Managing forest landing residue piles – a case study on the use of photogrammetry to support decision-making

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Abstract

The piles of woody residues that accumulate at forest landings across New Zealand present various operational, safety and environmental challenges for foresters and logging crews. Being able to measure the dimensions of these piles would help make decisions about the potential recovery for a biomass market, but also for risk. For example, it is recommended that residue piles should be no deeper than 3 m due to self-ignition risk. Depth can be difficult to measure, especially on undulating terrain. This case study used Unmanned Aerial Vehicle (UAV)-based aerial photography to first improve the calculation of total pile volume, and second to provide a 3D map to help determine pile depth for targeted rehabilitation.

A UAV was used to capture aerial photographs post-construction of a landing (before harvest), then again post-harvest with the residue pile formed. Georeferenced photogrammetric surface models were constructed and used to establish the relative height change of the surface pre- to post-harvest (and therefore total bulk volume) over the plan area of the pile. A ‘heat map’ of pile depth was generated, enabling assessment of areas requiring rehabilitation to meet best practice guidelines. This case study presents an improved methodology for assessing large piles over time, along with learnings of the method’s limitations for the practising forester.

Introduction

Piles of harvest residues that accumulate at forest landings present operational, safety and environmental challenges, making their management a key focus for plantation owners (NZFOA, 2007, 2019). The piles also provide increasingly tangible opportunities for utilisation due to growing demand for bioenergy (Pooch, 2021). Management and measurement of the material can take many forms from the application of ‘rules-of-thumb’ (Goulding, 2005), to passive material uplift monitoring, to active pile measuring and dimensioning (Hall, 1993, 1994; Hardy, 1996; Riedinger & Harvey, 2021). Standards and best practice allow for a range of slash prediction and measurement approaches, which can fit the resources available to the farm forester or the estate manager.

Harvest residue piles can carry appreciable risk over the months or years post-harvest (Clifford et al., 2020). The selection of stable landforms for pile storage is a focus of improvement (Dale, 2019) and instances of self-ignition only occur sporadically. However, for landing residue piles, landslip and fire remain the highest consequence outcomes from error.

The steep and variable terrain forms that dominate the New Zealand plantation estate can make observation or reconciliation of the depth or volume of piles difficult without intervention with heavy machinery. This represents a clear opportunity for harvesting process improvement and decision support.

With opportunities for biomass supply emerging, measuring the accumulated resource to provide short- and long-term availability projections is becoming increasingly important for suppliers (forest owners), but also potential customers, to grow confidence in supply. However, accurately measuring a pile of material draped over undulating terrain can be complex.

Safety considerations often preclude access to the pile surface by foot, so observations may need to be made from the pile edge. Early methods such as Hardy’s (1996) geometric approximation can give an indication of volume with a few measurements and some broad assumptions. Hall (1993) measured cross-sections of landing residue piles draped over landing-edges to determine volume, aided by a hydraulic excavator for deconstruction. Modern active (LiDAR) and passive (photogrammetry) remote sensing technologies clearly show opportunities for increasing accuracy over these earlier methods.

Riedinger and Harvey (2021) demonstrated a method that used consumer-grade Unmanned Aerial Vehicles (UAVs) and photogrammetry software to assess the bulk volume of landing residue piles on relatively level terrain. The method made use of the relatively flat terrain to minimise error when estimating the terrain surface under the pile.

Using georeferenced surface models, this case study demonstrates a proof of concept for a workflow that enables more accurate assessment of pile volume, by modelling the terrain under the pile ahead of harvest. It is intended to demonstrate that more accurate volume and depths can be measured on difficult terrain for inventorying residual biomass or for decision support on pile rehabilitation efforts.

Method

One small, recently constructed drive-through landing was selected for the study. The landing was located on rolling terrain and serviced a 4.8 ha harvest area of radiata pine.

After completion of construction, and before harvest, the landing was aerially photographed with a DJI Phantom Pro UAV (non-RTK) controlled by Map Pilot software. Weather conditions were clear and calm. Four large Ground Control Points (GCPs) were laid at the outward extents of four quadrants of the expected slash pile. The site was imaged in a grid pattern on a flat plane, achieving an average Ground Sampling Distance (GSD) of 5.79 cm/pixel. Waypoints for each GCP were averaged over 60 seconds with a Trimble Geo7x paired with a Zephyr Rover 3 receiver on a 2 m staff. The waypoints were later post-processed in Trimble GPS Pathfinder Office software to ensure positional accuracy in the range of ±5–15 cm.

