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Measuring harvest residue accumulations at New Zealand's steepland log-making sites

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Abstract

Background: When harvesting plantation forests of *Pinus radiata* (D.Don) in New Zealand, large residue piles commonly accumulate on or adjacent to processing sites. While the merchantable volume that is transported to market is carefully measured, little is known of the quantity of the piled, residual material. A working knowledge of residues is becoming more important as it is not only a potentially merchantable product for the bioenergy market, but when stored in perpetuity it can present a risk of self-ignition, and specifically on steep slopes, it presents a mobilisation risk if not stored correctly.

Methods: The area, bulk volume and depth of residue piles at 16 recently harvested steepland sites were measured from a wide geographic spread across New Zealand. Unmanned Aerial Vehicle imagery was used to build georeferenced photogrammetric models of residue piles (94 per cent of the studied volume). Pile area was determined from interpreting boundaries from orthophotos and volumes determined by interpolating the obscured terrain surfaces on duplicate photogrammetric models. The remaining 6 per cent of pile volume was measured with handheld GPS tracking of the perimeters and on-site estimation of average pile depth.

Results: For a mean harvest area of 18.9 ha, there was a mean of 2.4 piles per harvest site, 2600 m^3 bulk volume and 2900 m^2 of area covered. For every hectare harvested, a bulk volume of 170 m^3 is piled at the landing, or alternatively, 0.23 m^3 of bulk pile volume per tonne harvested. The manual terrain interpolation methodology was tested against collecting georeferenced pre-harvest terrain surfaces, yielding an average difference of 19% across two sites and six residue piles.

Conclusions: This research demonstrates the ability to investigate the bulk volume and site coverage of landing residue piles with equipment and software tools available to today's forester. Mean values for pile area and volume are presented to reflect the current state of knowledge and can be a reference point for future initiatives.

Keywords: Plantation forestry, slash, harvesting operations, biomass.

Introduction

Most plantation-grown radiata pine (*Pinus radiata* D.Don) is typically harvested between the ages of 25 and 35 years in New Zealand, depending on a range of factors including market conditions, site and stand management (Maclaren 1993). Currently, the average felling age is 29.5 years (MPI 2020) with an estimated average Total Recoverable Volume (TRV) of 585 m^3/ha (clearwood regime) or 593 m^3/ha (framing regime) across New Zealand (MPI 2015), with comparatively lower stocking levels and larger tree sizes in clearwood regimes (Maclaren 1993). The recovered volume, taken as logs to market, is accurately measured and can be reconciled against the inventory data that is typically available to forestry companies (Gordon 2005). A recent study detailed the residues left in the cutover, which showed the median volume of Course Woody Debris remaining was 88 m^3/ha (Harvey & Visser 2022). However, little is known about the residues that are left behind at the landings (processing areas).

The majority of plantations currently being harvested have been tended under a clearwood regime; a result of markets and common practice in the 1990s (Maclaren & Knowles 2005). In recent times there has been an increasing proportion of stands transitioned into framing regimes across New Zealand (MPI 2020). The regime change is expected to increase final crop stocking levels and decrease average piece sizes at harvest with time. Goulding (2005) estimated that in an average stand, 85 per cent of the total standing volume will be merchantable, leaving residues that will range from about 10 per cent in good condition, well-tended stands, to over 20 per cent for untended stands on moderately steep terrain.

Murphy (1982) showed that value loss at harvest due to stem breakage increases with increasing Diameter at Breast Height (DBH); one consideration when assessing alternative regimes. Breakage at any point along the stem results in a change in the objective function for maximising the stem's value; establishing a new, lower optimum for the remaining value. Stem breakage means a logging contractor needs to manage more stem 'pieces' and inevitably less log volume will leave the site; however, depending on where the breakpoint is along the stem, the value loss may only be trivial (Murphy 1982). Several studies have shown that most harvested trees are broken during felling in New Zealand and that the typical break height (for the first break) is around two-thirds of the height of the stem (Fraser et al. 1997; Lambert 1996; Twaddle 1987). Breakage typically results in the generation of un-merchantable woody debris, where the final section of stem before (and after) the break cannot conform to any available log grade specifications. Managing this additional debris provides only indirect benefits to logging contractors (e.g. tidy work area, reduced hazards) and can result in considerably reduced production.

