HARVESTING TECHNICAL NOTE

HTN11-02
2019

Helihawk Slash Grapple – First Production Trial

Summary

Build-up of 'slash' (woody debris from windthrown trees, broken tops and branches, and residues from harvesting operations) on the cutover in steep forested areas adjacent to waterways creates the risk of blockage of waterways, and mobilisation of debris downstream during high intensity rain storms. Forest industry stakeholders supported a project to design and build a helicopter slash grapple for improved extraction of slash from the cutover and adjacent waterways. This report summarises the results of the first production trial of the Helihawk Slash Grapple in a steep land radiata pine forest in the Gisborne region of New Zealand. The trial undertook a brief time study of a helicopter using the slash grapple in different types of slash material in an effort to determine productivity and operating cost. Results of analysis of time study data linked to net helicopter payload as measured by an on-board load cell, showed average net extraction productivity of 16.2 tonnes per productive flying hour when extracting slash and logs (tree heads). When a helicopter log grapple had extracted the log component of the slash first, then the slash grapple was used, average net extraction productivity increased to 18.5 tonnes per productive flying hour. It is recommended that as much log material is extracted first before using the slash grapple. In these conditions cost of slash extraction averaged $135 per tonne of slash removed.

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INTRODUCTION

Erosion and debris flows from forestry operations is currently a live topic. Severe weather events in the Nelson and Gisborne regions last year caused localised debris flows of 'slash' (woody debris from windthrown trees, broken tops and branches, and residues from harvesting operations) beyond the forest boundary on to neighbouring properties.

Recent events in Tasman Bay and Tolaga Bay, and the sediment issues in the Marlborough Sounds, have raised concerns about industry practice and the efficacy of management controls over plantation forestry (Wright *et al.* 2019). Public perceptions are that these events are due to poor forest management practices (Macfie 2018).

At an industry workshop sponsored by Forest Growers Research Ltd on harvest residue management on erosion prone land in Auckland in August 2018, the forest industry stakeholders present determined that one research topic should address improved extraction of slash from the cutover and adjacent waterways (FGR, 2018).

The objective of the project proposal was to design and build a helicopter grapple specifically for extraction of slash and to trial the slash grapple in an operational forest environment.

OBJECTIVES

This report focuses on the results of the first production trial of the Helihawk Slash Grapple (Figure 1) designed to determine the success of the grapple design, initial productivity and cost estimates.

The purpose of the trial was to measure the cycle times of the slash grapple and the payloads of slash and logs extracted.

Figure 1: Helihawk Slash Grapple

METHODS

Design and build of the Slash Grapple

The slash grapple used in this operation was designed by Helihawk Ltd of Taupo and built by Colchester

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Engineering Ltd of Matamata in February 2019 (Figure 2).

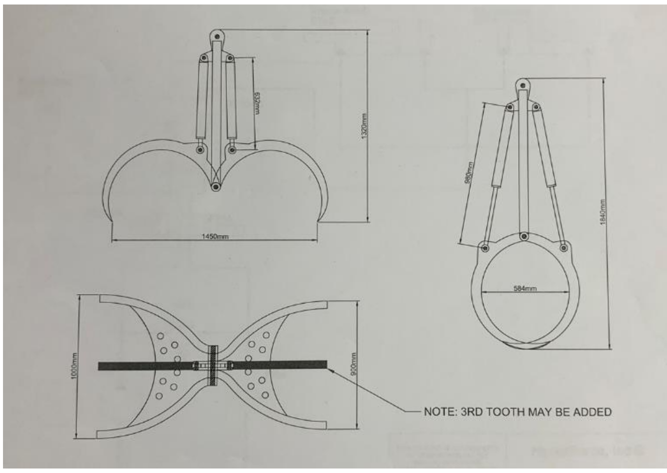

Figure 2: The grapple design

The height of the slash grapple was 1320mm, it had a maximum grapple opening of 1450mm, and weighed approximately 76 kg. It had the option of a third tine to be attached between the two main tines on each side of the grapple. With the attached Enerpac unit (comprising the Kohler engine and hydraulic pump) all up the unit weighed about 200kg.

Study Sites

The site for the helicopter extraction trial was in harvest area 1/04 in Kanuka Forest, owned by China Forestry Group New Zealand and managed by PF Olsen Ltd. The harvest area was 88.3 hectares of radiata pine, planted in 1991 and harvested from 2015 to early 2019. Terrain was very steep, with convex slopes running down deeply incised gullies to a permanent stream of approx. 5 metres width at the bottom of the gully. Average slope was 43^{o} on the south side of the stream, and average slope of 40^{o} on the north side. Figure 3 shows the trial area before extraction of slash.

Crew and Operation Description

The helicopter contractor undertaking this trial was Wairarapa Helicopters Ltd based in Masterton, and the pilot was Tim Williams a very experienced helicopter pilot.

