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: 1.2 **Report No. FGR-057**

Management of Harvesting Residues: Results from a Delphi survey of forest industry experts

Author:
Campbell Harvey

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

Date: 14 February 2022

TABLE OF CONTENTS

supported by forestgrowers commodity levy

EXECUTIVE SUMMARY

Woody residues that result from clearfelling steepland plantation forests present a significant opportunity for the New Zealand government's aim to de-carbonise the economy. The primary focus of plantation forest production has traditionally been roundwood, with woody residues commonly left on site to decompose, often due to limited market opportunities. The recent interest in woody residues, especially from sectors requiring fuel for industrial heating is relatively new to much of the plantation forest industry. The opportunity provided by this new biomass product stream has the potential to reduce risks posed by residue accumulations, improve profitability for the forest sector, generate employment for fuel processors and distributors and assist New Zealand in meeting its emissions reduction targets.

There have been several high-profile events where harvest residues have been entrained in floodwaters and debris flows. Already, many learnings from those events have been embedded in operational practice to better manage the risk of residue accumulations on steep terrain, especially around landings. However, there is an understanding that residues may remain uneconomic to bring to market for some forest owners. This research project explored the primary risks and solutions for managing those woody residues left on site.

A questionnaire was developed and administered using the Delphi technique. Delphi is used to arrive at a group opinion or decision by surveying a panel of experts. The survey was administered from July to October 2021. The questionnaire was circulated to around 40 forestry operations experts, of which 20 opted to be a part of the study. Questions were divided into five themes:

1. General questions regarding woody residue sale activity and forecasts.
2. Residues on the cutover.
3. Residues in and around waterways.
4. Residues at the landing.
5. Alternative forest management options.

Two rounds of the Delphi survey allowed the participants the opportunity to form consensus on each of the questions. Results showed that 35 percent of the questions resulted in a simple majority, 58 percent resulted in a plurality (more people selecting one answer than any one other answer) and seven percent of responses resulted in no form of agreement.

The experts were either reserved or optimistic about the future of woody residue markets, with roughly half expecting demand to remain the same as present and the other half expecting greater demand on residues in the next five years. Extracting large woody residues (generally defined as >10cm diameter and >0.8m in length) from steepland cutovers comes at a cost. With current harvesting systems, the experts estimated the cost of harvesting would need to increase by $2.40 – $8.50 per tonne.

Risk of windthrow in adjacent standing crops drives many planning decisions in steepland forests and any future harvest coupe size restraints would be met with increased planning requirements, especially for wind on exposed stand edges, including bordering stands on gully-bottoms or consideration of differential silvicultural treatment at stand edges.

Regarding steepland landings, the experts advised that piles of residues on and around landings should be retrieved from slopes greater than 15-20 degrees and pulled back several metres clear of the fill edge. Benches installed around steep slope landings for retaining landing residues were considered appropriate, ensuring they remain visible along their full length and sloped inwards towards the landing (with drainage cuts to the out-slope).

Regarding the management of trees around waterways, sweeping of felling debris from cutovers to flow paths (primarily side gullies) was identified as a key risk in steep terrain. The experts cautioned that the solution is not solely riparian zone management, but this is part of a suite of debris flow risk

reduction measures. A few windblown trees in a waterway or a floodplain can reasonably be left, but many in the same position would be cause for intervention.

Continuous improvement to ‘business-as-usual’ management techniques was favoured by the experts who took part in this Delphi survey. Managing woody biomass from harvesting, both as a marketable product or as residue from operations, requires a suite of best practices, whereby forest owners and managers must tailor a solution to the specific constraints of the site and environment.

INTRODUCTION

Harvesting plantation trees generates woody debris (harvest residues) at each stage of the process from the standing tree to the log truck. Woody residues can accumulate on the cutover or at the landing with the Whole Tree Harvesting (WTH) system that predominates in New Zealand operations. In contrast, for Cut-to-Length (CTL) systems, residue is more evenly spread on the cutover. Unintended stem breakage and delimbing accounts for a significant proportion of woody residue production. Somewhat unique to New Zealand is the relative absence of options for either selling or destroying woody residues that are both financially attractive and low risk.

Harvest residues have traditionally had negligible value (if any) to most small forest owners, or those with longer lead distances, regardless of where they accumulate on site. Where residues cannot be sold at a profit, management of the material follows 'best practice' whilst they decompose. However, specific to the management of residues, there is very little specific management guidance in documents such as the Environmental Code of Practice (NZFOA, 2009), except to ensure that any accumulation is contained, and the risk of mobilisation is minimised.

The plantation forest sector is now seeing increasing demand for woody residues, particularly from industrial energy users (Pooch 2021). Noting however that there are supply and demand imbalances at the regional level, woody residues that cannot be moved to market will still require some form of onsite management for risk reduction (Dale 2019).

As markets develop and best practice continues to evolve in New Zealand, various questions surround the appropriate management of harvest residues in steepland forests. The goal of this Delphi survey was to gauge the informed opinion of a group of New Zealand's harvesting operations experts, distributed across the country, in various roles and affiliations. For steepland plantation forests, the Delphi technique sought answers to some key challenges:

- What will it take to supply woody residues to a developing biomass market?
- Where are the opportunities for reducing the production and accumulation of woody residues?
- How should we manage residue accumulations to ensure they pose 'acceptable' risk?
- What alternative forest management options on steepland areas should be explored to improve environmental performance?

METHOD

A Delphi process was chosen to administer the survey as: *“the problem does not lend itself to precise analytical techniques but can benefit from the subjective judgements on a collective basis”;* and *“the individuals needed to contribute to the examination of a broad or complex problem have no history of adequate communication and may represent diverse backgrounds with respect to experience or expertise”* (Linstone & Turoff 1975).

The questionnaire was circulated to around 40 forestry operations experts, of which 20 opted to be a part of the study. While it is not implied that the group of operations experts who participated in this study have “*no history of adequate communication”* or “*represent diverse backgrounds with respect to experience or expertise*”, the Delphi technique gives a framework for such communication which is particularly useful where the participants are large in number and are distributed geographically.

A series of questions was developed to explore the knowledge and perceptions of harvest residues among the group of experts as a collective. Questions asked the participants to either rate on a scale of 1-5, or give numerical answers (e.g., cost estimate in dollars), or provide validation (yes/no replies). Each question provided opportunity for a respondent to clarify in writing the reason for their position, and relevant questions provided opportunities for alternative answers for the group to consider in later rounds.

Seven initial questions were not part of the Delphi technique (that is, they were not intended for establishing any consensus), then 103 questions provided the participants with an opportunity to form a consensus. In the later rounds, respondents would be able to change their own answers from earlier rounds if convinced by the answers and/or justifications of the others.

Round One of the questionnaire was sent out to more than forty past and present forestry managers throughout New Zealand (deemed to be experts in forest operations). Twenty of those experts replied with completed Round One questions (50% response). Anonymity was maintained throughout to preserve the integrity of the Delphi technique, allowing participants to consider their positions without influence or concern for sharing personal opinions. The results were summarised from Round One, and individualised reports of their answers were returned to each of the twenty participants against those of the group.

In Round Two the same questions were asked again, providing each respondent with the opportunity to change any previous answers. Results of Round Two were returned by the participants and analysed, with only a few minor changes when measured against returns for Round One for any one question, therefore no further Round was undertaken.

By the conclusion of Round Two, 117 questions had been asked in total. The results presented in the next section are those received at the conclusion of Round Two, which was the end of the Delphi technique.

RESULTS

Below is a summary of the results of the Delphi process at the conclusion of Round Two. Note that examples of questions presented to the experts are provided as an Appendix.

General (non-Delphi) Questions

Question 1: Over the next 5 years, do you anticipate the demand for forest residues in your region to increase/decrease/stay the same?

The participants were either reserved or optimistic about the future role of steepland harvest residues as a product in the bioeconomy. Regarding Question 1, 10 respondents out of 20 (50%) predicted the demand to stay the same, while nine out of 20 respondents projected an increase in demand (45%).

There was a wide spread of responses on the question regarding the potential difficulty of integrating biomass uplift into existing harvesting systems, and also the recent efforts on seeking/generating markets for harvest residues. This can reflect many things – but it is reasonably well established that market potential for woody biomass varies throughout New Zealand depending on supply, demand, and relative cost of competing energy sources (BioPacific Partners 2020; Hall 2017; Hall & Evanson 2007; Hall & Jack 2009).