Harvesting systems can be categorised as either Cut-to-length (CTL) or Whole Tree Harvesting (WTH). In CTL systems the trees are processed in the cutover where the residues are left and only the logs extracted to roadside or a landing for subsequent transportation. In WTH the stems are extracted to a landing where they are processed into logs. WTH remains the preferred harvest system on steep slopes as it offers greater productivity and value recovery by enabling a larger number of log sorts that meet both domestic and international demand. Even with the widespread adoption of mechanisation on steep terrain and expanding slope limits for CTL, WTH still remains the preferred extraction option for steep slopes (Berkett 2012; Raymond 2018; Visser 2018).

Where markets for the piled material either do not exist or extraction is deemed uneconomic, or no alternative management is applied (e.g. incineration), harvesting residues resulting from WTH accumulate at landings (Figure 1). Residues are not only the branches and tops, but also stem offcuts from felling breakage and trimming (Hall 1994). The poor form of some radiata pine crops means larger diameter segments will also accumulate at the landing. However, few market opportunities have developed to make use of the convenient accumulation of residues at steepland landings (Visser et al. 2019).

Large residue piles remaining after harvest not only exclude land from re-establishment, but they can also present ongoing management problems. Piles generate heat internally by decomposition and those where the rate of heat generation is greater than heat shedding (typically deep piles) are prone to self-combustion (Buggeln & Rynk 2002). Piles located on unstable, steep

FIGURE 1: An example of a residue pile at an operational landing in a radiata pine plantation.

terrain can mobilise and cause significant impacts on the natural and built environment (Phillips et al. 2012). While there are risks posed by storing large residue piles on steep terrain over long periods of time, the resulting accumulation at landings from WTH systems can benefit biomass extraction programmes due to easy access to the material.

Over the years, ‘fit-for-purpose’ management approaches have developed to ensure that permanent residue piles pose acceptable risk while they decompose *in situ* (Hall 1998; Visser et al. 2018). The Best Management Practices (BMPs) applicable at a particular site principally depend on the stability of the underlying soils and values at risk (NZFOA 2020). BMPs range from piling on a natural terrain bench adjacent the landing, to end-hauling loads to a nearby, unused landing with several other management options in between.

Research was conducted in the 1990s on various aspects of New Zealand’s landing residue piles, including work studies on the management of them (Hall 1993a, 1993b, 1994, 1998, 1999; Hall & McMahon 1997). Various methods for bulk volume measurement have been used previously, including measuring dimensions of individual woody residues as-cut (Hall 1994), volumes of piles using broad approximations of geometry (Hardy 1996) or measuring cross-sections of piles as they are deconstructed with heavy machinery (P. Hall, personal communication, 14 April 2021). Hall (1993a) established that the typical solid volume of residues discarded into the piles was approximately 4 per cent of Total Extracted Volume (TEV) for hauler operations. Additionally, the relative proportion of the various components of the tree hat made up the pile mass were reported through a detailed study of log-making residues, as the material was produced. This study showed that 66 per cent of the pile volumes were made up of woody stem sections, with the remainder being branch material (Hall 1994). This study was a snapshot of harvesting residue production at the time and a benchmark for future change.

There is a gap in recent literature and operational knowledge around the physical characteristics of landing piles. With a national increase in harvest mechanisation and greater incentive for industrial process heat users to transition to renewable energy sources (Climate Change Commission 2021), an up-to-date knowledge of the resource is necessary for the forest owners and managers aiming to make material available for the developing bioenergy market.

New tools are now available for measuring piles with complex shapes. Structure from Motion (SfM) photogrammetry has become an increasingly useful tool for detailed measurement and terrain modelling, with assessments of piles (of any material) an established research and commercial application of the technology (Tucci et al. 2019). Model construction pipelines use the known camera dimensions, identifying tie points on overlapping digital images to precisely define the camera pose in each image. Known camera locations and common points on overlapping images contribute to calculations of geometry by the principle of motion parallax and a ‘cloud’ of points (point cloud) of the scene is constructed, with each point assigned a location in three dimensions. With georeferencing, point clouds can additionally be given geographic or projected coordinates for use in mapping. Davis (2015) investigated the use of photogrammetry with imagery captured from an Unmanned Aerial Vehicle (UAV) to assess the volume of small (<10 m^3 each) residue piles on near-flat cutovers. Measurement of small accumulations of woody debris in natural and modelled fluvial systems has also been completed, with a key focus on SfM workflows (Spreitzer et al. 2019, 2020). A common limitation is the estimation of surfaces occluded by piled material. This is typically handled by automated interpolation of datum surfaces for small piles or simple (i.e. flat) ground (Ajayi & Ajulo 2021; Davis 2015), and manual inference/interpolation for more complex datum surfaces (Spreitzer et al. 2019). Both result in model error. Where resources permit, calculating the temporal change of georeferenced surface models can reduce or eliminate surface estimation, ensuring highly accurate models of all relevant surfaces, as demonstrated by Baldi et al. (2007).

