimbMAX-felled site and the manually felled site respectively. These results may alleviate some of the concern over possible negative environmental effects through the use of tracked ground-based machinery on steep slopes. It is recommended that longer term site disturbance trials are set up to better quantify sediment yield from sites using machines on very steep slopes.

In the ergonomic assessment, a standard checklist was used to interview two machine operators about ergonomic aspects of the ClimbMAX harvester. Comments were sought regarding the cab, seating, visibility and ease of maintenance. Generally the comments were favourable and the operators had few issues with operating on steep terrain in a non-levelling cab.

The traction winch rope tensions were measured on a ClimbMAX machine during operation on steep slopes in the Marlborough area. Average tensions during travelling, shovelling and felling were found to be 8.0, 1.8, and 1.6 tonnes respectively. During the traction winch rope tension study, the safe working load (SWL) of 14.2 tonnes for the 22mm swaged wire rope was exceeded for short periods only during machine movement.

While the soil disturbance assessment identified no real concerns, the degree of sediment movement off-site is an important factor to understand. Longer term environmental trials using sediment traps would answer more quantitatively the additional impact of using ground-based machines on very steep slopes.

BACKGROUND

The goal of the FFR harvesting research programme is to substantially improve productivity and reduce costs through developing technologies for mechanised harvesting in New Zealand's steep terrain forests. As part of the FFR harvesting programme, development of tree felling machinery for steep country harvesting is underway. FFR Intermediate Outcome 1 has developed the capability of machinery to operate on steep slopes.

The ClimbMAX Steep Slope Harvester, designed by programme co-investors AW Trinder Ltd and Kelly Logging Ltd, with funding assistance from FFR, is now marketed by ClimbMAX Equipment Ltd. The ClimbMAX was designed to extend the range of ground-based machinery on steeper terrain, either for felling and bunching in a cable logging system or "shovel-logging" in a ground-based extraction system. With its integrated traction-assisted winch system, the ClimbMAX is capable of operating safely on steep slopes up to 45^o on a range of soil types.

In early 2013 the first production machine (ClimbMax2) was studied during field testing in Marlborough [1] prior to delivery. The second evaluation of the ClimbMax 2 was undertaken in Maungataniwha Forest in Hawkes Bay, managed by Rayonier NZ Ltd (Figure 1).

The objective of the study was to measure productivity, soil disturbance, ergonomic aspects and winch rope tensions of the ClimbMAX Steep Slope Harvester.

Figure 1: ClimbMAX2 Steep Slope Harvester

TRIAL SITE

The study area consisted of two adjacent sites of one hectare each (Figure 2). One site was felled by ClimbMAX and extracted by swing yarder (Area A). The other site was felled manually and extracted by swing yarder (Area B). Slopes were mainly concave. Both sites were logged uphill to the landing shown to the left of the map.

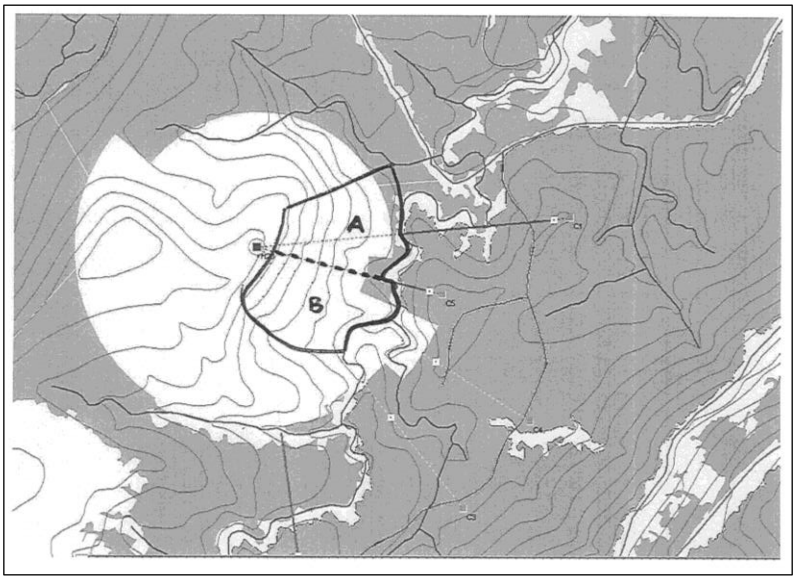

Figure 2: Paired sites for soil disturbance assessment: Area A - Felled and bunched by ClimbMAX; Area B - Manually felled area.