What is clear is that most participants (16 of 19, or 84%) have not recently measured harvest residue production, and therefore may benefit from assessing the available resource.

Delphi Questions

The participants achieved a simple majority (>50% selected the same answer) and plurality (more participants selected one answer than the remaining answers) for most questions after two rounds of deliberation (Table 1).

Table 1: Overall measurement of consensus from the 103 questions that offered the opportunity for the declaration of a majority vote.

Simple Majority	Plurality	No consensus (no general agreement)
35%	58%	7%

Managing residues on the cutover

These questions were designed to investigate the fundamental causes for harvest residue issues in steepland cutovers, some of the economics for their removal, and what aspects of harvesting operations can lead to lower residue loading on cutovers.

Question 2 asked what are the indicators of a 'high-risk' landform? This question was asked under the presumption that uncontrolled residue movement from the cutover is most often a result of erosion processes. Participants agreed that 'historic slip scars', 'weak parent material when weathered' and 'steep areas with wetness on the surface' were indicators of high risk. Factors that were not necessarily indicators of high-risk terrain were 'occasional butt-sweep' (referring to bent plantation trees) and 'early colonising vegetation'.

On regulation and its role in guiding harvesting activities, responses varied with no simple majority, except for Question 3 as to whether Regional Councils are offering guidance for reducing residue mobilisation risk (13 responded no and 7 responded yes) with almost every region in NZ represented in the group (noting that some participants operate over several regions).

Question 4 asked whether, in relation to cutover residues, the National Environmental Standards for Plantation Forestry (NES-PF) are clear and pragmatic guidance and Question 5 explored the usefulness of the Erosion Susceptibility Classification (ESC) map as a proxy for residue mobilisation risk. Results offered no clear agreement or significant movement away from the centre. There appears to be little interest for finer-scale ESC mapping, but comments did support aerial LiDAR coverage for improved planning.

Question 6: How common are significant harvest residue mobilisation events?
Extreme weather, triggering erosion processes has led to incidents where harvest residues mobilise uncontrollably, and this has been an area of significant research focus (Cave *et al.* 2017; Dale 2019; Phillips *et al.* 1996). Question 6 showed that most participants (14 out of 20) are aware of significant residue mobilisation events every year or so.

Question 7 explored the linkage between annual rainfall and its contribution to harvest residue mobilisation risk. Most participants agreed (15 of 20) that there is a linkage between annual rainfall and residue mobilisation risk. However, several comments made note that annual rainfall is *not* the major contributor to risk, but it is instead the infrequent 'weather-bombs' that put sites most at risk of mobilisation – with some respondents adding that 'low-rainfall' areas can be just as risky as 'high-rainfall' areas. Soils play a critical role in how sites respond to rainfall also. While the formal answer to Question 7 indicated agreement on annual rainfall being a risk indicator – the comments reveal that it is more a function of a site's exposure and response to *extreme* rainfall.

Question 8 explored at what slope should mobilisation risk mitigation measures be triggered, above-and-beyond usual best practice? Soils, rainfall, and existing slope instability are agreed indicators of high-risk cutovers. The interpretation of the question is important and may have led to the wide range of responses from as low as 15 degrees slope to 'would not consider reducing risk'. A plurality was reached for introducing risk-reducing measures at 30 degrees (6 out of 19 responses), followed by 35 degrees (4 of 19). With respect to interpretation, a landform that is identified as 'high risk' should have some mitigation measures applied as a function of normal harvesting practice (NZFOA 2007). 'High risk of mobilisation' may also be a measure generated internally (therefore not standardised across NZ) as the indication is that the NES-PF ESC map may not be regarded as a useful proxy (from responses to Question 5) at the finer scale at which harvest planning is generally completed.

Five specific risk scenarios were presented to the group to establish thresholds for intervention to lower the risk posed by windblown trees (also known as 'windthrow'). Question 9 asked "Under what circumstances should a forest owner/manager intervene to lower residue mobilisation risk posed by windthrown production trees during harvest?" Responses showed general agreement. The group agreed that 'one or a few windblown trees in a waterway or within the floodplain' is not cause for intervention, however 'many windblown trees in a waterway or within the floodplain' and 'many windblown trees on a high-risk slope' would require intervention. There was no clear preference 'where the windblown tree(s) are straddling a waterway, but above the 5% AEP flood level' or for 'a handful of windblown trees on a high-risk slope'. Some agreement on specific windblow scenarios is a good result as there is currently little formal guidance to establish a threshold for intervention. Even with a lack of formal guidance, the experts did have some common understanding on what that those thresholds for intervention should be.

Question 10 asked participants to provide an indication of what aspects of terrain or harvesting do or do not contribute to high residue volumes on a steepland cutover. Twenty separate scenarios were proposed with the group also given opportunity to add and rate their submitted scenarios. Of the initial 20 scenarios, three achieved simple majority, and 15 achieved a plurality. A summary of the questions where there was strong opinion of a factor being a significant contributor (maximum value of 5), or not a contributor (minimum value of 1) is given in Table 2.

Table 2: Contributors and non-contributors to high harvest residue volumes on the cutover (1 = not a contributor, 5 = a significant contributor).

	Scenario	Majority/Plurality (Mode)	Group Average (Scale 1-5)
Contributors	Windthrow	Majority (5/5)	4.5
	Broken terrain	Plurality (5/5)	4.4
	Poor deflection or blind areas in the harvest area (cable harvesting)	Plurality (5/5)	4.2
	Negative returns on pulp grades (pulp left off cutting instructions).	Plurality (5/5)	4.1
	Production pressure on harvesting crews (incl. low margin on harvest rates, inclement weather or breakdowns - limiting production)	Plurality (5/5)	3.9
	Untidy stem set-out for extraction	None (4/5 == 5/5)	3.8
Non-contributors	High total recoverable volume of the stand (t/ha)	Plurality (1/5)	1.8
	Ground-based whole tree extraction	Plurality (2/5)	1.8
	Shovelling/bunching stems on the cutover	Plurality (2/5)	2.1

Question 11 asked the participants about scenarios that contributed to low residue volumes on steepland cutovers. Again, the results where there was a significant departure from the centre are shown in Table 3.

Of the 18 scenarios provided, eight achieved a simple majority and nine achieved plurality, indicating high levels of agreement. A positive return from harvesting pulp logs is a clear driver for extraction from the cutover. With negative pulp log returns a frequent occurrence where pulp value is accounted for in its own right (as opposed to averaging across all grades), the participants agreed that this is a significant contributor to residue volumes on the cutover.

With increasing local demand for biomass, increasing prices should help to ensure extraction of biomass suitable for pulp. Two new scenarios stand out in Table 3: with the group agreeing that company/forest owner cutover residue standards and fixed felling heads have a role to play in reducing cutover residue volumes.

Table 3: Contributors and non-contributors to low harvest residue volumes on the cutover (1 = not a contributor, 5 = a significant contributor).

	Scenario	Majority/Plurality (Mode)	Group Average (Scale 1-5)
Contributors	Positive returns on pulp grades (pulp on the cutting instructions).	Majority (5/5)	4.6
	Clear company/forest owner standard(s) for permissible harvest residues	Plurality (4/5)	4.1
	Tidy set-out for extraction	None (4/5 == 5/5)	4.1
	Controlled tree falling (fixed head mechanised)	Majority (4/5)	4.1
	High deflection over cable yarding corridors	Plurality (4/5)	3.9
Non-contributors	No significant departure from the centre on any scenario.		

Noteworthy, because it contradicts Table 2, is the scenario ‘minimised shovelling in the cutover’. The group on average agreed that this does not lead to low residue volumes (average=2.3, majority reached), whereas previously, the group had established that ‘shovelling/bunching stems on the cutover’ did not contribute to high volumes. This may be a result of variable practice or possibly that this practice requires more investigation into its impact on cutover residue volumes as rates of mechanisation continue to climb (Visser 2018). Overall, there was good agreement on what does contribute to lower cutover residue volumes, with common scenarios such as tidy set-out for extraction and adequate cable deflection, indicating relative consistency from the group.