This research aims to provide the latest benchmark for the bulk volume of harvest residues accumulating at New Zealand’s steepland landings by using modern and accessible measurement methods, demonstrating and discussing modern procedures that a forest owner/manager may use to gain a better understanding of their own resource. Improved understanding of landing residue volumes promises to assist marketing the material, and/or decisions concerning containment where residues are to remain on site in perpetuity.

Methods

Sixteen recently harvested steepland sites were made available by participating forest companies for this research. All sites were radiata pine plantations, managed under typical silvicultural regimes and covered a wide geographic spread across New Zealand (Table 1). Forest managers provided data on regime, pre-harvest inventory, volume of each log grade sold, and harvesting method where available. Except for stands MH and GN that were grown under framing regimes, all other sites were clearwood regimes.

The area and bulk volume were measured for all landing residue piles associated with a harvest area at each of the study sites. Three techniques were used for measuring the landing residue piles. The first technique (applied to the majority of piles) made use of photogrammetric models derived from UAV photography (example see Figure 2). Two consumer-grade UAVs were used for this study. The specifications for each model are detailed in Table 2. The second technique made use of portable Global Positioning System (GPS) tracking of pile perimeters (±6m accuracy) coupled with estimation of average pile depth. The second methodology was used on five small piles only – accounting for approximately 6 per cent of the total volume surveyed. The third was used on two sites only as validation for the first method. This involved collecting georeferenced pre- and post-harvest photogrammetric models of the sites.

TABLE 1: Harvesting site details.

Site Code	Region	Extraction System	Harvest Area (ha)	Stand Age (yrs)	Extracted Volume per Hectare (m^3/ha)
GJ	Canterbury Waitaha	Ground-based	8.7	29	472
GT		Cable	31.0	30	546
MH		Ground-based	12.6	No data	No data
GN	Tasman Te Tai-o-Aorere	Cable	9.5	29	611
MG		Ground-based	36.8	25	392
HT	Gisborne Te Tai Rāwhiti	Cable	25.3	27	553
PK		Cable	23.0	25	507
MA		Cable	16.7	28	594
MC		Cable	8.3	27	866
PE		Cable	6.9	26	507
HF		Cable	13.9	27	553
MO	Marlborough Te Tauihu-o-te-waka	Ground-based	41.1	No data	No data
TP		Ground-based	21.2	27	407
PC	Wellington Te Whanga-nui-a-Tara	Mixed	8.2	28	746
RK		Cable	6.1	26	795
TK	Otago Ōtākou	Cable	33.5	33	841

The image capture methodology adapted as fieldwork progressed. For the initial three sites (GT, MH & TP) images of residue piles were captured by manually controlling the position of the UAV camera, firstly capturing images in a wide arc around the residue pile(s) then directly overhead of the pile(s), ensuring significant overlap between images. The process is described in Riedinger & Harvey (2021). Image capture was refined for the remaining sites by using the Pix4Dcapture flight control application (Pix4D S.A., Prilly, Switzerland). Pre-programmed flights standardised image capture (see Figure 2), ensuring image overlap exceeded 60 per cent at take-off elevation. Overlap, flight extents and UAV height were set to provide coverage beyond each pile's extent and a Ground Sample Distance lower than 3 cm/pixel at the take-off elevation.

Georeferencing was used to ensure accurate dimensioning of all except two models (Sites GT and MH). Four Ground Control Points (GCPs) were arranged around residue piles, in locations visible to the UAV camera sensor. GPS coordinates of each GCP were averaged over 60 seconds using a Trimble Zephyr 3 Rover receiver (Trimble, Sunnyvale, CA, U.S.A.) and subsequently post-processed to 5-15 cm accuracy using local base-station datasets.