The study area had an average tree size of 0.6 m^3 and a stocking of 745 stems per hectare (sph). The forest was in its first rotation converted from native forest (Figure 3). Slopes were convex in shape, ranging from 15 to 45 degrees and were up to 250m in length. The soil type on the site was well-drained (Drainage class 5) Sand (Placic Pan Podzols) with a depth range to a slowly permeable horizon of 0.45 - 0.89 m. At the time of felling, soil conditions on the site were wet, with isolated pockets of semi-swamp terraces.

Figure 3: The trial site

STUDY METHODS

1. Machine Productivity

The objective of collecting machine productivity information was to allow a productivity estimate for Maungataniwha Forest and compare this to other studies of the ClimbMAX completed in other regions. The operator's work method was to fell mostly downhill in the steeper sections, and across slope in other areas. After felling several trees, the machine would move downhill a few metres to enable slewing/bunching using gravity. Trees were bunched tip-first, approximately on the contour, bunched butts were sometimes crossed. Standing non-merchantable trees were either felled or pushed aside. Native logs were frequently moved to enable access. Trees were extracted by swing yarder using a grapple. Continuous time study data were collected according to the cycle element descriptions in Table 1 and results analysed.

Table 1: Cycle Element description

Fell (FELL)	Slew to position head, back-cut or scarf and back cut, tree falls to the ground.
Move down (M DN)	Movement downhill
Move up (M UP)	Movement uphill
Bunch (BUNCH)	Slew, pick up felled trees and/or pieces, slew and place tree or piece into a bunch. Repeated for a single long piece or butt stem.
Clear unmerchantable pine (CLR UNM)	Slew, push tree over or fell, move tree aside if necessary.
Clear native logs or stumps (CLR NAT)	Slew, pick up a log or stump and place it aside.
Slew 180^o (SL 180)	Slew 180^o prior to a change of direction of movement or to view the surrounding area.
Other delay(OP DEL)	Operational delay (e.g. Pause for communication, clear slash)
Mechanical delay(M DEL)	Mechanical delays (e.g. repair/replace chain).

2. Site Disturbance

The objective of assessing site disturbance was to collect quantitative information about whether using ground-based machinery on very steep slopes would have an unacceptable impact on the soil compared to current harvesting methods. Site disturbance was measured using an established soil disturbance survey method [2].

Soil disturbance results were described for 1007 sample points for the area felled with the ClimbMAX and 1098 sample points for the manually felled area. Both areas were extracted using a grapple equipped yarder prior to measurements being taken. The description of soil disturbance categories is outlined in Table 2.

Table 2: Description of Soil Disturbance Categories

CATEGORY	DESCRIPTION
Undisturbed	Original litter in place
Shallow disturbance	Slight topsoil and litter disturbance
Deep disturbance	Subsoil exposed and rutting
Slash cover	Soil covered by slash
Non-soils	Such as tree stumps

For this study an additional sub-category of 'topsoil and subsoil mixing' under the category for 'deep disturbance' was used because there was exposure of sub-soil clearly due to ground-based equipment.

3. Ergonomic Assessment

A perceived barrier to the uptake of the ClimbMAX harvester is ergonomics, especially operator comfort, given that the machine does not feature a levelling cab. The objective of this part of the study was to undertake an ergonomic assessment, using a standard checklist [3], to better understand what the current operators thought about working on very steep slopes while harnessed to the seat. Two experienced ClimbMAX operators were interviewed about their perceptions of the cab, visibility, seating, maintenance and other issues.

4. Traction Winch Rope Tensions

A common misconception with tethered steep slope feller bunchers is that they are suspended and may fall over or slide uncontrollably without the winch rope holding them in position. This perception is also a potential barrier to uptake of this new technology. Demonstrating that the winch rope is designed for traction assistance and does not hold the machine on the hillside was the objective of this part of the study.

Understanding how much work the traction winch was doing, what forces and when they are being applied to the traction winch was therefore seen as important.

Winch rope tensions were measured on a different ClimbMAX to the Maungataniwha operation. This investigation was carried out on a harvesting operation in the upper Wairau Valley in the Marlborough region. The machine was working in a partial wind thrown stand where it was required to fell remaining standing trees and shovel fallen trees into bunches for extraction by cable yarder. The machine was anchored to a stump at the top of a ridge from where it descended the 34^0 slope (65%) to a maximum distance of 246m before working its way back to the top.