Finally for cutover residues, insights were sought on the impact of large woody residue removals on harvesting operations. Woody residues are typically uneconomic to extract (McMahon *et al.* 1998) and well below the optimum piece size for New Zealand’s mechanised and high productivity harvesting configurations. Mandating the extraction of residues from cutovers is expected to reduce harvesting system efficiency and therefore increase harvesting cost. There will only be an economic incentive for residue removal if the price paid for residues reflects the reduced efficiency of the harvesting system.

Question 12 explored what that productivity drop (in tonnes per day) might be, and what the increase in logging rate (in dollars per tonne) would also be reasonably be expected to be.

Figure 1 indicates the range of expected effects on productivity, incurred costs and prices that might incentivise extraction of residues from the cutover. For clarity, where a participant indicated a range of values, the mid-point was taken. The central 50% of results estimate that production rates will drop anywhere between 24 – 50 tonnes per day (11 responses) and increase the associated logging rate between $2.40 – 8.50 per tonne (10 responses).

Furthermore, Question 13 asked what price bin wood must be (assuming a typical harvest setting in steep country and a 50 km cart to market) to make its extraction from the cutover financially attractive? The experts indicated they would be inclined to supply a market from a steepland forest at a 50-kilometre radius at a rate between $51 – 79 per tonne (16 responses). This includes additional harvesting cost, loading, bin wood transport and profit margin. For additional context on the markets at the time of the Delphi surveys, the diesel price was approximately NZ$1.50 per litre (MBIE 2021) and the weighted average A-grade export log was NZ$182 /JAS f.o.b. for the June 2021 quarter (MPI 2021). Regional differences in harvesting rates and biomass demand are evident, much like the variable log markets. However, these are useful starting points for assessing the effect of additional demand on harvesting resources and how that may contribute to market price equilibrium in the biomass market.

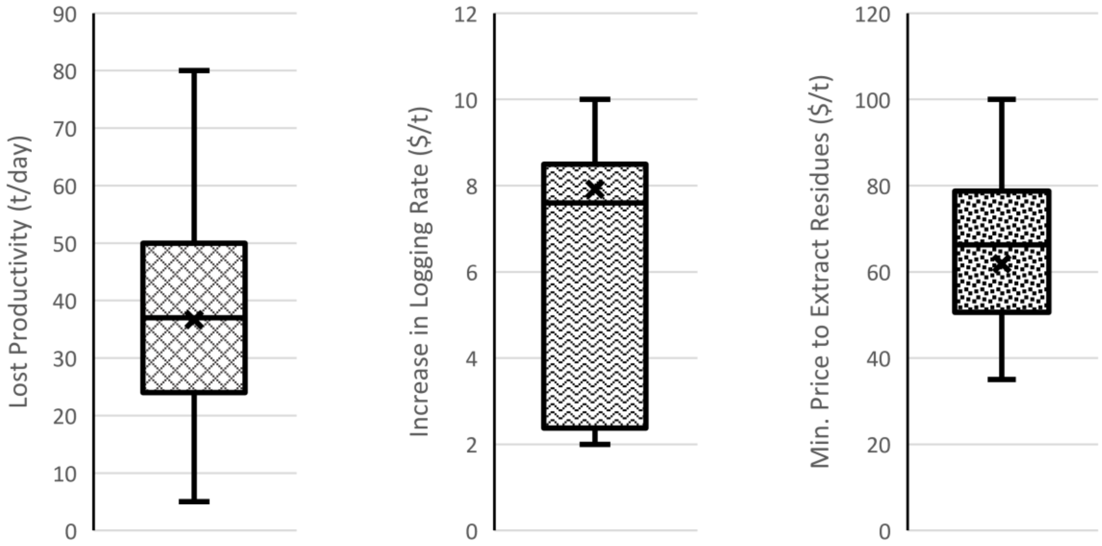

Figure 1: Left - Estimated lost productivity in tonnes per day by extracting residues from the cutover. Centre - Estimated increase in logging rate required to offset the reduced productivity of extracting residues from the cutover. Right - Estimated minimum delivered residue value required to make extracting the material financially attractive.

Managing residues in and around waterways

Residues located in waterways are arguably one of the more immediate and quantifiable risks for biomass mobilisation in many forests. Understanding the drivers of streamflow peaks during extreme rainfall events has progressively improved (Henderson *et al.* 2018), and this information increasingly underpins planning decisions. Forested terrain that is steep and broken, or simply extremely steep, has fundamental challenges associated with full suspension over the waterways, as well as system productivity for the highly mechanised systems. For a logging contractor and forest owner, this can present profitability challenges while also protecting soils, waterways and worker safety.

The participants considered four questions on the management of residues around waterways.

Question 14 asked the group what mechanism typically delivered the most residues to waterways? Half the group selected 'sweeping of felling debris during extraction' (a plurality). This is a mechanism whereby the cable harvesting system will span over felled trees, pulling the stems from the cutover towards the hauler landing. For cable harvesting, to optimise tension in the wire rope cables and the payload on the cables, the stems are most often extracted under conditions of 'partial suspension', meaning that cable tensions are reduced and part of the stem drags over the ground. Partial suspension can result in a sweeping action when the stems move downhill, pulling debris (branches and broken tops) down with them. A second consideration in cable harvesting is one of lower environmental impact. Cable harvesting is considered 'best practice' on steep slopes compared to tracking for ground-based harvesting due to the relative risks associated with soil disturbance (FITEC 2005). Winch-assisted ground-based operations also often 'shovel-log' felled stems downhill, which tends to accumulate woody residues along the path of the shovelled stems in a similar manner to partial suspension during cable harvesting.

The second most frequent choice of mechanism that typically delivered the most residues to waterways was ‘slope failures (landslide)’. Of 20 respondents 5 selected this mechanism, reflecting the known fragility of steep terrain and its linkage with residue mobility.

The remaining three questions sought solutions from the participants.

Question 15 asked to what extent should a riparian buffer be relied on as a tool to mitigate the movement of cut-over residues to waterways?

A majority was reached on the question on using riparian strips as barriers to harvest residue movements to waterways. The group was neither strongly in favour nor opposed to the functional use of riparian strips (3 of 5, majority reached). In comments, several respondents noted that riparian strips are a last line of defence or that they cannot be relied upon, with one noting that riparian widening and structural reinforcement via planting of Redwoods (*Sequoioideae*) is being trialled to improve the effectiveness of the riparian zone for the next harvest.

Question 16 related to managing legacy plantings right up to watercourses in erosion-prone, steepland forests. What is typically the most appropriate course of action at harvest? On managing legacy plantings right to the water’s edge, two options were strongly favoured. Overall, the preference of the participants was to allow some form of flexible management approach – rather than a ‘one size fits all’ rule. The most favoured option (9 of 20 selected) was to: *“Apply mixed management. Fell and extract trees from riparian margins where operations can ensure minimal impact on streams. Abandon areas where harvesting impact on streams may be unacceptable”*. This approach allows some discretion by planners and fit-for-purpose management under the set of site-specific constraints.

The second most popular choice (7 of 20 selected) was to: *“Harvest all trees from riparian margins; leaving high stumps strategically and managing impacts on the stream and area covered by a 5% AEP flood”.* Those respondents who selected the second option may hold the belief that any abandonment of standing trees in the riparian margin carries unacceptable risk. Isolated standing trees, while being a high probability to windthrow, are also a significant hazard during harvesting, aerial spraying operations, and other subsequent silvicultural operations. With clearly divided opinion, this presents an opportunity for further clarification through structured research.

Question 17 explored the opportunity to suggest a solution, asking the participants to define a practical, robust, and defendable interpretation of a waterway from which slash should be removed?

The NES-PF currently adopts the waterbody definition from the Resource Management Act 1991: ‘*water body means fresh water or geothermal water in a river, lake, stream, pond, wetland, or aquifer, or any part thereof, that is not located within the coastal marine area*’ (RMA, 1991). The definition of a ‘river’ is nested within ‘waterbody’ and includes *‘intermittently flowing…fresh water’* (RMA, 1991). Establishing the starting point for a waterbody, that would flow as a ‘river’ during an extreme rainfall event, is essential to the proper application of the standard. These definitions have the potential to cause issues for foresters, contractors, and regional councils alike as it is difficult to give practical, pragmatic direction to harvesting contractors when the extent of the rare, ephemeral waterbody is unknown.