Photogrammetric models were constructed using Agisoft Metashape (Agisoft LLC, St. Petersburg, Russia) according to the flowchart in Figure 3. Input data for each model were the aerial photos (including geotag information) and post-processed GCP waypoints. GCP centres were located on aerial imagery prior to assignment of post-processed waypoints. 'Medium'

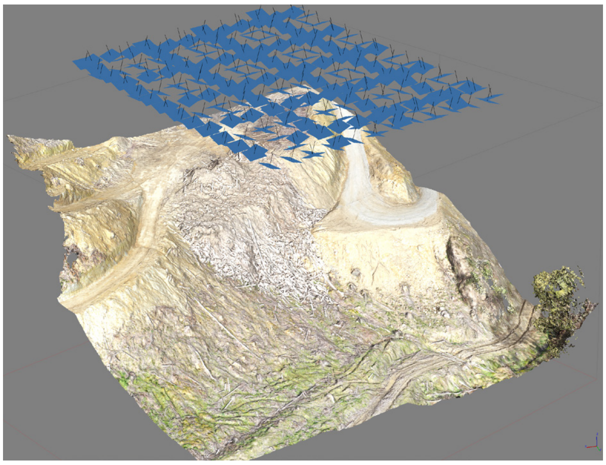

FIGURE 2: Example Agisoft Metashape point cloud of a residue pile and surrounding terrain. Blue squares show the location and orientation of the camera on a grid above the pile.

TABLE 2: Specifications of UAVs used to capture images of landing residue piles.

UAV Model	Camera Sensor	Positioning System	Rated Max. Flight Time per Charge
DJI Mavic Pro	1/2.3” CMOS Effective pixels: 12.35 million	GPS/GLONASS	27 min
DJI Mavic 2 Pro	1” CMOS Effective Pixels: 20 million	GPS+GLONASS	31 min

Source: DJI User Manuals

resolution point clouds (standard Agisoft Metashape setting) were constructed in Agisoft Metashape, which were then downsampled to output 0.1 m resolution Digital Elevation Models (DEMs), along with orthophotos of varying resolutions; dependant on the limitations imposed on the pre-programmed flightpath.

The DEM for each pile was imported into RoadEng9 Terrain (Softree, Vancouver, B.C., Canada) and a Triangular Irregular Network (TIN) model generated. A duplicate model of each residue pile was created and terrain obscured by the pile was estimated by manual interpolation due to the unique geometry of most sites. Manual interpolation required features such as the fill batter top edge or fill batter bottom edge to be manually projected underneath the pile, forming an estimated terrain surface. The resulting difference between the unaltered, original TIN (with pile surface) and the duplicate TIN (with the interpolated terrain surface) yielded the bulk volume measure of each pile.

Maximum pile depths were additionally calculated by the difference in elevation between the interpolated surfaces and the unaltered, original surfaces using CloudCompare software (2.5D Volume function, www.cloudcompare.org). Histograms of pile depth on a 0.1 m raster grid were filtered for depths >0.1 m to eliminate noise on the pile boundaries. Maximum depth was established at the 90 per cent threshold to also eliminate noise at the upper threshold (random woody residues