A clamping tension monitor was fixed to the traction winch rope approximately 15m away from the anchor stump at the top of the ridge. The tension monitor was connected to a laptop computer which stored the tension data at a rate of 10 readings per second. The tension in the ClimbMAX traction winch rope was measured while the ClimbMAX was operated on slopes up to 43^0 for a continuous period of 2 hours 24 minutes (2.4 hours).

RESULTS

1. Machine Productivity

Distribution of the continuous time study data during the felling and bunching of 157 trees is shown in Figure 4.

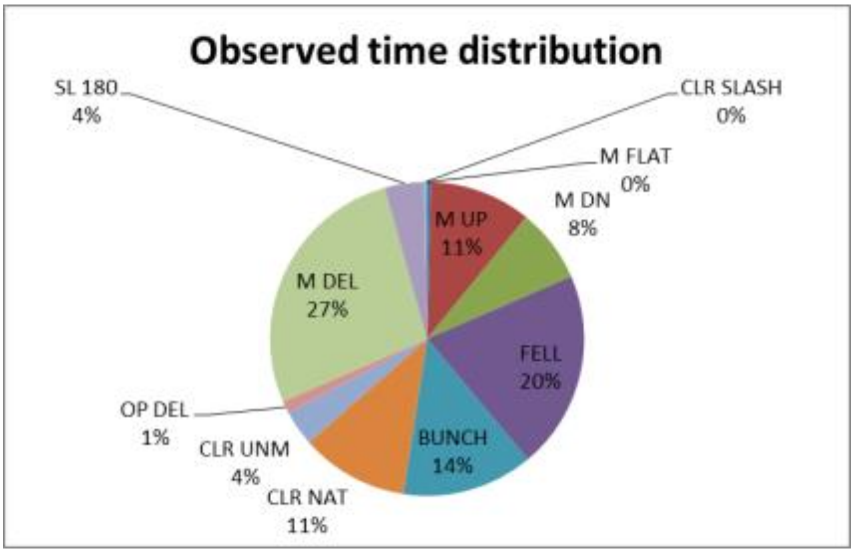

Figure 4: Distribution of observed time

Felling and bunching comprised 34% of total observed time. Mechanical delays (M DEL) comprising 27% of total observed time were mainly associated with the felling saw and refuelling. If these delays were excluded, felling and bunching time comprised 47% of the work cycle.

Moving up and down slope (M UP and M DN) and slewing to move (SL 180) accounted for 23% of the total observed time, or 31% of delay free time. Due to the plantation forest being first rotation converted from native forest, there were many large native tree stumps and logs. During the felling of 157 trees there were 87 incidents of clearing native logs or snags during felling and bunching (CLR NAT). This accounted for 11% of observed time (15% of the productive cycle time) with a frequency of 55%. There were also 40 instances of clearing non-merchantable trees – CLR UNM – (or 25% frequency) which accounted for 4% of the total observed time (5% of productive cycle). Some non-merchantable trees were felled; others were swept aside with the felling head/boom.

Table 3 shows the results of time study analysis. The productive cycle time was 53.2 seconds. The productivity of the ClimbMAX in Maungataniwha forest was 67 trees per productive machine hour (PMH).

Table 3: Results of time study analysis (delay free time)

Cycle Element	Average time per cycle (seconds)	% of Cycle
Fell trees	14.9	28.0
Bunch	9.9	18.6
Slew to Move/180°	3.0	5.6
Move uphill	7.6	14.3
Move downhill	5.6	10.5
Move on flat	0.3	0.6
Clear native logs	8.1	15.2
Clear unmerchantable trees	2.6	4.9
Other	1.2	2.3
Total (sec)	**53.2**	**100.0%**
Trees/PMH	67.4	
Tree size (m^3)	0.6	
Productivity (m^3/PMH)	40.4	

The estimate of delay-free productivity (personal and mechanical delay excluded) was 40.4m^3 per productive machine hour (PMH) in tree size of 0.6 m^3 per tree.