Opinion was divided amongst the expert participants. The most support was for defining a minimum catchment size (e.g., 3 ha) to be the starting point of a waterway (5 selected of 18 – a plurality). The application of this would be a simple GIS analysis and re-mapping of waterways (for the purposes of debris clearance). Four opinions each were given to adhering to existing national spatial datasets: the Ministry for Environment (MfE) River Environment Classification, or the Land Information New Zealand (LINZ) New Zealand River Centrelines datasets. Both MfE and LINZ datasets are known to have their respective differences but are widely used, regardless of their limitations.

Some comments noted that little is known about the flow rate or flow speed that is required to mobilise woody material, and that should have some bearing on the start point of a flow path that requires clearing of debris. One respondent queried whether under extreme rainfall conditions (e.g., 5% AEP) even water table drains on roadways may be considered waterbodies, implying that some reasonable interpretation of the standard is necessary.

Overall, a standardised map-based solution was the preference of the participants that allows clear direction to planners, contractors, and councils.

Managing Residues at the Landing

Piles of woody residues, consisting of bark, branches and off-cuts continue to accumulate at forest landings and remain long after time of harvest. An increase in demand for biomass is expected in the coming decade due to the monetisation of greenhouse gas (GHG) emissions from burning non-renewable fuels such as coal and gas. This provides the opportunity to reduce the volume of residues stored at landings. However, there remains a need to effectively manage the material.

An open market for biomass will ensure that the lowest cost and most accessible material will be preferentially collected. It may be that under some market conditions, industrial-grade logs (such as pulp and bin wood) will be re-directed to biomass markets rather than to export and domestic fibre markets, in preference to lower-quality, lower-quantity (and higher cost) landing residues. This means there remains a need for forest managers to plan and manage residue piles, with current guidelines and standards remaining subject to continuous change.

Similar to the section on cutover residues, the group was given a list of 23 factors that may or may not contribute to high residue pile volumes at the landing.

Question 18 asked respondents to rank each factor on a scale of 1 (no contribution) to 5 (significant contribution) on its contribution to high residue volumes at the landing. Majority agreement was reached on five factors, with pluralities established for the remaining factors.

Table 4 summarises the four factors that resulted in a significant shift away from the centre. Failing to make positive returns on pulp logs featured again as a major contributor to high residue volumes, indicating that the group felt strongly that this drives residue accumulations.

Table 4: Contributors and non-contributors to high harvest residue volumes at the landing.

	Scenario	**Majority/Plurality (Mode)**	**Group Average (Scale 1-5)**
Contributors	Negative-returning pulp grades/pulp left off cutting instructions	Majority (5/5)	4.5
	Environmental crop damage (e.g., hockey-stick butts, snow damage)	Plurality (5/5)	3.9
Non-contributors	Bunching stems on the cutover	Plurality (2/5)	1.8
	Clearwood tending regime (low stocking and pruned)	Majority (2/5)	2.2

Crop damage from the environment (such as snow damage) fell into a similar category. Stem defects (such as excess sweep or large knots) are seldom allowable on sawlogs; therefore, pulp or chip grades are usually the only remaining avenue for sale. Bunching stems for extraction is a method used for increasing the efficiency of the extraction operation and the participants tend to agree that it also reduces landing residue volumes. Bunched stems tend to be better aligned for ‘breaking-out’, resulting in less breakage during extraction. Reduced breakage in turn reduces the need for cutting off waste sections for a ‘flush’ log-end – a typical specification of sawlog grades.

The final factor that does not contribute to landing residue volumes as indicated by the group (by majority) was a ‘clear wood’ tending regime, where the stand is pruned and thinned to a lower final crop stocking (i.e., fewer trees per hectare) than ‘structural’ regimes. Earlier research has established that larger diameter trees (as typical of the clear wood regime) tend to result in higher breakage rates on felling (Murphy 1982). However, the clear wood regime also results in fewer trees per hectare. The participants observed that this combination of factors does not result in increased landing pile volumes over the alternative 'structural' regime.

Solutions and clarification to known issues were asked of the participants, with most attaining either a majority, or at least much greater clarity.

Question 19 asked whether the forest industry should continue to allow the incineration of residue piles? The group responded firmly yes, that burning needs to remain an available tool, but in the knowledge that it does carry risk.

The remaining seven questions in this set considered engineering controls and specific thresholds for residue storage.

Question 20 asked whether piled residues may be stored permanently on unmodified slopes, cuts or compacted fill slopes up to what maximum slope? On storing piles permanently on sloped ground, 12 of the 19 responses were divided between a maximum of 15 to 20-degree slopes. The preference (8 of 19 selected) was to store piles of residues permanently on slopes no greater than 15 degrees (Figure 2).

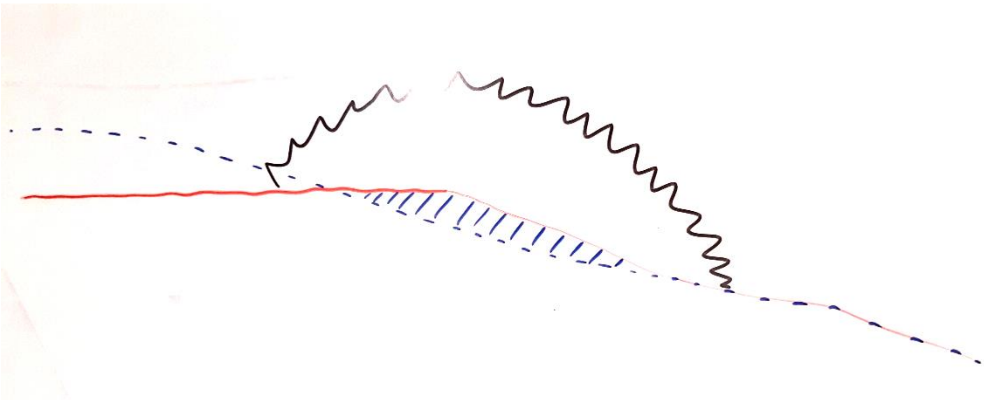

Figure 2: Residue pile stored on an easy fill slope, including over fill sections.

Question 21 asked whether the pile should be pulled back, clear of the fill-edge on slopes steeper than the limit given in Question 20. Results showed that the majority responded yes (18 of 20). Question 21 related to the respondent's own selection of maximum slope, not the average of the group, however the message is clear that (a) if the rule is exceeded, then (b) pull all the residues back off the slope.

Question 22 asked if the response to Question 21 was 'yes', what minimum separation from the fill edge is appropriate for effective risk reduction? When piling residues on landing surfaces, the participants offered mixed opinions on separation from the landing edge. There was no majority answer from the group, however 15 of 18 responses replied between 2 – 4 metres of the fill edge, which is approximately the working corridor needed for an excavator.

In the comments there were some caveats. More than one respondent had little faith in the strength of earth fill with the added surcharge of residue piles, stating or inferring that it would be prudent to place residues on flat cut surfaces (commonly referred to as 'on the hard').

Installing benches below and around landings to hold residue piles and minimise their cumulative impacts on harvesting operations is common practice. How benches are designed and/or utilised is thought to divide opinion amongst forest practitioners. This Delphi process has established however that there is a degree of commonality among expert opinions.

Question 23 asked whether benches should remain visible along their full length. The group agreed (16 of 19).

Question 24 asked which method is most appropriate for constructing slash benches in steep terrain? For construction of slash benches, a majority (11 of 20) agreed that the most appropriate geometry of a bench includes a surface sloped into the terrain, with cuts installed though the raised outer fill for drainage (Figure 3, left). Five additional responses agreed that the in-sloped method is valid, but also accepted an outward sloping bench (Figure 3, right).