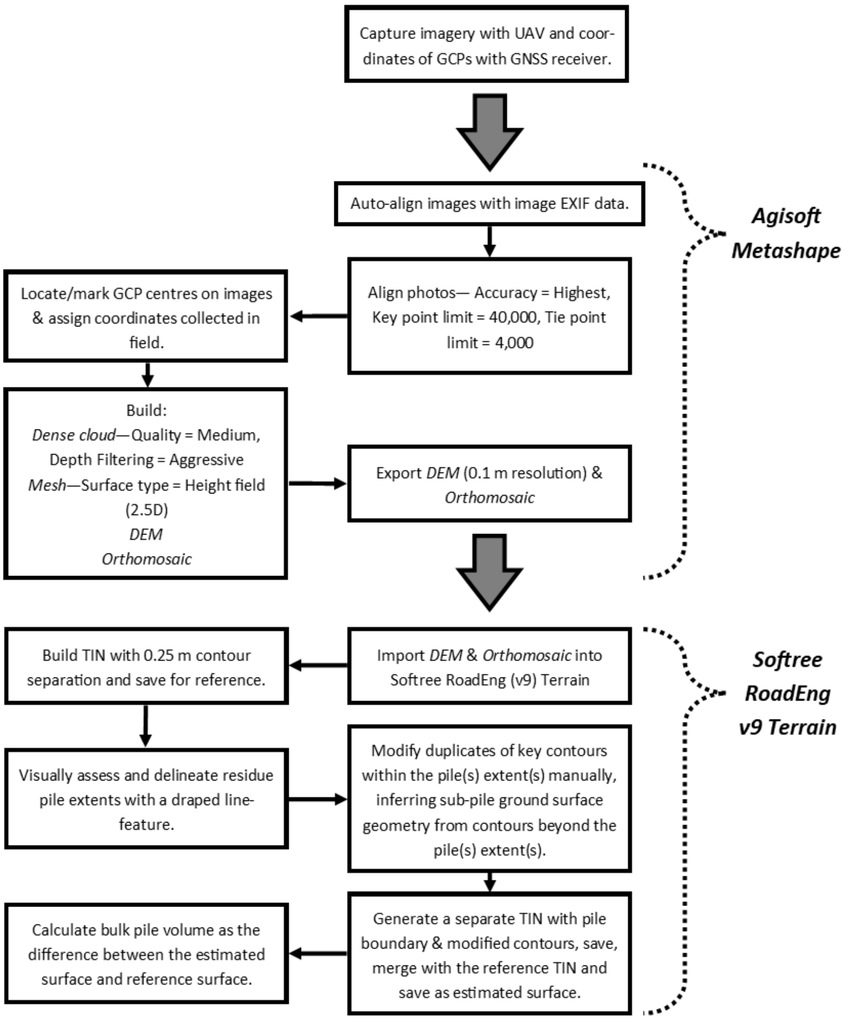

FIGURE 3: Surface and volume calculation pipeline.

poking up out of the pile). Average pile depth was calculated for each site by dividing total bulk volume by the total pile plan area.

To establish a measure of the manual interpolation method's accuracy, two sites were scanned after construction (but prior to harvest), then again post-harvest; these two sites contained six residue piles. The manual terrain interpolation method was completed 'blind' (prior to constructing the pre-harvest terrain model) and for each residue pile, two volume measures were calculated: one by computing the difference between the interpolated terrain surface and the post-harvest (pile) surface, and the other between the georeferenced pre-harvest datum (terrain) surface and the post-harvest (pile) surface.

Results

The study sites represent a typical range of harvesting systems employed to clearfell steepland forests in New Zealand; from tracked ground-based to cable hauler. Pile areas and volumes differ significantly between sites (Table 3). To compare in more equal terms, pile areas are also expressed in pile area per hectare harvested, as the harvest areas range in size from 6.1 to 41.1 ha. Of note is that several sites had residue piles that (when combined) covered approximately 0.5 ha each. Not all of the pile area is lost planting area however as landing surfaces are seldom replanted in New Zealand operations due to the need for soil rehabilitation and ongoing nutrient management (Hall 2000).

Model accuracy was estimated using the Agisoft post-processing report feature and the user specified GCP locations. Except at three sites, the RMSE in the *x*-direction ranged from 1.4-4.9 cm, in the *y*-direction from 0.3-6.2 cm and in the *z*-direction from 0.2-5.9 cm for all sites. Site TP used GCPs but no automated flight control, gaining an *x*/*y*/*z* RMSE of 4.5/8.3/3.2 cm. Sites GT and MH neither used automated flight control, nor GCPs, therefore gained *x*/*y*/*z* RMSEs for estimated camera locations of 85/59/68 cm and 78/72/40 cm, respectively.

Similar to pile area, bulk pile volumes varied significantly among study sites. Table 4 details the volume measured, and the directly comparable metrics of bulk volume per hectare harvested and bulk volume per tonne harvested.

The measures of average pile depth and maximum pile depth (see Table 3) indicate that for most harvests, there is little difficulty in achieving a pile height less than 3 m to align with current industry guidelines.

Table 5 provides the summary statistics from Table 3 and Table 4. Each site has been considered a data point in generating the mean values. A reduced dataset size is indicated where data could not be provided by the hosting forest manager.

TABLE 3: Ground covered by residue piles and depth statistics.