The tree size handled by the ClimbMAX was not representative of clearfell tree size in most New Zealand forests. However, this productivity compares favourably with other studies of the ClimbMAX given the site factors encountered in Maungataniwha forest. This equates to daily production of 280m^3/day (assuming 7.0 productive machine hours) and comfortably matched the productivity of the extraction system if the trees were laid in tidy bunches. A previous study in Marlborough showed a productivity rate of 67m3/PMH or 32 trees/PMH[1].

2. Site Disturbance

In the Maungataniwha forest study, the ClimbMAX felled area was visually similar to the manually felled area (Figure 5).

Figure 5: A view of the two sites assessed for site/soil disturbance: Area A (right) was felled by ClimbMAX; Area B (left) was manually felled.

In the Maungataniwha forest study, the undisturbed and shallow disturbance measures for the ClimbMAX felled area was similar compared to the manually felled area (Table 4).

The deep disturbance value for the ClimbMAX felled area was 14% compared to 8% in the manually felled area. Further analysis of the deep disturbance showed that most of the deep disturbance was due to the exposure of subsoil (topsoil removed and mineral soil mixed).

Table 4: Soil/Site disturbance comparisons (%)

Soil disturbance value	Maungataniwha Manual felling and yarding	Absolute error (± %)	Maungataniwha ClimbMAX and yarding	Absolute error (± %)	Marlborough ClimbMAX and yarding	Absolute error (± %)
Undisturbed	6	1	4	1	7	1
Shallow disturbance	9	2	7	2	53	2
Deep disturbance	8	2	14	2	9	1
Slash cover	64	3	60	3	26	2
Non-soil	13	2	15	2	5	1
Total	100		100		100	

Rutting is soil disturbance that might lead to rilling and gully erosion. Of the total deep disturbance observations in the machine-felled block, it was found that only about one-quarter of deep disturbance was due to rutting (33 out of 138 observations of deep disturbance).. While the difference in deep disturbance between the two areas in Maungataniwha forest was statistically different there was no significant difference in the rutting component of deep disturbance between the area felled with the ClimbMAX (3.3%) and the area felled manually (2.6%). This is shown in Table 5. The ClimbMAX did not increase the amount of rutting from what was caused by normal yarder extraction. This result may alleviate some of the concern over possible negative environmental effects through the use of tracked machinery on steep slopes.

When comparing the deep disturbance between Maungataniwha forest and Marlborough forest study areas the results are similar although in the Marlborough study site of the 9% sample points that showed deep disturbance, 89% of them were rutting.

Table 5: Comparison of deep disturbance counts in paired study areas

Type of disturbance	ClimbMAX felling + Yarder	Manual felling + Yarder
Top soil and mineral soil removed exposed or mixed	105 (10.4%)	63 (5.7%)
- 5-15cm rut	22	21
- 16-30cm rut	11	7
Rutting Sub-total	33 (3.3%)	28 (2.6%)
Deep disturbance total	138 (13.7%)	91 (8.3%)
Total observations	1007 (100%)	1098 (100%)

To help try and explain some of the differences in soil disturbance, data were collected on soil strength using a Scala penetrometer to provide California Bearing Ratio (CBR) values. The mean recorded CBR value in Maungataniwha forest was <1.5 on slopes ranging from 10^0 to 40^o. This compares with data collected from the Marlborough forest study area where recorded CBR values averaged 2.1 and slopes ranging from 11-34 degrees. Both soils were classified as weak soils.

While the soil disturbance assessment identified no real concerns, the degree of sediment movement off-site is an important factor to understand. It is recommended that longer term site disturbance trials (using sediment traps) are set up to better quantify the sediment yield from sites using ground-based machines on very steep slopes.

3. Ergonomic Assessment

Two experienced ClimbMAX operators were interviewed about their perceptions of the cab layout and controls, visibility for the operator, seating and machine maintenance. The interview method was based on a standard ergonomic checklist[3].

Cab Layout and Controls

Observations:
Many injuries to forest machine operators occur getting in (access) and out of the cab (egress). If the access is difficult the operator is likely to jump from the cab, causing injury. Cab size and layout are important for efficient work. The cab must not be cramped and the climate must be able to be easily controlled.