Wairarapa Helicopters Ltd is the holder of an Air Operator Certificate issued by the Civil Aviation Authority of New Zealand under Rule Part 119 to undertake helicopter operations. The helicopter was an AS350 Squirrel BA/B2 variant. It had a cruise speed of 125 knots and a flight range of 700km, or approximately 3 hours flying time. The total lifting capacity (working load limit) of the Squirrel BA/B2 was about 1000kg.

Figure 3: The trial area

The versatility of this helicopter allowed it to carry a payload of up to about 800 kg of slash material and be able to fly in deeply incised gullies and land on very small landing areas.

The landing was above the stream and the predominant flying direction was along the gully, running roughly north-east to south-west, extracting the slash and logs to benches above the stream edge.

The pilot extracted grapple-sized loads of slash and logs according to the profile of the terrain and the availability of material.

Fatigue is recognised as a major human factors hazard because it affects people's ability to do their job safely. Fatigue is defined as a physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties. Fatigue was managed in this operation by ensuring the pilot had a long rest each night and flying periods were limited to 2 hours. It was noticeable to observers the high level of mental alertness and operator concentration required to operate the helicopter and the grapple simultaneously with identifying loads of slash to be moved, and the available drop zones, relative to the terrain. This pilot was very skilled at undertaking all these tasks safely.

Study Design

The original plan was to divide the block into areas by flight distance and age of slash, and extract the slash over a period of two full days.

The following measurements were planned:

1. Measure the payload of each load.
2. Record the total cycle time and the element times of each extraction cycle.
3. Record the total number of loads extracted.
4. Sample measurement of slash dimensions after extraction.

Prior to commencement of the trial, the operational plan was discussed between the Project Leader, the pilot and ground crew, and the trial measurement team. The areas of the harvest setting that were scheduled for extraction using the slash grapple were identified.

RESULTS

Helicopter Slash Grapple: Old Logs & Slash

At first it was attempted to extract old logs and slash (Trial Period 1), with the slash grapple. It seemed to the pilot that the third tine on the slash grapple was preventing efficient pick up of the log heads. After about 18 minutes (16 cycles) the third tine was unbolted from the slash grapple, and for the remainder of Trial Period 1 (48 minutes, or 42 cycles) slash was extracted without the third tine on the grapple. Results showed that without the third tine, loads were slightly lower (295kg vs. 344kg) but the difference was not significant in terms of total cycle time.

During the first period of observation (old logs and slash extraction using the slash grapple), the helicopter operated for approximately 66.2 minutes productive flying time with the slash grapple, during which time it extracted 58 loads (17.91 tonnes) of slash and logs a distance of approximately 10-20 metres to a bench above the stream.

The elements of the slash extraction cycle were: fly empty, load grapple, and fly loaded and drop. Because of the rapid opening of the hydraulically controlled grapple during flight, it was not possible to separate the 'drop' time element from the 'fly loaded' element of the cycle. The element proportions of total cycle time for the slash grapple in Trial Period 1 are shown in Figure 4.

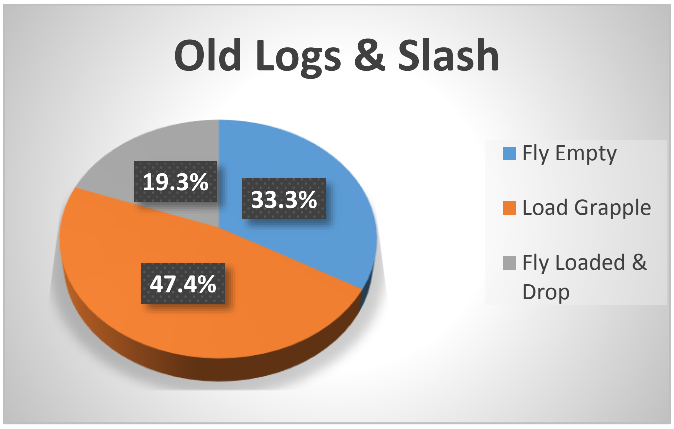

Figure 4: Proportion of total cycle time: Slash Grapple

Delays accounted for only 9.3 minutes of total time (12.3%), comprising mechanical delay (taking the third grapple tine out) and operational delay (repositioning the helicopter). This resulted in utilisation of 87.7%.

A summary of results extracting old logs and slash with the slash grapple (Trial Period 1) is given in Table 1. Given the total weight of slash and logs combined that was extracted in this period, net productivity was calculated at 16.23 tonnes per productive machine hour or PMH. At hourly helicopter cost of $2500 this equates to $154 per tonne of slash extracted.