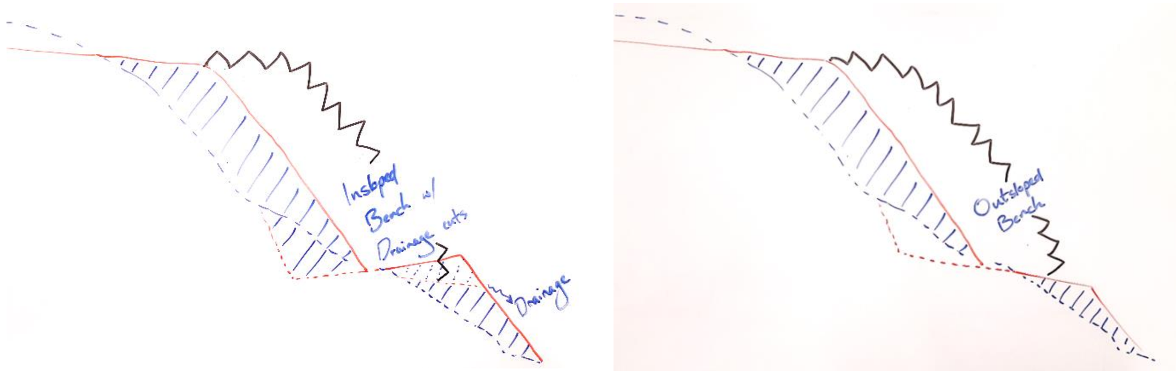

Figure 3: Example sketch of an in-sloped slash bench (left) and an out-sloped slash bench (right) for the storage of residues adjacent to the landing.

Question 25 asked whether 'pocket benches' (as in Figure 4) are acceptable as an off-landing slash storage solution? A majority agreed that 'pocket benches' are an appropriate engineering control.

Question 26 asked under what conditions is a pocket bench not appropriate for slash storage? Responses relating to the conditions where a 'pocket bench' is inappropriate, included areas… "prone to sheet-slip type landslides" (13 responses), also "in locations prone to groundwater seepage through soil layers" (12 responses) and "where the pocket ('trench') is dug into weathered parent material" (5 selected). In the steepland forestry context, land that exhibits one or more of these attributes is very common (to almost ubiquitous) therefore the use of the 'pocket bench' may be limited to isolated scenarios only.

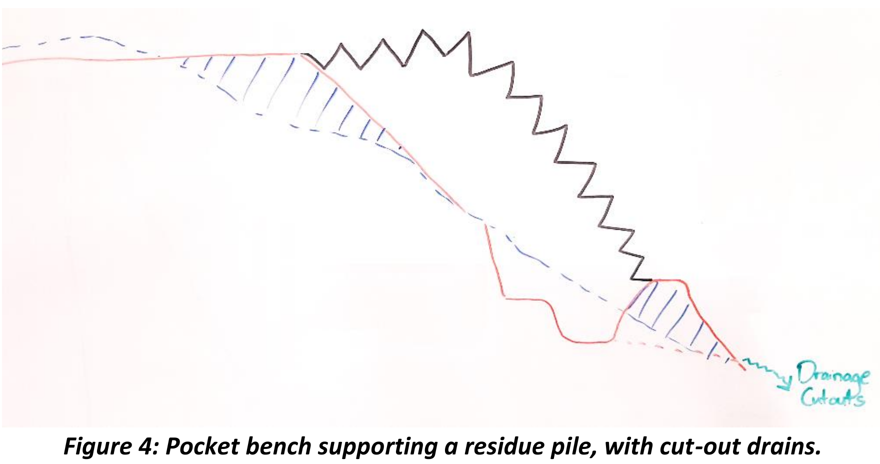

Figure 4: Pocket bench supporting a residue pile, with cut-out drains.

By aggregating responses to the questions from this section, the group view was to retrieve the residue piles from the benches shown in Figure 3 and Figure 4 post-harvest, due to slopes being steeper than the threshold of 15-20 degrees. If stored permanently, those retrieved residues would be located a minimum of 2 and 4 metres from the fill edge – or beyond the fill/virgin ground boundary. The merits of incinerating the pile(s) should also be considered versus the risks (fire, emissions, impact on the public etc.).

Alternative Forest Management Options

The final section requested the group to consider 'big-picture' solutions as plantation forestry moves forward into the future.

Question 27 explored how effective respondents believed an industry-wide transition to alternative, coppicing tree species on 'high risk' sites could be for reducing (but not eliminating) the frequency of post-harvest landslips? A move to coppicing species on steep slopes for erosion control was not strongly favoured or opposed by the group with an average rating of 3.2 (of 5). Comments included some concern about the market risk of such a change. With forestry being a long-term investment the risk of 'going it alone' at medium-to-large scale in any one region is significant. The worst-case-scenario is to pass on a stranded asset to the following generation. Radiata pine is a proven performer as a plantation species and as timber, with typically acceptable return on investment, well-developed markets and existing domestic milling infrastructure. Large scale conversion from plantation management carries significant risk for any forest owner without an industry-wide move (combined direction from other large forestry entities).

Question 28 explored the options of New Zealand harvesting practices trending toward smaller harvest coupes and boundary or adjacency constraints (such as waiting to harvest the adjacent coupe for some years). The New Zealand plantation forest industry could put logical limits on harvesting coupe size in alignment with standards elsewhere in the world (Visser *et al.* 2018). This aims to limit the exposure of a large, forested catchment to the 'window of vulnerability' between harvest and adequate re-establishment of the next crop (Phillips *et al.* 1996).

One real concern with this proposal from industry has been about the increased windthrow on the boundaries of the harvest coupe. It is conceivable that increased windthrow could lower productivity from forests, exacerbate safety issues, increase residue generation, and impact slope stability negatively due to the weight of windthrown trees on fragile soils.

Question 28 asked respondents to suggest possible solutions for reducing the incidence of stand-edge windthrow in steep terrain? The results are given in Table 5.

Table 5: Possible solutions to the issue of stand-edge windthrow by reducing harvest coupe size in steep terrain. Participants were encouraged to select all that may apply.

Possible Solution	**Number of Selections**
Plan coupe boundaries with the prevailing wind in mind.	16
Coupe boundaries to be on the gully-bottom where possible.	7
Consider alternative silviculture on planned coupe boundaries, i.e., retain higher (or lower) stocking where future exposed boundaries will be.	6
Plant the borders of coupes with more wind-firm alternative species.	4
Full transition to alternative, more wind-firm species.	3
Monocultural coups but differing species in adjacent coupes.	2
Mixed species coupes.	1
Participant submission: Harvest plan whole catchment area and take out full settings at higher altitudes and leave the lower altitude settings for X years.	1
Participant submission: Almost any of the above options may help at the margin.	1

Consistent with the suggestions about alternative species, there is preference for a variation of current practice, without changing species. Planning to locate coupe boundaries along 'lower risk' edges and improving the wind resistance of the new coupe boundaries through differential silviculture were the clear recommendations from the group.

Finally Question 29 asked respondents what is best for the forest industry as-a-whole in terms of an individual owner's or a company's freedom to assess, manage and be accountable for the slash mobilisation risk?

The majority (11 of 20) gave this a 4 out of 5. A rating of 5 corresponded to: "*It is better for an individual / a company to assess and manage all components of slash mobilisation risk in operations and the individual / company assume full accountability if a slash event happens*". This result has been interpreted as meaning that the group of experts felt that the skills and experience required to manage residues along with other aspects of the forestry business lies within forest companies (i.e., the forest industry) rather than with the regulator (territorial authorities such as Regional and District Councils). However, this response also recognises the key role of oversight by the regulator as the majority was not ranked 5 out of 5. Comments from respondents confirmed this. It was recognised that both groups (the industry and the regulators) coexist and need to bear their own responsibilities to mitigate environmental and safety risks effectively.

DISCUSSION

This Delphi survey is a useful benchmark that establishes a sample of the forest industry's collective consciousness for many of the challenges that harvest residues present currently as the biomass market develops. It has not been completed in isolation. Significant work has been completed by the University of Canterbury (UC), Energy Efficiency and Conservation Authority (EECA), Bioenergy Association of New Zealand (BANZ), Scion, and individual biomass suppliers and processors at various parts of the forest biomass supply chain. Some large forest owners have also formed direct partnerships with early adopters of biomass utilisation for process heat, and with intermediaries such as large fuel suppliers.

This research recognises that demand from the developing biomass market is unlikely to perfectly match the forest industry's ability to supply forest residues. Harvesting volumes will continue to respond to the log markets, regional age-class distribution, and contractor availability. Demand for woody biomass will show seasonal variation and respond to relevant market conditions (i.e., for commodity log products). With the dynamics of an open market, there will likely be forests where the costs (at the time of harvest) to extract, collect, process, load, and transport forest residues to end users will be too high to meet the market price (based on the energy content of the residues). This is evident already with the participants of this Delphi process indicating that the returns on chip and pulp logs directly influence residue volumes available on the cutover and at the landing. Log export market demand for logs of lower specification will play a key role in establishing the price ceiling for landing or cutover residues.