Site Code	Total # of Piles	Combined Pile Area (m^2)	Pile Area per Hectare Harvested (m^2/ha)	Mean Pile Depth (m)	Max Pile Depth at the 90% threshold (m)
GJ	1	1360	160	1.6	4.3
GT	2	4730	150	0.7	2.2
GN	3	1500	160	0.7	1.7
HT	3	3680	150	0.8	1.7
HF	4	3450	250	0.7	2.1
MH	2	3730	300	0.5	2.8
MO	1	2630	60	2.8	5.5
TP	2	1040	50	0.9	2.1
PK	1	4910	210	0.9	2.3
PE	2	1340	190	0.9	2.2
MA	3	3750	220	0.5	1.6
MC	2	2680	320	0.7	1.9
MG	1	1480	40	1.4	3.7
PC	2	1920	230	1.2	3.1
RK	1	2280	370	0.9	2.3
TK	7	5560	170	0.8	-

TABLE 4: Volumes of residue piles.

Site Code	Combined Bulk Volume (m^3)	Bulk Vol. per Hectare Harvested (m^3/ha)	Bulk Vol. per Tonne Harvested (m^3/t)
GJ	2190	250	0.53
GT	3520	110	0.21
GN	1100	120	0.19
HT	2770	110	0.20
HF	2250	160	0.29
MH	1880	150	No data
MO	7235	180	No data
TP	940	40	0.11
PK	4474	190	0.38
PE	1104	160	0.32
MA	1831	110	0.18
MC	1958	240	0.27
MG	2096	60	0.15
PC	2317	280	0.38
RK	2160	350	0.45
TK	4396	130	0.16

The assessment of accuracy for the six piles over two sites (Sites PE and HF) found that the mean difference between the volumes yielded by the manual interpolation method and the georeferenced pre-harvest datum surface method was 19%, with a range of 49%. Five of the six pile volumes were underestimated by the manual interpolation method – where the assumption is made that the georeferenced datum surface method is correct and the datum surface (landing shape/height etc.) remains constant between pre-and-post-harvest data collection visits.

Discussion

One of the goals of this study was to provide an up-to-date benchmark of residue pile volumes. Previous benchmarks were provided by earlier studies. For example, a 1993 study investigated the retrieval of residue piles at four hauler landings, which involved surveying the bulk volume of material moved and that beyond the machine's reach (Hall 1993a). The mean bulk volume and mean TEV were 1400 m^3 and 6694 m^3, respectively. By assuming the density of freshly harvested radiata pine is 1 t/m^3, the estimated bulk volume of residue

TABLE 5: Mean values for all parameters across all sites (n=16).

Attribute	Value
Harvest Area (ha)	18.9
Number of Piles per Site	2.4
Bulk Pile Volume per Site (m^3)	2600
Pile Area per Site (m^2)	2900
Pile Area per Hectare Harvested (m^2/ha)	190
Bulk Pile Volume per Hectare Harvested (m^3/ha)	170
Pile Depth (m)	0.92
Max. Pile Depth (at the 90% threshold) (m) **15 sites*	2.6
Bulk Vol. / tonne harvested (m^3/t) **14 sites*	0.23

piles in 1993 was approximately 0.21 m^3/t harvested. A subsequent study in 1994 measured the solid volume of branch and stem material discarded from six log making operations on radiata pine cable hauler sites and three ground-based harvesting sites (Hall 1994). For the hauler sites (assuming that they were steepland harvests and therefore comparable) mean measured solid log making residue volumes were 13.8 per cent of TEV, excluding the Douglas-fir (*Pseudotsuga menziesii)* stand datum. Making the same assumption on radiata pine density and assuming a bulk density of 0.25 t/ m^3 for woody residues (Visser et al. 2010), the comparative bulk density figure for residues in the 1994 study is 0.55 m^3/t. That places the 1994 result at the upper end of the range measured in this study. Recognising that a series of assumptions underlie these comparisons, it is significant that the bulk volume per tonne harvested the 1994 result is more than double the result from one year earlier. This study corroborates the results in the study by Hall (1993), although market conditions, harvesting machinery and harvest practice have changed markedly during the intervening years.