Table 1: Helihawk Slash Grapple: Old Logs & Slash

Net Productive Time (Min)	66.22	87.7%
Delay time (min)	9.31	12.3%
Total Time (min)	75.53	100.0%
Total volume extracted	17.91	tonnes
Total No. Loads of Logs	58	loads
Average Payload	309	kg/load
Average Net Cycle Time	1.14	min/load
Net productivity in loads	52.5	loads/PMH
Net productivity in tonnes	16.23	tonnes/PMH
Cost per tonne of slash	154.05	$/tonne

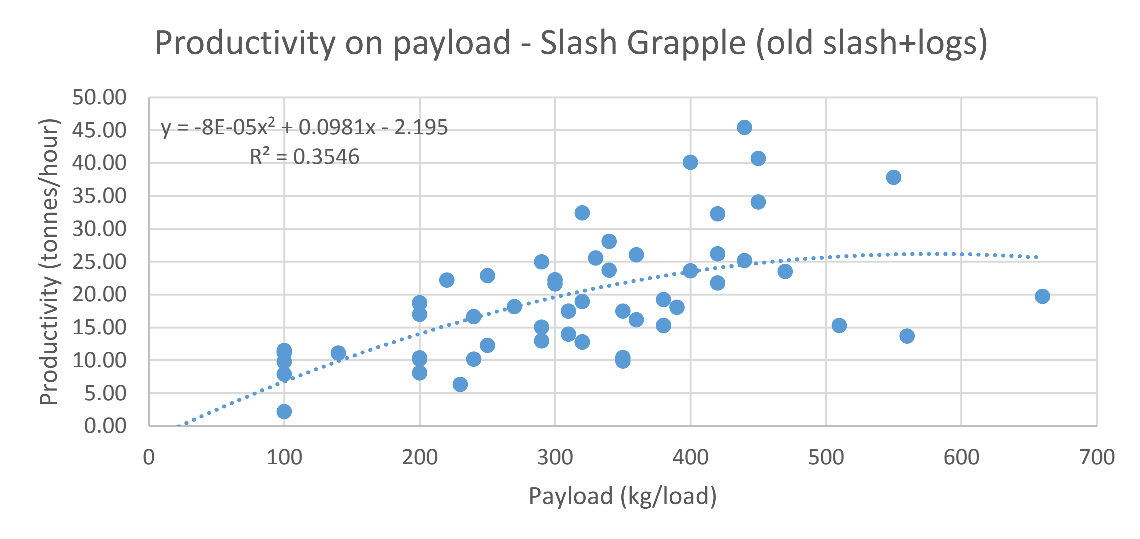

Figure 5: Helihawk Slash Grapple: Old logs & slash – Productivity (tonnes/PMH) related to payload (kg)

Looking at the effect of payload on total cycle time, there was only a weak relationship. The shortest cycle times were around one-half minute (minimum 31.3s) lifting a payload of only 100kg. Overall average payload was 309kg (ranging from 100 - 660kg) taking just over one minute (1.14 min) total cycle time to extract (range 31-165 sec). Converting cycle time and payload to productivity in tonnes per productive hour showed a better relationship with payload (Figure 5).

In retrospect the large Log Grapple should have been used first, to remove the dry logs that were laying over top of the slash. These logs laying over the slash stopped the slash grapple from being as productive as it could have been. Because the slash was old the effectiveness of the slash grapple did not reach full potential of its design as the material being picked up broke and fell back to the stream bed. If this was fresh green slash it would have held together and more of it would have been removed in one lift.

Large Log Grapple: Fresh Logs/Heads

Later the same day the helicopter moved to an area of fresher slash in a part of the block that had been logged about 3 months earlier. The slash grapple was switched over to the larger of the two Helihawk Log Grapples to pick the larger log material off the top (Trial Period 2). This operation was straight forward Heli-logging.

During this second period of observation (extraction of fresher logs/tree heads using the large Helihawk Log Grapple), the helicopter operated for approximately 47.64 minutes productive flying time, during which time 27 loads, or 11.92 tonnes of logs, were extracted from the stream bed (Table 2).

Table 2: Large Helihawk Log Grapple: Fresher Logs

Net Productive Time (Min)	47.64	86.9%
Delay time (min)	7.19	13.1%
Total Time (min)	54.83	100.0%
Total volume extracted	11.92	tonnes
Total No. Loads of Logs	27	loads
Average Payload	441	kg/load
Average Net Cycle Time	1.76	min/load
Net productivity in loads	34.0	loads/PMH
Net productivity in tonnes	15.01	tonnes/PMH
Cost per tonne of slash	166.53	$/tonne

With the large Helihawk Log Grapple delays accounted for 7.19 minutes of total time (13.1%), comprising operational delays only (repositioning the helicopter). This resulted in utilisation of 86.9%.

Given average total productive cycle time was 1.76 min to extract average payload of 441kg, productivity was calculated at 34 loads per hour, or 15.01 tonnes per productive flying hour. At the hourly cost of $2500 the log extraction cost was $166 per tonne of logs extracted.

With the large Helihawk Log Grapple there was more variation of productivity on payload than with the slash grapple (Figure 6).