Post-harvest, and with the residue pile in place, the same imaging procedure was carried out again. Weather conditions were overcast with a light breeze. GCPs were laid in the four quadrants about the residue pile, their waypoints collected (later post-processed), and images taken with the UAV flying in a grid pattern. The average GSD achieved was 3.67 cm/pixel. To eliminate performance bias, no attempt was made to influence the placement of the residue pile by the logging crew.

The pre- and post-harvest georeferenced photogrammetric point clouds were generated in Agisoft Metashape software using the UAV images and post-processed GCP locations. Vegetation was minimal on both visits, requiring no additional filtering for ground points. Both point clouds were down sampled to 10 cm raster format, with orthophotos also generated.

Pile volume was calculated in Softree RoadEng9 Terrain software. Visually delineating the residue pile boundary from the orthophotos and setting the boundary as the TIN model limit, the volume was calculated using the software's 'Calculate Volumes' function. Depth maps were generated by computing the height differences between the pre- and post-harvest models in CloudCompare v2.10.2 software using the 'Compute 2.5D volume' function.

The elevation of stationary check points (tops of stumps clearly visible in both pre- and post-harvest orthophotos) was assessed on pre- and post-harvest terrain surfaces to establish the accuracy of the terrain models.

Results

On the completed models, the total Root Mean Square Error (RMSE) of the location of the GCPs was 6.9 cm in the pre-harvest model and 1.8 cm in the post-harvest model. A comparison of absolute Z-values (surface heights) on stationary check points (observable in both models) showed an average height deviation of +17 cm, with a standard deviation of 6 cm over n = 8 check points. Applied over the 1,800 m^2 pile, the initial volume is therefore reduced by 310 ±110 m^3 to correct for the height difference found by the check points. This yields a total bulk pile volume of 2000 ±110 m^3 (2 s.f.), with the pile having an average depth of 1.3 m.

The measures exclude a small section on the eastern extent, which was not modelled in the pre-harvest survey, as indicated in Figure 1. This does highlight the importance of surveying a large enough area for the pre-harvest survey as residue piles can often extend beyond planned areas.

The distribution of the pile depth as an output of the CloudCompare analysis (Figure 2) shows that 99% of the pile's area is below the best practice target depth of 3 m (NZFOA, 2019). This result is represented visually in the heat map of pile depth (Figure 3).

Discussion

This paper presents a modern and improved methodology for assessing the volume and depth of piles of harvest residues on any terrain, using tools that will be accessible to many foresters. Substitutes are also available for the hardware and software tools used in this example.

The methodology does not yield instantaneous results, with processing and model building taking