Managing residue pile area requires balancing of competing interests. Soil area covered by a residue pile(s) can represent an opportunity cost by reducing land area available for establishing the succeeding crop. However, concentrating residues by piling high carries an increased risk of self-ignition. Self-ignition thresholds in radiata pine residue piles requires further research to expand the working knowledge, however anecdotal evidence has formed the basis for the current BMP for residue pile height (3 m) (NZFOA 2020). For the piles measured in this study, the average maximum depth is below the current target BMP for height. Increasing the average pile height may allow more land area to be replanted, however high stacking can only be done on stable ground (NZFOA 2020), with the understanding that increasing pile height on a slope decreases its stability and increases risk of mass movement. The results show that on these study sites, maintaining low overall pile depth takes priority over maximising replanted area.

Further insight into the results of individual sites should consider operational factors. Additional reasons for a high or low pile area per hectare may be explainable by the log market conditions, landing layout, machinery used, management instructions or terrain form. Such finer details are beyond the scope of this study and may require much larger datasets to establish meaningful conclusions.

New Zealand plantations are now trending more towards framing regimes. The majority of sites measured in this study were clearwood regimes, as is typical of most 1990s crops. Framing regimes when compared to clearwood (typically) have higher TRV, higher stocking and smaller piece size. Reduced piece size has been shown to lower the breakage rates (Murphy 1982), however with more stems per hectare the effect may be negated. Whether the physical differences between regimes results in a measurable difference in landing residue volumes (all other factors controlled) is yet to be established.

This research was completed soon after a number of major mass mobilisation events (Cave et al. 2017). As such the measurements made for this study may already reflect changes to practices for both creating and storing harvest residue piles on or near landings in steep terrain. It is recognised that the current strong emphasis on both minimising environmental risk as well as creating biomass market opportunities for renewable energies may have already resulted in changed residue management practices (Dale 2019; Visser et al. 2018). While this study cannot predict those changes, it can serve as a benchmark and reference point to measure future developments against.

This research demonstrates the ability to investigate the bulk volume of residue piles with the modern equipment and software tools available (or cloud-computing substitutes) to today's forest manager. Previous methods required measurement in association with heavy machinery or estimation of both the terrain below and the surface of the pile (Hardy 1996), making use of the tools available at the time. The method employed in this study improves on previous methods by better modelling the pile surface. One way for improving terrain estimation would be to site residue piles on as flat ground as possible. Whilst clearly advantageous for measurement accuracy, several factors precluded the viability of the idea for this study. With additional time, more accurate results would be obtained by establishing a georeferenced datum surface of the completed landing formation, prior to piling with harvest residues – as used for the validation of the method employed in this study. Where serious consideration is given to removal of the product, accuracy may become increasingly important, justifying modelling landings (and surrounds) pre-harvest.

Results from this project can assist forest managers to predict the bulk volume of residues that may accumulate at a steepland landing during a WTH operation. Estimation of volumes is recommended by guidance documents for current legislation (MPI 2018) to ensure storage capacity is adequate – or alternatives are planned for. These results are advantageous for feasibility studies on a forest's ability to supply a biomass market with landing residues. Finally, this study sets the latest benchmark for residue volumes as harvesting machinery, methodology and markets develop over time.

There is little, recently published information on the volumes of harvest residues discarded at New Zealand's steepland landings. This study addresses the question, but much more can be done at a finer scale with the resources and data available to commercial operators. It is intended that this study provides accessible ideas and tools to foresters who are looking to supply (but not currently supplying) a biomass market. It is important that the industry collects information on the material as security of supply is critical to business cases for heat users considering conversion from fossil fuels to residual biomass. While international log markets continue to demand small-diameter or industrial logs, residual biomass will play a vital role in meeting bioenergy demand locally. The procedures discussed in this paper require limited training and many can be completed with cloud-computing services, reducing computing capacity issues.

Conclusions

This is a renewed look at residual biomass accumulations at landings and demonstrates how an investigation could be conducted in a forest or forest estate with tools readily available to today's forester. It sets the latest benchmark for landing residue pile volumes in New Zealand's steepland plantations. Markets for harvest residues are developing, regime change is occurring, and innovations to harvest systems are promising to reduce the production of broken/low quality material. The information provided on current steepland pile volumes offers New Zealand forestry companies, forest owners and the biomass market, a better understanding about the current availability of the material in steepland plantations and therefore potential for increased utilisation.

Competing interests

The author declares that they have no competing interests.

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