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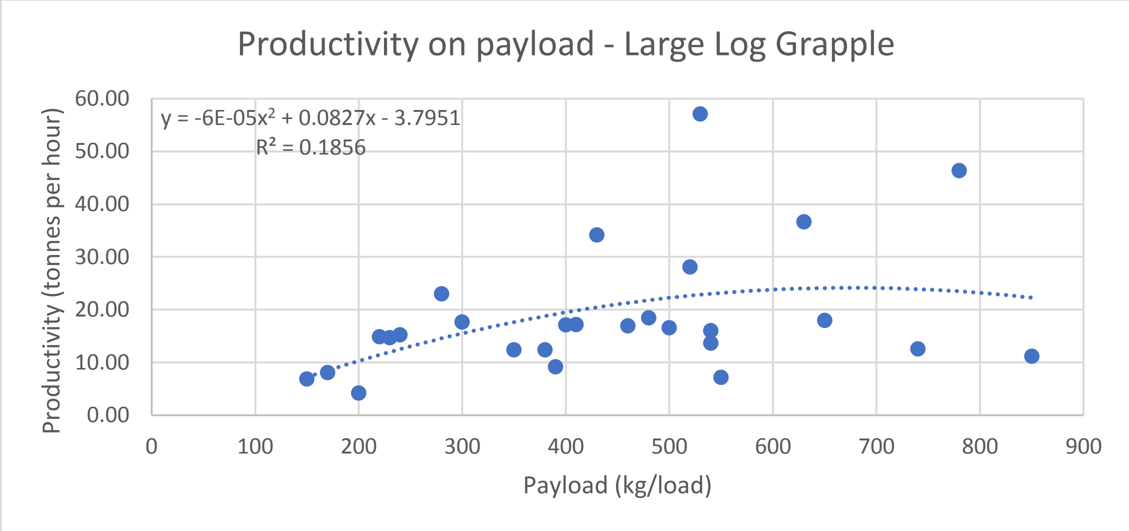

Figure 6: Helihawk Log Grapple: Fresh logs only – Productivity (tonnes/PMH) related to payload (kg)

Helicopter Slash Grapple: Fresh Slash

In the third period of observation (Trial Period 3), the Helihawk Slash Grapple was put back on the helicopter, after the logs had been lifted off using the large Helihawk Log Grapple. The third tine was put back on the slash grapple as it was expected that having removed the larger material the slash grapple would be easier to use, and slash loads would be larger than earlier achieved.

During Trial Period 3, the helicopter operated for approximately 47.45 minutes productive flying time, during which time it extracted 45 loads (14.62 tonnes) of slash a distance of approximately 10 metres to a bench above the stream (Table 3).

Table 3: Helihawk Slash Grapple: Fresh Slash

Net Productive Time (Min)	47.45	100.0%
Delay time (min)	0.00	0.0%
Total Time (min)	47.45	100.0%
Total volume extracted	14.62	tonnes
Total No. Loads of Logs	45	loads
Average Payload	325	kg/load
Average Net Cycle Time	1.05	min/load
Net productivity in loads	56.9	loads/PMH
Net productivity in tonnes	18.49	tonnes/PMH
Cost per tonne of slash	135.22	$/tonne

There were no delays during this period of observation. Given the total weight of slash that was extracted in this period, net productivity was calculated at 56.9 loads per hour, or 18.49 tonnes per productive flying hour. This equated to a cost of $135 per tonne of slash extracted.

It was obvious from observation that despite the helicopter working in a difficult area, with a deeply incised gully, slash extraction was successful due to removing the large logs and tree heads first before using the slash grapple.

Looking at the effect of payload on total cycle time, there was no relationship. However, as with the earlier observation of the slash grapple, converting cycle time and payload to productivity in tonnes per productive hour showed a good relationship with payload (Figure 7). Payloads over 350 kg showed some high potential productivity, with one load exceeding 700kg.

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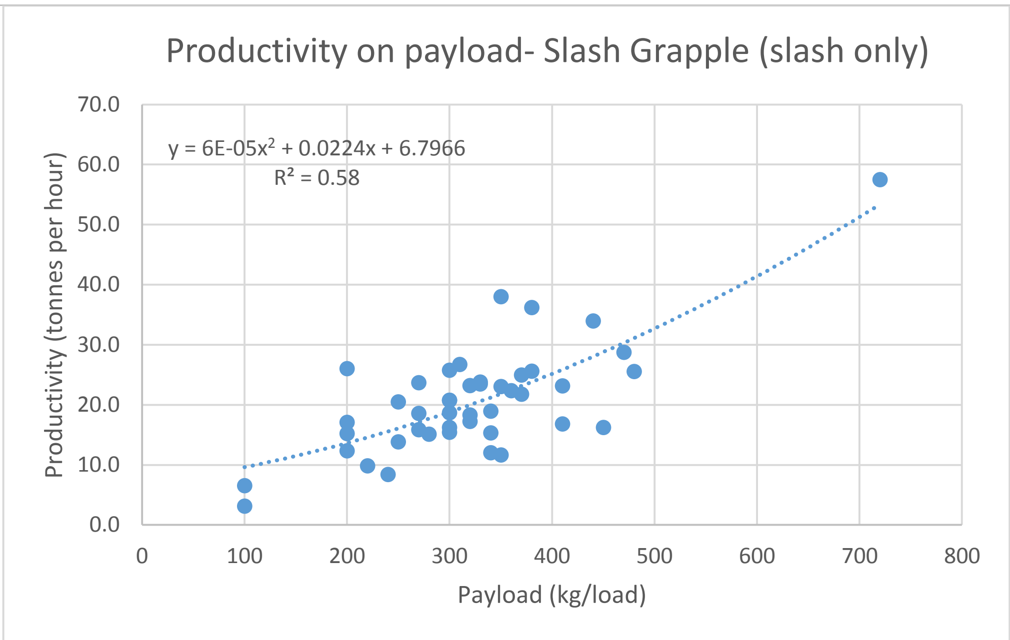