Another factor that has been the focus of much study overseas, and with some case studies in New Zealand, is system efficiency for extracting, processing, loading, and transporting forest residues. With low margins for the product (typically), system efficiency is critical to ensure economic viability. What has not been the focus of any significant local study in New Zealand is the indicative cost of retrieving residues from the cutover. In order of economical preference for sources of residual woody biomass this is the last option however, with the preferred order being:

1) Billet wood, made during log processing
2) Landing residue piles (bin wood)
3) Large diameter/long length cutover residues

With diesel prices around $1.50 /litre during the study (MBIE 2021), the survey participants indicated that a harvesting rate increase would be required (Figure 5) to justify the reduced harvesting productivity from extracting residues down to 0.8 m in length and 10 cm small end diameter (SED).

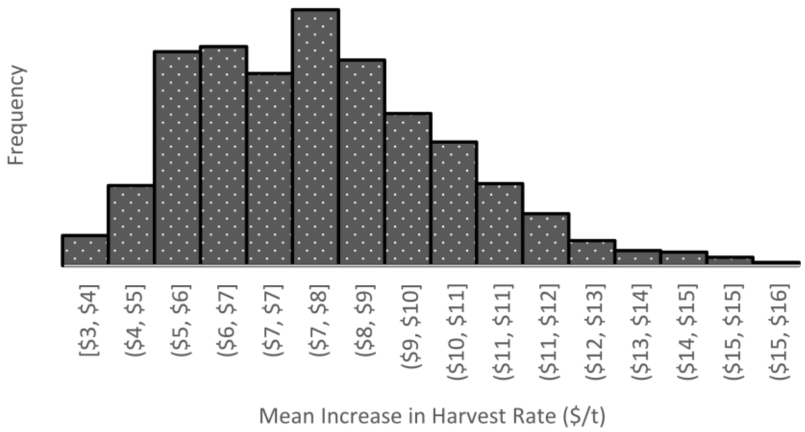

Figure 5: Mean harvesting rate increase in dollars per tonne as indicated by the group.

Figure 6 relates this increase in mean harvesting rate to the increase on the price of diesel, as diesel fuel makes up approximately 15% of a harvesting crew's daily cost (inferred from Forme 2019). It is anticipated that a 'fair' price for woody residue material from the cutover will reflect the original harvesting rate, plus the increase in harvest rate (Figure 5), plus the costs of comminution and distribution (plus profit margin).

The relative cost price ceiling for low-grade export logs should be a function of the market price of the export logs (at wharf gate), plus the cost of comminution. A factor should be added for the gain in recovery rates (allowing for lower specifications), plus any additional distribution and handling costs (for the extra processes in the supply chain). Consumers' willingness to pay export log price equivalent and overall process efficiency remain the most critical elements to drive the utilisation of any woody residues. The most controllable element for any forest owner and contractor remains process efficiency.

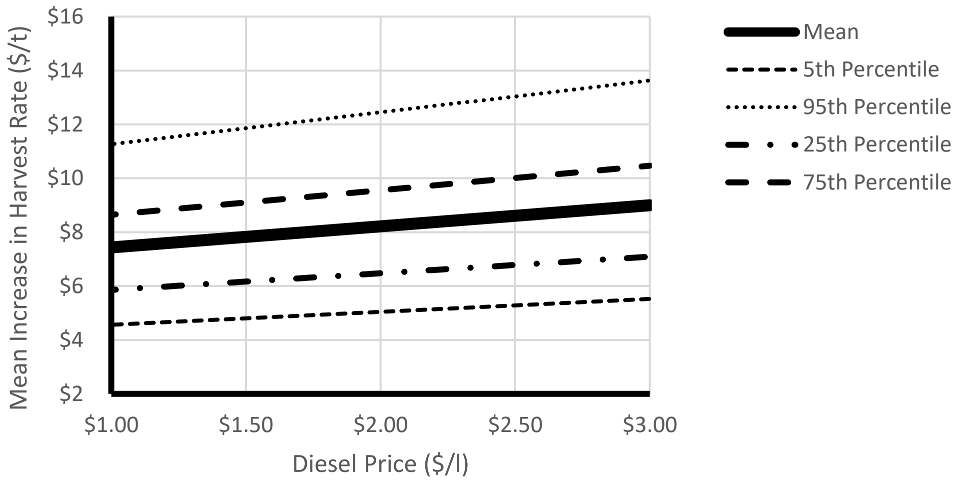

Figure 6: Sensitivity analysis on the mean increase in harvest rate required (as indicated) to extract residues from the cutover against diesel price at a typical rate of 15% of daily system cost.

The opportunities that the expanding domestic biomass market offers the forest industry are many and varied. Not only can biomass potentially add to the profitability of forestry, but it has the potential to reduce the risks of storing the material on site post-harvest and add to regional employment throughout the value chain. For most steepland forests there appears to be few drawbacks to extracting residual biomass to meet the country's energy needs (with a decarbonisation focus) and remain competitive.

A healthy, functioning biomass supply chain and strong market demand for residues however is unlikely to eliminate harvest residue accumulations across all harvesting sites or regions in New Zealand. Because of the dynamics of log and residue markets and anticipating the need to retain harvest residues on many cutover sites (as is the status-quo), the current focus on continuous improvement for onsite residue management should continue.

In 2019 the NZFOA reported on many of the immediate issues resulting from storm events in a workshop with industry representatives (Dale 2019) which resulted in several priorities for further action. This Delphi survey has approached the key issues differently to the 2019 NZFOA report with specific cases and thresholds for intervention put forward to assess whether industry experts form collective agreement on certain regular occurrences and practice.

The Delphi technique tends to be effective because of its anonymous nature. Participants can equally give reasoned opinions, in their own time, free of influence or fear of causing offence, whereas those opinions may not be possible in a face-to-face workshop setting. Anonymity in the process also eliminates any concerns about individuals putting forward personal opinions – however this does require confidence in the administration of the Delphi process. The results presented in this report do remain subjective, formed of the opinions and experience of the participating forest operations experts.

Unsurprisingly, the Delphi results and the NZFOA report share several commonalities, showing consistency of industry opinion over time and under different circumstances. Market options for biomass extraction remain a priority with the potential to provide tangible and intangible benefits all along the value chain. Smaller harvesting coupe sizes for Radiata pine, whilst being a proposed solution for hydrological variations over a rotation in a large catchment, and reducing risk for catchment-wide disasters, remain unpopular due to commonly observed windthrow on exposed stand boundaries (and associated safety/soil stability issues).

Tree falling with mechanised felling heads has been an area for investigation with both the 2019 NZFOA report and the experts during this Delphi process identifying felling head technology as having potential for reducing cutover residues. Two published studies have verified informal accounts of the benefits and drawbacks of fixed felling head trials in steepland plantations (Prebble & Scott 2019, Prebble 2021).

Cutover residue accumulations in and around watercourses have been a significant challenge with planting across watercourses without setbacks affecting today's harvests. Best practice has established methodologies for minimising impacts; however, some conflict inevitably results with other best practices (such as minimising earthworks), and the need to accommodate heavy machinery. Continual reassessment of best practice is required due to the adoption of new, mechanised harvesting methods. The group's responses reflect the progressive nature of best practice, indicating a clear, collective preference to manage as considered lowest impact for the specific individual site.

In 1999, a survey was circulated amongst eleven forestry companies on the management of logging slash in streams and debris flows (Baillie 1999). The survey gathered 19 responses, covering the management of approximately 60% of New Zealand's plantation estate at the time. Most respondents used stream size or flow type (ephemeral/perennial) to determine the slash management practices applied for a given reach. To minimise slash entry into a stream, cable yarding systems used skylines, carriages, gully to ridge extraction, full (or partial suspension) & directional felling. One further result of the current study is that respondents have identified log 'sweeping' during cable extraction as a key driver for high residue volumes in gullies – indicating that partial suspension may be less favoured in key high-risk scenarios.