Operator comments:

- "The cab is easy to get into when the machine is on the level but a bit tricky when it is at 40° and it is wet. Would be good with more hand holds"
- "I always think about easy access to the machine when I park it. It is best if the boom is off centre then there is plenty of space to stand on the tracks"
- "Emergency exits from the cab need to be big enough to get out of and there need to be enough exits so you can get out even if the machine has flipped right over"
- "The doors with electric/hydraulic rams are good. They stay put"
- "The cab is nice and comfortable with plenty of space to stow stuff"
- "There is enough space to stand up in the cab"
- "The cab is not too noisy and there are no irritating sounds or vibrations"

In general, although the cab was considered well sound-insulated and spacious, with good visibility, the operators questioned had concerns over access to and from the cab from ground-level - especially with the machine parked on a steep slope.

Visibility for the Operator

Figure 6: View from the cab and the winch/slope display.

Observations:
Poor visibility reduces productivity and increases the risk of accidents. However, the cab windows have to be well protected by bars and grills and prevent internal reflections reducing operator vision.

Operator comments:

- "The view is good from the cab. I can see the tracks and there is a window low down facing forward"
- "There is a roof window, with bars over it, so I can see enough of the trees above. But I normally plan two or three trees ahead and from that distance can see the whole tree through the front window"
- "The air conditioner gets rid of misting on the windows"
- "I don't have any window wipers and do need them. As long as the window is clean and you use Rainex the water just beads off. If you get a bit of bar lube on the glass then the rain sticks and it gets smeary. Best with clean windows"
- "On hot days the heat from the engine behind the cab is too much and the air conditioning sometimes can't keep up"
- "Sometimes, when facing uphill, the sun shines straight into the cab and it can be hard looking into the sun and working. It can get glary. If I can I just move to a better spot with less glare"
- "Have LED lights which are really good but can't see the top half of the tree with them"
- "I use the lights on overcast days and they really make felling easier"

Seating

Figure 7: ClimbMAX operator seat

Observations:
One of the main causes of back problems is sitting in the same position for a long time. The operator's seat should be fully adjustable to give good support for the thighs and back and make it easy to reach the controls. Arm rests should also be fully adjustable and comfortable.

Operator comments:
- "Because the cab is not level on the hill there is a lot of strain on the seat. I broke the first seat. We are now looking at a race car seat with shoulder and lap belt."
- "I keep the harness tight and that feels good. A loose harness is tiring because you are fighting against sliding around in the seat"
- "If I have been in one position for a long time - to give my shoulders a break from the straps I will sometimes push my feet against the bar at the front of the cab just to relax the muscles"
- "You become very aware of the slope with the seat and cab fixed and not self-levelling. I don't have to think about the slope, I can feel it"
- "I lean into the head rest too"
- "The arm rests are good"
- "I have operated both non-levelling and levelling cab machines and even in the levelling cab I would often not level the cab to get a feel for the terrain, especially when moving"

Generally the comments were favourable and the operators had few issues with operating on steep terrain in a non-levelling cab. One operator who had operated both non-levelling and levelling cab machines commented that in the levelling cab machine he would often not level the cab in order to get a feel for the terrain, especially when moving. Both operators found no discomfort from working on very steep slopes by the seat belt design and they both liked the ability to feel the steepness of the ground and felt they never became complacent because of it. It is apparent that the issue of non-levelling cab is not significant.

Maintenance

Operator comments:
- "It can get a bit tricky doing maintenance when the machine is on 30° or more. There is not a lot to stand on. On the newer machines they have put in more grating so there are more footholds"
- "As long as you keep three points of contact you are quite stable when climbing around the engine bay"

Machine Travel and Stability

Operator comments:
- "The blade is at the back of the machine and always faces downhill. It is good to know that I can hit a button and that blade digs in in 1.5 seconds … if I need to"
- "The blade is good for getting the machine nice and stable"
- "I can use the blade to carve a path for the rope, say like over the lip of a ridge"
- "After thousands of hours I am still learning what this machine can do. We have developed ways to efficiently attach the (angled) felling head to a vertical tree"
- "With the blade and the rope the machine feels very secure. And you can feel the steepness of the slope so never forget about it"
- "The machine is quite forgiving when slewing because there is a lot of weight down low, with the blade, winch and rope"

4. Traction Winch Rope Tensions

Continuous data were collected for a period of 2 hours and 24 minutes for rope tension and tasks performed (moving, felling and shovelling). One data set capturing 45 minutes of typical operation at the study site is shown in Figure 8.