Figure 7: Helihawk Slash Grapple: Fresh slash only – Productivity (tonnes/PMH) related to payload (kg)

To compare the difference between extracting slash and logs together using the slash grapple (Trial Period 1) with separating the larger log material then extracting the slash, the data from Trial Periods 2 and 3 were combined and compared with results from Trial Period 1 (Table 4).

Table 4: Logs & slash together vs. separate extraction.

Results	Logs + Slash	Logs then slash
Delay % of total time	12.3%	7.0%
Utilisation % of total time	87.7%	93.0%
Total No. Loads of Logs	58	72
Average Payload (kg)	309	369
Average Net Cycle Time (min)	1.14	1.32
Net productivity (loads/PMH)	52.55	45.43
Net productivity (tonnes/PMH)	16.23	16.75
Cost per tonne of slash ($/t)	154.05	149.28

The effect of extracting large logs first then using the slash grapple was to increase payloads for both the log extraction and the slash extraction compared to extracting logs and slash at the same time. This resulted in higher average productivity when the two operations were conducted separately rather than attempting to use the slash grapple to extract logs and slash at the same time.

Helicopter Extraction: Small Log Grapple

On Day Two of the trial (Trial Period 4), the technique of removing the log material before using the slash grapple was trialled again, this time using the smaller Helihawk Log Grapple (Table 5). The pilot thought that with the smaller log grapple he was able to get into places he couldn't before with the larger grapple.

Table 5: Small Helihawk Log Grapple: Fresh Slash

Net Productive Time (Min)	40.86	85.8%
Delay time (min)	6.76	14.2%
Total Time (min)	47.62	100.0%
Total volume extracted	7.13	tonnes
Total No. Loads of Logs	25	loads
Average Payload	285	kg/load
Average Net Cycle Time	1.63	min/load
Net productivity in loads	36.72	loads/PMH
Net productivity in tonnes	10.47	tonnes/PMH
Cost per tonne of slash	238.75	$/tonne

During this period of observation (fresh log extraction using the small log grapple), the helicopter operated for approximately 40.86 minutes productive flying time, during which time it extracted 25 loads of logs (7.13 tonnes) a distance of approximately 10 metres to a bench above the stream. On several occasions the grapple flipped sideways, incurring a delay while

the helicopter lifted the grapple and came back around for another attempt. This resulted in 14% delays. The pilot said later that this was because of the nature in which the logs had landed, they were crossed up with some sticking up vertically. These vertical positioned logs made controlling the grapple far harder than extracting ones lying flat on the ground. It was more difficult to get the grapple into a position where the self-release would activate and clamp onto the log, the flipping was the result of the grapple falling off the log causing the extra attempts at log pick up.

Compared to the data collected during the use of the large log grapple, the payloads were much smaller (285 kg vs. 441kg) and productivity was lower (10.47 vs. 15.01 tonnes/productive hour. There was however a good relationship between productivity and payload when using the small log grapple (Figure 8).