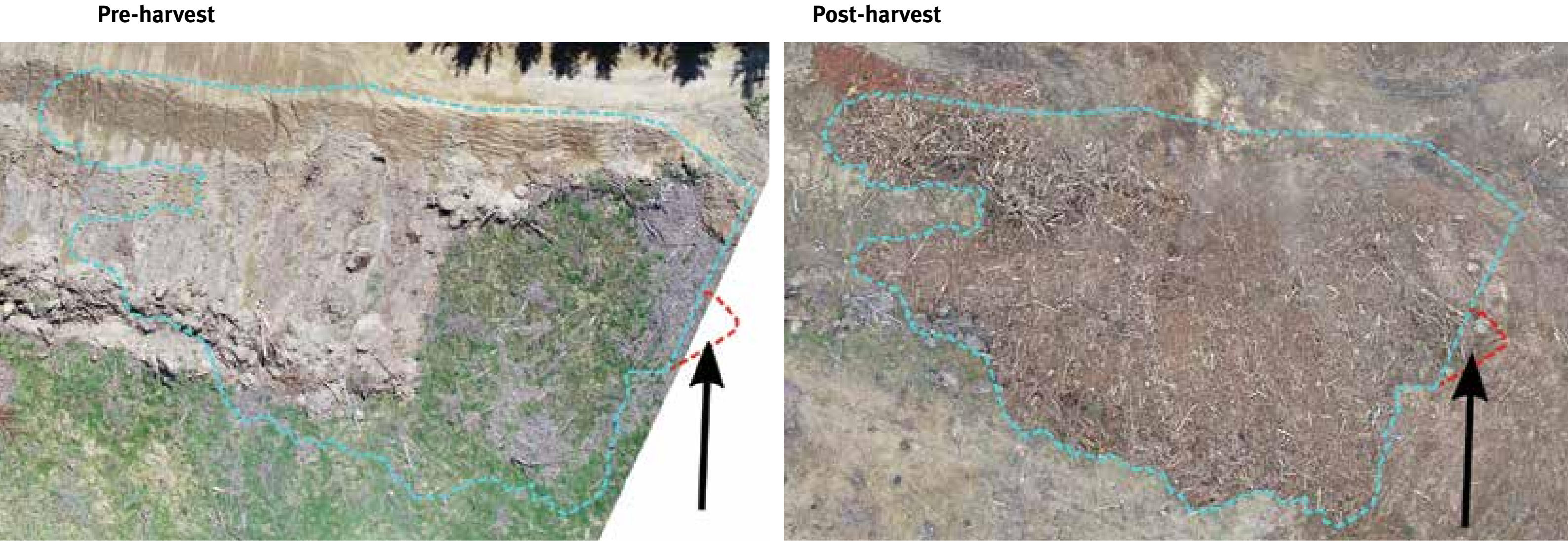

Figure 1: Comparison of orthophotos for the pile showing a small area missed in the pre-harvest image (arrowed)