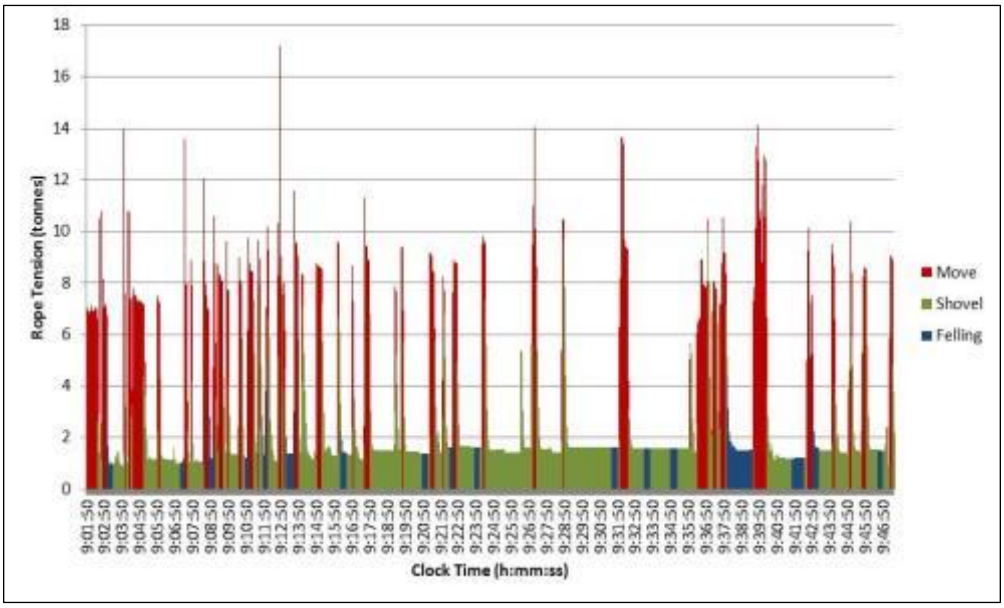

Figure 8: ClimbMAX operating tensions: example 45 minute period while felling and shovelling in partial wind-throw.

The ClimbMAX winch rope was 22mm in diameter and had a safe working load (SWL) of 14.2 tonnes. Average rope tensions while travelling, shovelling and felling were 8.0, 1.8, and 1.6 tonnes respectively and ranged from 0.67 to 17.22 tonnes.

Over the data collection period of 2.4 hours the safe working load (SWL) of 14.2 tonnes was exceeded by 3.1 tonnes (22%) for a very short period (two seconds) on only one occasion (while moving). As such the ClimbMAX winch tension system was deemed to be performing to specification.

Highest tensions observed were while the machine was moving. This is in contrast to another study of a felling machine tethered to a separate winch machine at the top of the hill. In this other study the highest tensions were recorded during felling[4].

Further tension monitoring work could investigate the reasons why the winch rope tension was highest during moving. This could be controlled by the on-board tension management system. The manufacturer (ClimbMAX Equipment Ltd) stated that the next version of the machine has better control of rope tension while the machine is moving.

CONCLUSIONS

A ClimbMAX steep slope harvester in Maungataniwha forest felled and bunched 40m^3/PMH. The number of trees felled per productive hour was higher than that recorded in two previous studies, but the productivity (in cubic metres) was lower since Maungataniwha forest had higher stocking and very small trees. Small tree size and the need to clear old native logs out of the way were the main reason for the lower volume productivity.

A soil disturbance assessment showed the area felled by the ClimbMAX to have more ground disturbance than the area felled manually, however rutting (soil disturbance that might lead to rilling and gully erosion) showed no significant difference between the two areas. The ClimbMAX did not increase the amount of rutting from what was caused by manual felling and yarder extraction. This result may alleviate some of the concern over possible negative environmental effects through the use of tracked machinery on steep slopes. While the soil disturbance assessment identified no real concerns, the degree of sediment movement off-site is an important factor to understand. Sediment trap trials would answer more quantitatively the additional impact of using ground-based machines on very steep slopes.

The ergonomic assessment was generally favourable and operators found no discomfort from working on very steep slopes by the seat belt design. Both operators liked the ability to feel the steepness of the ground and felt they never became complacent because of it.

An investigation of winch rope tensions showed the ClimbMAX on-board tension control system was working to specification and generally the tension stayed within safe working load limits. Highest tensions were generated when moving the machine which was in contrast to other studies, where the highest tensions were recorded during felling.

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