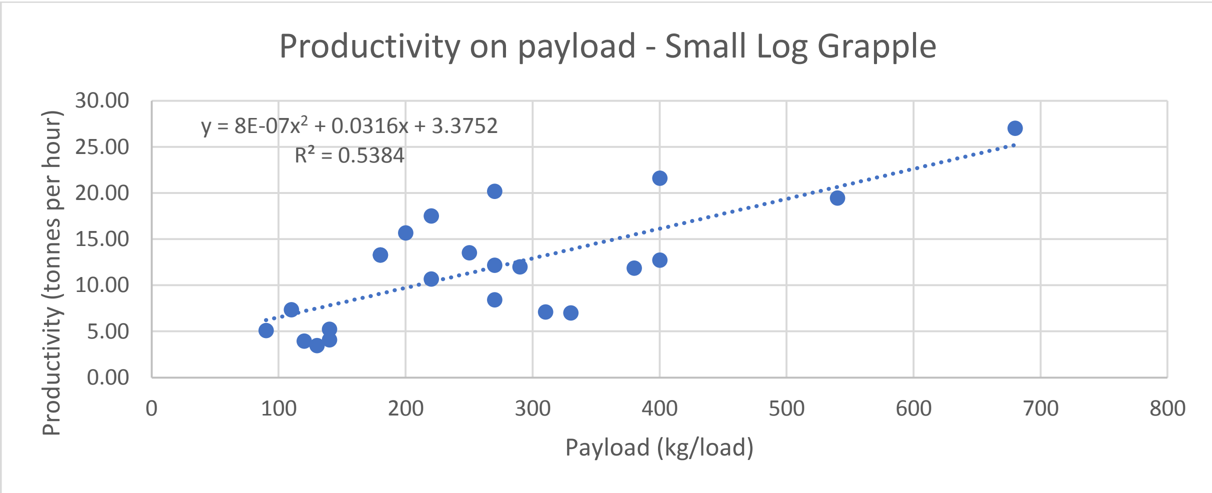

Figure 8: Small Helihawk Log Grapple: Fresh logs only – Productivity (tonnes/PMH) related to payload (kg)

Helicopter Slash Grapple: Fresh Slash Only

Later in Day Two of the trial, the smaller Helihawk Log Grapple was removed and the Helihawk Slash Grapple fitted to extract the last of the slash in the trial area (Trial Period 5). During this period the helicopter was refuelled, incurring a delay of 8.44 minutes. For this final period of observation the slash grapple was fitted to the helicopter and the remaining slash in the area where the small Helihawk Log Grapple had removed the logs was extracted to a bench about 10m away from the stream bed.

The element proportions of total cycle time for the slash grapple in Trial Period 5 are shown in Figure 9. Compared to Trial Period 1 when logs and slash were extracted, the helicopter spent less time loading the grapple (37% of time compared to 47%).

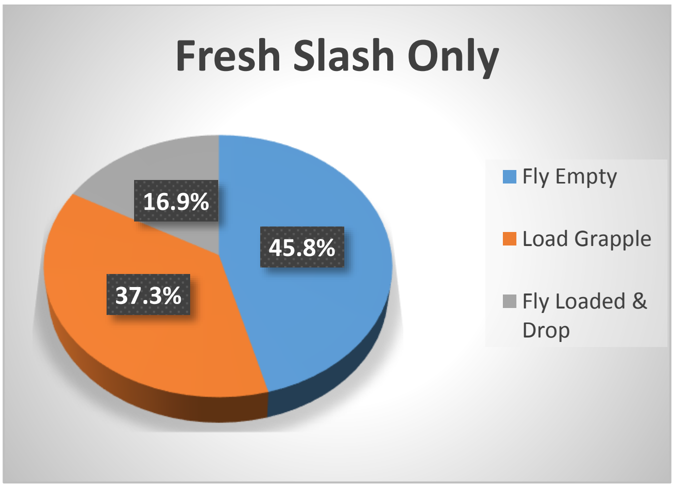

Figure 9: Proportion of total cycle time: Slash Grapple

During Trial Period 5 (extraction of fresh slash only with the slash grapple after logs had been removed using the small log grapple), the helicopter operated for 31.36 minutes productive flying time, during which time it extracted 26 loads (6.94 tonnes) of slash. There was a good relationship between productivity and payload when using the slash grapple after logs were removed with the small log grapple (Figure 10).