Landing residues represent the most convenient and readily available material to supply a biomass market. It is clear however, that not all sites will have the ability or economic viability to supply the new market. The Delphi process has both highlighted differences in opinion, and broad consensus on managing piles of material at the landing where it cannot be marketed. Of note is the experts' opinions of the temporary nature of off-landing residue containment structures such as benches and pocket-benches, in steep terrain. The results of this study infer that terrain steeper than 15-20 degrees is unsuitable for the permanent storage of residue piles. The result is significant and consistent with the NZFOA report by Dale (2019) as steepland forest land regularly exceeds 20 degrees slope in New Zealand and benching for residue piles is a regular part of steepland harvest management. The inevitable result is that many or most residue piles would require retrieval onto the flat landing platform post-harvest.

The Delphi technique did not seek consensus on new ways of work to improve the extraction of woody biomass. With the experts generally expecting the same or increasing demand for forest residues, and industrial energy users issuing similar signals (Fonterra Co-operative Group Limited 2019; Pooch 2021) optimisation of biomass recovery at the landing is expected in future. Should demand for woody biomass increase, it may become a regular part of logging across New Zealand's steepland forest estate. Loading 'hook-bins' for uplift during harvest, sorting and piling to load onto 'bin-trucks' and retrieving piles post-harvest are currently methods being used in the pursuit of improved harvest efficiency.

Woody biomass quality (i.e., contamination with bark, rock, sediment, and other impurities) and the moisture content of biomass are key foci for current bioenergy customers, in addition to volume and supply security. Therefore, the problem posed is, how does a forest owner and logging contractor provide a biomass product to agreed specifications for acceptable profit (or minimised cost) while ensuring adherence to the core business of producing quality roundwood products? Further (or more widespread) demand for the product may initiate a step-change in harvesting systems to handle log and residue products more efficiently. Centralised and automated processing and sorting facilities are one such proposal (FGR 2020). While biomass extraction process improvements remained outside the scope of this Delphi process, investigating a variety of options will be critical to ensuring that the more remote plantation forests are accessible for woody biomass utilisation, thereby improving the industry's ability to supply increasing demands from the existing forest estate.

CONCLUSION

Using the Delphi questionnaire approach in this study has been effective in discussing a series of complex challenges for managing harvest residues with experts of varying professional experiences. The system of inquiry has enabled the participants to interact in a structured way, allowing clear justifications in response to the questions.

A significant proportion of the experts shared optimism for the evolving biomass market. Several hurdles necessitate market, engineering, and harvest system solutions to enable biomass products to be marketed from more remote steepland plantation forests.

The operations experts tended to prefer a continuous improvement approach to changing the management of harvest residues. Tools such as the NES-PF ESC map provide coarse risk identification, and it was the opinion of the group that aerial LiDAR is more useful for operational planning, with its finer resolution.

Wind-firmness of plantation trees remains a widespread concern that informs many harvest and forest management decisions. Careful stand boundary planning (for prevailing wind) or differential silviculture to protect exposed edges has been recommended by the group. Aside the known limitations of Radiata pine, it has been a successful plantation tree species. Therefore, suggestions of planting alternative species at scale has drawn little support from the group. Developing current standards is favoured.

Where landing residues cannot be marketed, retrieval of piles is recommended for slopes over 15-20 degrees, regardless of engineered controls such as benches. Incineration of residues as a method of disposal where there are no economic solutions should remain an option where appropriate.

Riparian buffers are supported as a partial solution to reduce the occurrence of woody debris entering waterways but are recognised as being a partial barrier only used in conjunction with other best practice methods, such as reducing generation of residues, and maximising extraction and utilisation of woody biomass. The Delphi process has confirmed that best practice for residue management comprises a suite of management options which allows foresters to cater to the individual risks and needs of the specific site.

The New Zealand forest industry has extensive research, comprising operational knowledge and experience for the management of Radiata pine plantations on steepland sites. The experts polled in this study would continue to build on this, to increase supply of woody biomass for new markets and continue to meet the challenges posed by steepland forest sites.

ACKNOWLEDGEMENTS

The results presented in this report reflect the opinions and experience of the group of forest operations experts at the time of the Delphi questionnaire, with subsequent analyses and interpretation by the author. The author would like to thank the participants for their contributions to this study.

REFERENCES

Baillie, B.R. (1999). *Management of logging slash in streams of New Zealand - results from a survey*. LIRO Project Report 85. 32 p. Rotorua, NZ: Liro Forestry Solutions. Retrieved from https://fgr.nz/documents/download/4077?2132325627

BioPacific Partners, FPInnovations, NAWITKA, & Russell Burton & Associates. (2020). *Wood Fibre Futures: Investment in the use of commercial forest biomass to move New Zealand towards carbon-zero*. (Stage One Report), 133 p. Wellington, NZ: Ministry for Primary Industries (MPI). Retrieved from https://www.mpi.govt.nz/dmsdocument/41824-Wood-Fibre-Futures-investment-in-the-use-of-commercial-forest-biomass-to-move-New-Zealand-towards-carbon-zero-Stage-1

Cave, M., Davies, N., & Langford, J. (2017). *Cyclone Cook Slash Investigation*. 121 p. Gisborne, NZ: Gisborne District Council. Retrieved from https://www.gdc.govt.nz/__data/assets/pdf_file/0013/10408/cyclone-cook-slash-investigation-2017-report.pdf

Dale, R. (2019). *Workshop report: Harvest residue management on erosion prone land*. FGR Workshop Report. 18 p. Rotorua, NZ: Forest Growers Research (FGR). Retrieved from https://fgr.nz/documents/download/7601?612598755

FGR, Forest Growers Research. (2020). *Automation & Robotics PGP Programme*. (Web page). Accessed: 3 April 2020. Retrieved from https://fgr.nz/programmes/harvesting-and-logistics/automation-robotics/

FITEC, Forestry Industry Training and Education Council. (2005). Best practice guidelines for Cable Logging. Guideline document. 129 p. New Zealand: FITEC.

Fonterra Co-operative Group Limited. (2019). *Sustainability Report: For the Year Ending 31 July 2019*. Report. 50 p. New Zealand: Fonterra Co-operative Group Limited. Retrieved from https://view.publitas.com/fonterra/sustainability-report-2019/page/1

Forme. (2019). *INFORME Harvesting 2019*. Forme Consulting Group Limited. 48 p.

Hall, P. (2017). *Residual biomass fuel projections for New Zealand - indicative availability by region and source.* Report. 71 p. Rotorua, NZ: SCION. Retrieved from https://www.usewoodfuel.org.nz/documents/resource/Wood-residue-resources-report-2017_Revised.pdf

Hall, P., & Evanson, T. (2007). *Forest residue harvesting for bioenergy fuels: May 2007-Phase 1*. (1), 28 p. New Zealand: Energy Efficiency and Conservation Authority (EECA). Retrieved from https://www.bioenergy.org.nz/documents/resource/Report-forest-residue-harvesting-fuels-part-1-Scion-EHE-EECA-May2007.pdf

Hall, P., & Jack, M. (2009). *Analysis of large-scale bioenergy from forestry: Productivity, land use and environmental & economic implications*. Report. 170 p. Rotorua, NZ: SCION. Retrieved from https://niwa.co.nz/sites/niwa.co.nz/files/imported/__data/assets/pdf_file/0007/95668/Large-scale-forestry-for-bioenergy.pdf

Henderson, R., Collins, D., Doyle, M., & Watson, J. (2018). *Regional Flood Estimation Tool for New Zealand Part 2*. Report 2018177CH. 48 p. Wellington, NZ: National Institute of Water and Atmospheric Research Limited (NIWA). Retrieved from https://niwa.co.nz/files/2018177CH-Flood-Frequency-Final-Report-Part2-NIWA.pdf

Linstone, H.A., & Turoff, M. (1975). Introduction. In H. A. Linstone & M. Turoff (Eds.), *The Delphi Method: Techniques and Applications*. Reading, Massachusetts: Addison-Wesley Publishing Company.