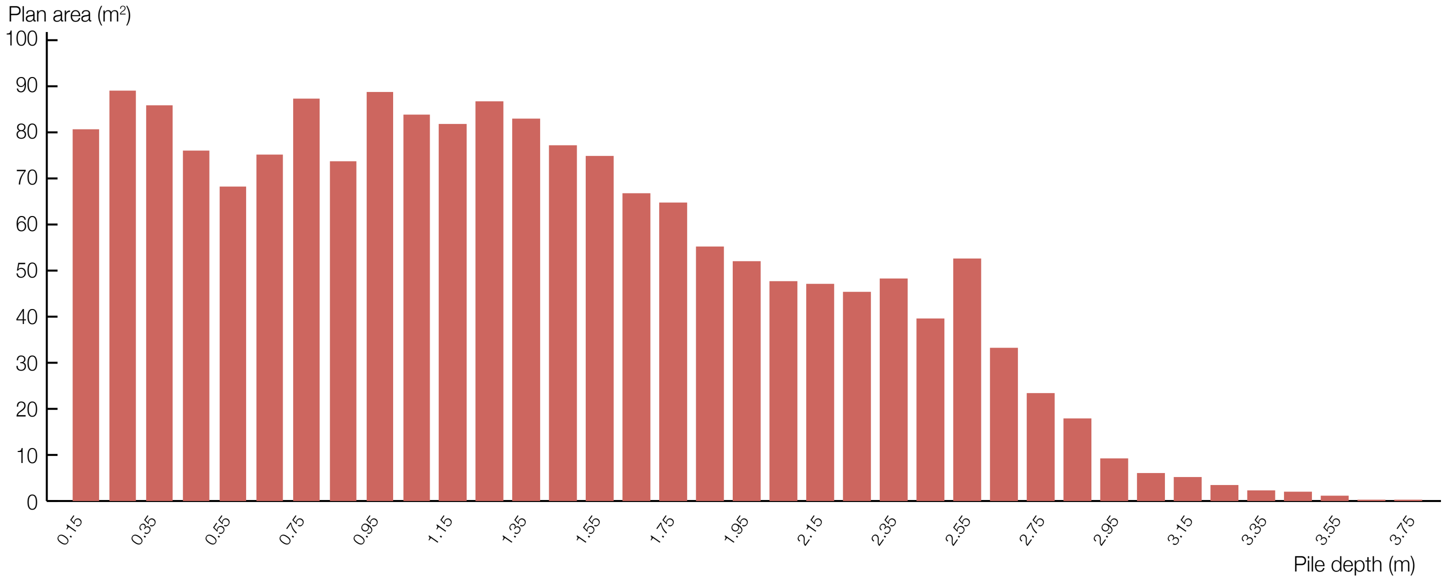

Figure 2: Pile depth distribution

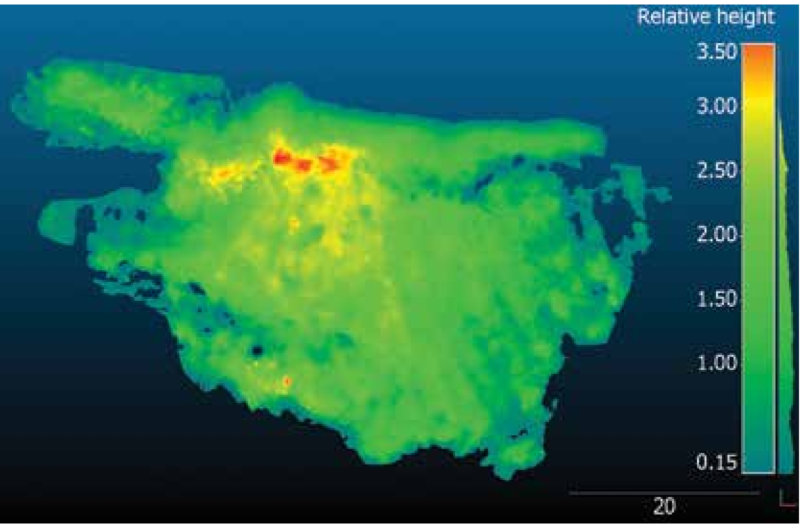

Figure 3: Full depth map of the residue pile, with the areas shaded in red exceeding the 3 m best practice threshold for fire risk

approximately four hours in the office in addition to planning and carrying out each UAV flight and associated GCP waypoint capture. The total time invested may be one-to-two workdays for one person per landing. As such, this workflow has greater value when its use is targeted. The best use of this methodology (or similar) may be for monitoring large piles that develop over several harvests.

An example can be a residue pile at a 'super-skid' where harvest volume is aggregated from multiple harvest coups and processed on the same site. Tracking pile growth over time would enable a forester to make informed decisions about pile rehabilitation efforts. Quality information may lower the chances of spontaneous ignition by incorrect visual assessments. As an extension of the result presented, georeferenced depth maps could also give direction to heavy machine operators carrying out pile rehabilitation, enabling accurate and efficient use of machinery and labour.

The methodology is not restricted to use on residue piles. It may be useful to foresters for other applications where storage of a material occurs on uneven ground, or where terrain changes occur, such as river ag/degradation, earthworks or quarry management. With any of these applications, typical current computing power limits the studies to relatively small areas at the point resolutions presented in this case study (100 ppsm). Related also to residue piles and the state of knowledge on self-ignition, the method provides an opportunity to combine with further study of pressure, humidity and temperature within a pile as the material settles and dries.

Two challenges to the application of the procedure were noted during this case study. First, without influencing the placement or management of the pile by the logging crew, the extent of the final pile can be difficult to predict during the initial flight and image capture of the terrain. This is evidenced by the studied pile extending over the boundary of the initial terrain model. The issue of eliminating performance bias may not be significant during the course of normal operations, however, enabling some direction of the pile's management.

The second challenge noted relates to roadline clearance of trees around the landing. Photogrammetry requires a clear line of sight from the camera to the ground from multiple locations to build an accurate terrain model. Occlusion of the ground by tree crowns (standing or felled) or dense undergrowth can require a terrain estimation procedure to be used, such as that embedded in Agisoft Metashape or CloudCompare (Zhang et al., 2016). Depending on the complexity of the terrain, and the extent occluded, these processes may or may not be appropriate.

Similar limitations are evident with aerial and ground-based LiDAR, but often to a lesser extent. While LiDAR pulses can generally penetrate vegetation to return ground points, the typical depth and density of landing residue piles is likely to preclude it from being any more use than photogrammetry in this application.

One solution for occlusion of terrain at the future pile extents is to simply ensure an adequate roadline salvage boundary to enable the data capture, or to merge with existing LiDAR datasets (where available).

Consideration should also be given to other factors if attempting to apply a similar methodology. Stationary machines, people or anomalies caught in the UAV photographs will be reconstructed in the photogrammetric model. These may be removed from point clouds manually by deleting points or by using a terrain estimation procedure, but at the expense of time and/or accuracy. Terrain forms can change between the capture of the first and second models due to machine tracking and soil settlement. The impact that terrain changes have on the results will vary and may not be easily measurable, except in the exposed, immediate surrounds of the residue pile.

Aside from aiding operational decisions, emerging biomass market opportunities may offer a secondary benefit for the accurate measurement of the residue resource. Subsampling the production of woody residues in an estate could aid in building models of the volume (or the fraction of the volume), which could be supplied to biomass markets. While it is recognised that residue pile retrievals may be a localised short-term solution while supply chains and harvesting processes adapt to faster uplift of log-making residues, this measurement approach enables data capture while those developments occur.