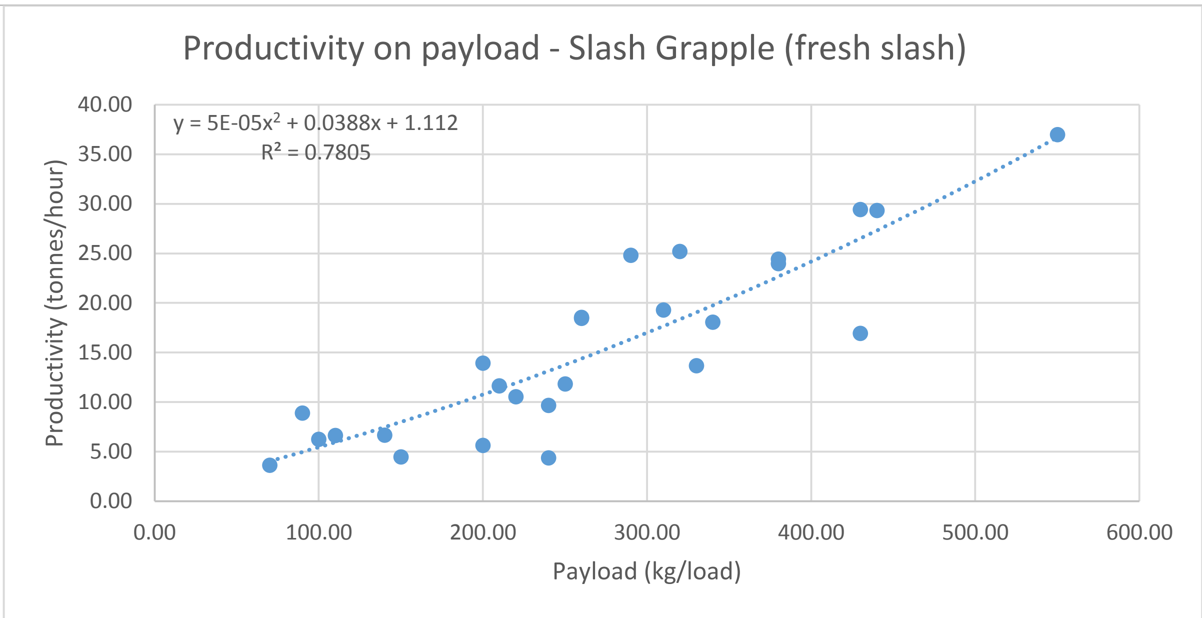

Figure 10: Helihawk Slash Grapple: Fresh slash only – Productivity (tonnes/PMH) related to payload (kg)

A summary of results achieved during Trial Period 5 is given in Table 6.

Table 6: Helihawk Slash Grapple: Fresh Slash (Trial Period 5)

Net Productive Time (Min)	31.36	100.0%
Delay time (min)	0.00	0.0%
Total Time (min)	31.36	100.0%
Total volume extracted	6.94	Tonnes
Total No. Loads	26	Loads
Average Payload	267	kg/load
Average Net Cycle Time	1.21	min/load
Net productivity in loads	49.75	loads/PMH
Net productivity in tonnes	13.28	tonnes/PMH
Cost per tonne of slash	188.27	$/tonne

The payloads were smaller than in Trial Period 3, when the Helihawk Slash Grapple extracted slash after logs had been lifted off using the large Helihawk Log Grapple (267 kg/load vs. 325 kg/load) and productivity was lower (13.28 vs. 18.49 tonnes/productive hour).

Given the net productivity, calculated at 13.28 tonnes per productive hour, extraction cost during Trial Period 5 was calculated at $188 per tonne of slash extracted.

A sample of this slash was measured (Table 7).

Table 7: Measured stem dimensions of a sample of slash

Stem type	***N***	***LED cm***	***SED cm***	***Length m***
Largest piece	*1*	*18.0*	*14.5*	*5.3*
Smallest piece	*2*	*10.0*	*6.0*	*3.0*
Average	*3*	*14.0*	*10.2*	*4.0*

The final measurements taken during the trial were the flying times over a range of distances to enable calculation of helicopter flying speed. If longer travel loaded distances were envisaged, the cycle times could be calculated using these estimates of average helicopter speed (Table 8).

Table 8: Average Helicopter speed (m/s) over varying distances (m)

Cycle	Distance (m)	Fly Empty Speed (m/s)	Fly Loaded Speed (m/s)	Average Speed (m/s)
1	150	7.04	8.12	7.54
2	150	4.70	5.73	5.16
3	300	6.58	12.91	8.71
4	300	14.81	18.65	16.51
5	300	11.71	-	11.71
6	300	-	8.86	8.86
Average 150m distance		**5.64**	**6.72**	**6.13**
Average 300m distance		**9.84**	**12.30**	**10.93**
Overall Average		**8.29**	**10.18**	**9.14**

DISCUSSION

The National Environmental Standards for Plantation Forestry (NES-PF 2017), as part of its permitted activity specification, states that slash from harvesting must not be deposited into a water body, or onto the land that would be covered by water during a storm event with a 5% Annual Exceedance Probability (AEP). If this does occur, then slash from harvesting must be removed from the water body, and the land that would be covered by water during a 5% AEP flood event, "unless to do so would be unsafe", to avoid blocking or damming of a water body, eroding river banks, significant adverse effects on aquatic life or damaging downstream infrastructure, property, or receiving environments, including the coastal environment.

Using manual workers to remove harvest residues from steep or incised gullies, can readily be recognised as a dangerous task. Sending machinery down into gullies close to waterways to remove harvest residues, while effective, often results in soil disturbance that destabilises the streambank, increasing the risk of bank collapse, and sedimentation of waterways (Visser *et al.* 2018). It could be argued that the implementation of safe and efficient helicopter slash extraction substantially reduces or eliminates the unsafe nature of manual stream cleaning, and minimises the risk of negative environmental outcomes.

Despite the fact that this was the first production trial with the slash grapple, it was quite apparent that the slash grapple extracted loads significantly faster than the log grapple working in the same area of stream, even though the loads were of smaller average size.

Extraction productivity of the slash grapple ranged from 18.5 tonnes/PMH after log removal with the large log grapple (15.0 tonnes/PMH), down to 13.3 tonnes/PMH after removal of logs with the small log grapple (10.5 tonnes/PMH).

The time studies, although of relatively short duration (3.89 hours productive time), are indicative of the range of productivity expected with helicopter slash extraction operations. Cycle times of sample data collected using the slash grapple versus the two types of log grapple (large and small) helped the observers to understand the different operating techniques involved and the effect they had on the helicopter cycle times and productivity of slash extraction. Interestingly, all three types of grapple showed broadly similar total cycle times (ranging from 1.05 min/cycle up to 1.76 min/cycle), however the average payloads were quite different (ranging from 441kg/load down to 267kg/load.