MBIE, Ministry of Business Innovation and Employment. (2021). *Weekly fuel price monitoring*. Web page. Accessed: 2 November 2021. Retrieved from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/weekly-fuel-price-monitoring/

McMahon, S., Evanson, T., Hall, P., & Baillie, B. (1998). *Cable Extraction of Pulp: Effect of minimum extracted piece size on productivity*. LIRO Report 23(14), 5 p. Rotorua, NZ: Logging Industry Research Organisation (LIRO). Retrieved from https://fgr.nz/documents/download/4328?829207617

MPI, Ministry for Primary Industries. (2021). *Wood product markets*. Web page. Accessed: 2 November 2021. Retrieved from https://www.mpi.govt.nz/forestry/new-zealand-forests-forest-industry/forestry/wood-product-markets/

Murphy, G. (1982). *Value savings from alternative felling patterns on steep country*. LIRA Report 7(8), 4 p. Rotorua, NZ: Logging Industry Research Association Inc. (LIRA). Retrieved from https://fgr.nz/documents/download/5053?973453426

NZFOA, New Zealand Forest Owners Association. (2007). New Zeland Environmental Code of Practice for Plantation Forestry. In K. Richards, A. Woolhouse, B. Coombs, B. Gilmore, C. Phillips, G. Moore, G. Sutton, H. Arnold, H. Stevenson, J. Hura, J. Stulen, K. Meredeth, L. Walter, K. Greig, N. Ngapo, P. Weir, R. Green, S. Strang, S. Heine & T. Payne (Eds.), (Version 1 ed., pp. 168). Online: New Zealand Forest Owners Association. Retrieved from https://www.nzfoa.org.nz/resources/file-libraries-resources/codes-of-practice/44-environmental-code-of-practice/file

Phillips, C., Pruden, C., & Coker, R. (1996). Forest harvesting in the Marlborough Sounds - flying in the face of a storm? *New Zealand Forestry, 41*(1), 27-31.

Pooch, J. (Producer). (2021, 26 January 2022). The future energy needs of Southland and Canterbury thermal heat users. Webinar. New Zealand: Bioenergy Association of New Zealand (BANZ). Retrieved from https://www.usewoodfuel.org.nz/resource/web2110-future-energy-needs-of-southland-and-canterbury-thermal-heat-users

Prebble, R. and Scott, D. (2019). Comparison of Felling Heads to Reduce Tree Breakage. Technical Note HTN11-01. Rotorua, NZ: Forest Growers Research Limited (FGR). Retrieved from https://fgr.nz/documents/download/8145?1077817821

Prebble R. (2021). Survey of Fixed Felling Heads in New Zealand. FGR Report FGR-052. Rotorua, NZ: Forest Growers Research Limited (FGR). Retrieved from https://fgr.nz/documents/download/9568?1893271592

Visser, R. (2018). *Benchmarking Harvesting Cost and Productivity – 2017 Update*. FGR Report HTN10-02. 4 p. Rotorua, NZ: Forest Growers Research Limited (FGR). Retrieved from https://fgr.nz/documents/download/7091?936289211

Visser, R., Spinelli, R., & Brown, K. (2018). *Best practices for reducing harvest residues and mitigating mobilisation of harvest residues in steepland plantation forests.*, Enviro Link Contract 1879-GSD152, prepared for Dr. Murry Cave, Gisborne Regional Council. July 2018 53 p. Gisborne, NZ: Gisborne District Council (GDC). Retrieved from https://www.gdc.govt.nz/__data/assets/pdf_file/0012/13710/best-practices-for-reducing-harvest-residues-and-mitigating-mobilisation-of-harvest-residues-in-steepland-plantation-forests.pdf

APPENDIX: DELPHI SURVEY QUESTIONS REFERRED TO IN TEXT

1. Over the next 5 years, do you anticipate the demand for forest residues in your region to Increase/Decrease/Stay the same?

2. What indicators show that a landform is ‘high risk’ for slash mobilisation?

3. Does your Regional Council provide additional (i.e., in addition to the NES-PF) guidance for how to manage residue mobilisation risk? This may be of any form: i.e., written guides, advice on site visits, workshops etc.

4. How clear/pragmatic is the guidance in the NES-PF and its supporting documentation for managing the risk of harvest residue mobilisation?

5. How reasonable is the NES-PF Erosion Susceptibility Classification map as a proxy for slash mobilisation risk? Red/Orange/Yellow = Very High/High/Moderate slash mobilisation risk respectively.

6. How common are significant harvest residue mobilisation events?

7. Should annual rainfall be given consideration in terms of its contribution to harvest residue mobilisation risk?

8. On a landform that is ‘high risk’ for slash mobilisation, above what slope would you consider applying techniques/practices to reduce harvest residue mobilisation risk?

9. Under what circumstances should a forest owner/manager intervene to lower residue mobilisation risk posed by windthrown production trees during harvest? Assume the windthrow material is ‘sound enough’ to withstand being picked up with a grapple.

10. Rate each factor / statement in terms of its contribution to a high residue volume on a steepland cutover: *Top selected contributors are detailed below:*
    - Windthrow
    - Broken terrain
    - Poor deflection or blind areas in the harvest area (cable harvesting)
    - Negative returns on pulp grades (pulp left off cutting instructions).
    - Production pressure on harvesting crews (incl. low margin on harvest rates, inclement weather or breakdowns - limiting production)
    - Untidy stem set-out for extraction
    - High total recoverable volume of the stand (t/ha)
    - Ground-based whole tree extraction
    - Shovelling/bunching stems on the cutover

11. Rate each factor / statement in terms of its contribution to a low residue volume on a steepland cutover: *Top selected non-contributors are detailed below:*
    - Positive returns on pulp grades (pulp on the cutting instructions)
    - Clear company/forest owner standard(s) for permissible harvest residues
    - Tidy set-out for extraction
    - Controlled tree falling (fixed head mechanised)
    - High deflection over cable yarding corridors.

12. Our research has indicated that a steepland cutover typically has 30 m3/ha of pulp and bin wood (i.e., all sound wood greater than 0.8m in length and 10 cm in SED) remaining post-harvest. If a harvesting crew was required to extract all/most of this material, what would be your best estimate of: a) lost productivity (tonnes/day); & b) increase in logging rate ($/tonne)?

13. Assuming a typical harvest setting in steep country in your region, what price would bin wood have to be ($/tonne delivered, freshly harvested) to make extracting it from the cutover financially attractive? Assume a distance to market of 50km.

14. Which mechanism typically delivers the most residues to waterways?

15. To what extent should a riparian buffer be relied on as a tool to mitigate the movement of cut-over residues to waterways?

16. In managing legacy plantings right up to watercourses in erosion-prone, steepland forests, what is typically the most appropriate course of action at harvest?

17. The NES-PF currently defines a river by its ability to move freshwater. Slash is to be removed from the floodplain of a 5% AEP event. What is a practical, robust, and defendable interpretation of a waterway from which slash should be removed from the 5% AEP floodplain?

18. To what degree do each of the following factors contribute to high residue pile volumes at the landing? *Most significant contributors and non-contributors shown below:*
   - Negative-returning pulp grades/pulp left off cutting instructions
   - Environmental crop damage (e.g. hockey-stick butts, snow damage)
   - Bunching stems on the cutover
   - Clearwood tending regime (low stocking and high pruning)

19. Burning residue piles on forest landings should continue to be an available tool (assuming proper management). Vote from 1 (total ban) – 5 (must always remain an option).

20. Piled residues may be stored permanently on unmodified slopes, cuts or compacted fill slopes up to a maximum slope of what?

21. Should residues piled on engineered fill surfaces in terrain that is steeper than your selection above, be pulled back clear of the fill edge?

22. If Yes to Q21, what minimum separation from the fill edge is appropriate for effective risk reduction?

23. Should benches that are constructed to retain slash remain visible along their full length?

24. Which method is most appropriate for constructing slash benches in steep terrain? (refer to Figure 3).

25. Are ‘pocket benches’ (ref. to Figure 4) acceptable as an off-landing slash storage solution?

26. If yes to Question 25, under what conditions is a pocket bench not appropriate for slash storage?

27. How effective do you believe an industry-wide transition to alternative, coppicing tree species on ‘high risk’ sites be for reducing (not eliminating) the frequency of post-harvest landslips?

28. If NZ harvesting practices trend toward smaller coups and boundary constraints (wait to harvest the adjacent coup(s) for X years), what possible solutions are there for reducing the incidence of stand-edge windthrow in steep terrain?

29. What is best for the forest industry as-a-whole on the following spectrum in terms of an individual’s / a company’s freedom to assess, manage and be accountable for slash mobilisation risk?