This case study highlights a question that inevitably arises with the increase in data resolution, especially where the research into spontaneous residue pile ignitions in New Zealand is sparse: What constitutes a pragmatic threshold for intervention to lower a pile's height? Research into decomposition-related ignitions indicates that there may be seasonal, composition, moisture and density variables which all contribute to any one pile's risk, and these change over time (Buggeln & Rynk, 2002). The 3 m target currently provides a pragmatic approach for foresters and loggers. Those variables that could better indicate ignition risk may remain impractical to monitor in New Zealand operations.

Conclusion

This case study has presented a methodology for monitoring the development of landing residue piles for their depth and total volume. The methodology makes use of equipment and software that is increasingly available to operational foresters. By using georeferenced photogrammetry to create models of the landing surface before harvest, then again of the pile post-harvest, it has enabled an improved calculation of volume (over previous methods) and also a depth map that could justify and aid pile rehabilitation efforts. With proper regard to the discussed limitations, the methodology can also be used for applications that require measurement of change over time, especially for complex surfaces such as the stepped landing formation in rolling/steep terrain as demonstrated in this case study.

References

Buggeln, R. and Rynk, R. 2002. Self-Heating In Yard Trimmings: Conditions Leading To Spontaneous Combustion. *Compost Science & Utilization*, 10(2): 162–182. doi: 10.1080/1065657X.2002.10702076

Clifford, V., Bayne, K., Melnik, K., Yao, R., Ballie, B., Parker, R. and Pearce, G. 2020. *Factors Contributing to Spontaneous Combustion of Slash at Skid Sites*, 69. Retrieved from: www.researchgate.net/profile/H-Pearce/publication/355871377_Factors_contributing_to_spontaneous_combustion_of_slash_at_skid_sites/links/6181e504a767a03c14e7e7a7/Factors-contributing-to-spontaneous-combustion-of-slash-at-skid-sites.pdf

Dale, R. 2019. *Workshop Report: Harvest Residue Management on Erosion Prone Land*. Forest Growers Research report. Rotorua, NZ: FGR. Retrieved from: https://fgr.nz/documents/download/7601?612598755

Goulding, C.J. 2005. Measurement of Trees. In M. Colley (Ed.), *Forestry Handbook* (4th Ed). Tauranga, NZ: The New Zealand Institute of Forestry (Inc).

Hall, P. 1993. Dismantling of Accumulations of Logging Residue Around Hauler Landings. *LIRO Report*, 18(6). Rotorua, NZ: Logging Industry Research Organisation New Zealand. Retrieved from: https://fgr.nz/documents/download/4578?2046499472

Hall, P. 1994. Waste Wood at Logging Landings. *LIRO Report*, 19(15). Rotorua, NZ: Logging Industry Research Organisation New Zealand. Retrieved from: https://fgr.nz/documents/download/4514?102200476

Hardy, C.C. 1996. *Guidelines for Estimating Volume, Biomass, and Smoke Production for Piled Slash*, 28. Retrieved from: www.fs.fed.us/pnw/pubs/pnw_gtr364.pdf

New Zealand Forest Owners Association (NZFOA). 2007. *New Zealand Environmental Code of Practice for Plantation Forestry*. In K. Richards et al. (Eds.), (1st Ed.). Online: NZFOA.

New Zealand Forest Owners Association (NZFOA). 2019. Forest Practice Guides. *Harvest Slash*. Wellington, NZ: NZFOA.

Pooch, J. (Producer). (26 January 2022). *The Future Energy Needs of Southland and Canterbury Thermal Heat Users*. Retrieved from: www.usewoodfuel.org.nz/resource/web2110-future-energy-needs-of-southland-and-canterbury-thermal-heat-users

Riedinger, L. and Harvey, C. 2021. Structure-from-Motion Photogrammetry as a Tool for Harvest Residue Pile Measurement. *New Zealand Journal of Forestry*, 65(4): 6–11.

Zhang, W., Qi, J., Wan, P., Wang, H., Xie, D., Wang, X. and Yan, G. 2016. An Easy-to-Use Airborne LiDAR Data Filtering Method Based on Cloth Simulation. *Remote Sensing*, 8(6). doi: 10.3390/rs8060501

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