The results from the time study data clearly showed the slash grapple achieved a shorter cycle time compared to either of the two types of log grapple (1.05 min/cycle vs. 1.76 min/cycle for the slash grapple and large log grapple, and 1.21 min/cycle vs. 1.63 min/cycle for the small log grapple respectively). Productivity in terms of tonnes extracted per productive flying hour was noticeably higher with the slash grapple than with either of the log grapples. This could be attributed to the fact that the pilot had removed the larger logs off the top allowing quicker load times using the slash grapple.

Analysis of the element times of the total cycle time using the slash grapple, comprising fly empty, load grapple, and fly loaded/drop, showed that when only slash was extracted, the helicopter spent a smaller proportion of total time loading the grapple than when slash and logs were extracted (37% of time compared to 47%). It was concluded that using the slash grapple after the large logs were extracted first increased the payloads for both the log extraction and the slash extraction compared to extracting logs and slash at the same time. Average productivity was higher when the two operations were conducted separately rather than attempting to use the slash grapple to extract logs and slash at the same time.

The most compelling outcomes from this first trial of the slash grapple have been the ease at which the pilot was able to operate the slash grapple, the closing power of the grapple, and the ability to open the grapple in mid-flight to spread the slash across the cutover, rather than piling it in one place. Results clearly showed the success of the slash grapple design, and the potential for increasing the productivity of slash extraction.

Performance with the slash grapple in the trial area was influenced by how fresh the slash was, the amount of large log material present that required clearing, whether the slash was buried or sitting on top of the stream, and how deeply incised the gully was in the lower reaches of the setting, restricting access for the helicopter. Removal of slash would be much more cost effective straight after the block has been logged when slash is still green.

The size of the slash grapple was well matched to the size and hourly cost of the helicopter, and the deeply incised nature of the terrain. A larger slash grapple would require a much larger helicopter (at higher cost) and may not be able to access all the slash in deeply incised gullies.

This trial showed the potential for extraction of fresh slash using a helicopter for indicative net productivity of 18.5 tonnes/PMH and net costs of $135 per tonne of slash removed. Dividing the net helicopter cost ($9,730) by the length of stream cleaned in the trial (87m) gave a cost of approximately $112 per metre of stream length.

When this cost was extrapolated to the full 500m of stream length, and spread across the total volume from the 88.5 hectares of the harvest setting (total recoverable volume of 53,421 m^3) this resulted in an additional cost of only $1.05 per cubic metre of merchantable wood produced.

CONCLUSION

Past experience has shown that helicopters are the most expensive systems used to harvest sensitive areas. While the environmental impact is low, high operating costs limit their potential to sensitive or high risk areas only. This limitation is off-set to some extent by their potential high productivity (Baillie 2010). To maximise the production potential of helicopter operations careful planning and management is required to ensure efficient operation at minimum cost (Kirk & Smith, 1992).

Critical factors to the economic success of helicopter slash extraction operations are the position of the drop zone as close to the slash source as possible and ensuring that personnel and machinery capacity are optimised to the expected payloads to maintain high productivity in tonnes per hour.

This initial trial showed that the slash grapple designed and built by Helihawk Ltd was well matched to the task required and the helicopter used for the trial. Removing the large logs and tree heads first before using the slash grapple was shown to be the best technique.

Close proximity of the drop zone above the stream minimised helicopter cycle times. In this study 55% of cycle times with the slash grapple were less than one minute duration. The helicopter was able to extract slash which would be high cost and hazardous for manual slash extraction (the more traditional method of stream cleaning).

Environmental benefits included improved safety, full suspension and spreading of loads across the drop zone avoiding piling, no soil disturbance and impact on the stream bed and banks, and short slash extraction period (facilitating rapid re-establishment of the harvest area).

This study confirms previous observations that using helicopters is a costly exercise, However in high risk areas of steep terrain and deeply incised gullies with permanent streams that are part of the headwaters of major rivers, or are subject to high intensity rain storm that are increasing in frequency throughout New Zealand, this method of slash removal may be cost effective, compared to manual slash extraction, or the cost of breaching resource consent conditions.

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Efforts to extract unmerchantable (and therefore non-extracted) slash above the break point of extracted stem wood using helicopters has potential to reduce the environmental risk of mobilisation into debris flows during high intensity storms.

RECOMMENDATIONS:

The following recommendations are made arising from this study:

1. Validate results from this initial trial of the slash grapple with a second helicopter production trial in terrain with fresh slash and less log material present.

2. Investigate the option to design and build a hauler slash grapple to use with a mechanical grapple or a grapple carriage, or a motorised drop line carriage.

3. Further examine the performance and system cost of the slash grapple over a range of extraction distances to develop a cost and productivity model for helicopter-based slash extraction.

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- Warren Rance and his staff from PF Olsen Ltd, Gisborne, representing the forest owners.

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