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The Quantification of Logging Residues in Oregon with Impacts on Sustainability and Availability of Raw Material for Future Biomass Energy

Chet Miller[1], Kevin Boston[2]*

[1] Oregon State University, Department of Forest Engineering, Resources and Management, Corvallis OR 97331, USA
[2] Humboldt State University, Department of Forestry and Wildland Sciences, Arcata CA 95521, USA

Abstract

With an increasing societal desire to move towards renewable energy sources, interest in utilizing forest logging residues, logging slash, as a feedstock for new energy products is expanding. The Northwest Advances Renewables Alliance (NARA) is working to develop processes for transforming logging residues or slash into aviation fuel, Jet-A. As part of NARA, this study evaluated the availability, utilization, and the material that would remain on sites following clear-fell logging in the Pacific Northwest (USA). Little work has been performed to quantify the volume of harvest residues that are available for biomass material or to determine the volume remaining on site after harvesting with current utilization practices for private forest lands in the Pacific Northwest (PNW). To quantify these two amounts, the volume from logging residue from six sample harvesting units was measured to determine the available biomass and the quantity that remains on site. First, all of forest harvest residues piles were measured; these are considered the available biomass sources. Second, transects with a minimum total length of one-thousand-foot line-intersect sampling was performed to estimate the volume of residual material, not placed into piles, that will remain on site. The results will show both what is available for collection and the minimum amount of slash that will remain in the unit. The results from this study's measurement showed that the previous estimates of available residues in piles, may overestimate available residues by at least 20%. The volume of residues left in piles was dependent on logging system. Cable yarding left nearly 60% of total logging residue that remained on site. The average pile ranged between 62 m^3/ha and 79 m^3/ha remaining on site. Ground-based operations using shovels may leave as little as 39 % on site with a range between 79 m^3/ha and 40 m^3/ha) remaining on sites with 110 m^3/ha in piles.

Keywords: Logging residues, Availability of raw material, Biomass energy, Oregon

1. Introduction

Societal pressure is constantly pushing to improve the sustainability of forest practices in the PNW. Logging residues have become a recognized as a potential source for renewable energy in the US. Currently, most sawmill residues are already used as raw materials for pulp and paper, landscaping or engineered wood products (Ince et al., 2011) and the market values for these products are typically much higher than the value obtained for the material as feedstock for biomass energy production. Therefore, much of the feedstock for new bioenergy projects will need to come from new material that is not currently being used, specifically post-logging residues or logging slash. New practices must be developed to economically collect this material while developing, maintaining, and enhancing sustainable forest practices.

This study evaluated the availability of logging residues, material that remains after traditional harvesting operations in the PNW for energy production and the sustainability of these practices. However, the extraction of logging residues raises concerns about the potential changes to wildlife habitats and maintenance of nutrient pools while determining the supply of raw material available for processing.

The creation of a standard for the amount of material that should remain following harvest has been primarily achieved through state forest practice rules. In Oregon, the forest practice rules require that for even-aged harvests that create openings greater than 10 ha require a minimum of five wildlife trees per ha, residual trees left provide structure for the future rotations and five logs per ha remain following harvest (ORS 527.676).

*Corresponding author: Tel: +1 7078263935 E-mail: kevin.boston@humboldt.edu
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The nongovernmental organization, The Forest Guild (2013) has developed guidelines for residue retention following logging in the PNW. Their voluntary guidelines include estimates of woody material retention levels to maintain wildlife habitat and the availability of soil nutrients. They recommend two metrics. The first is a generalize land cover. It recommends that on gentle slopes that 30% of the fine woody material (FWM), material less than 15 cm in diameter, remain on site following biomass collections. The minimum volume to remain is increased on steeper slopes to 50% of the FWM. For the second metric, they recommend that 5% ground-cover of large woody debris, material greater than 13.7 cm, remain on sites to promote conditions found in unmanaged forests (Forest Guild, 2013).

The guidelines developed by the Forest Guild recognize the importance of down woody material on the sustainability of the ecosystem due to both nutrient management that impacts long-term site productivity and wildlife habitat. A complete discussion of nutrient cycling is beyond the scope of the work in this study as it would require a detailed discussion of the various soil and geochemical processes. It is often stated as concern when harvesting considers increasing the intensity of removal of tree material.

Logging residues can provide habitat features for a variety of small animals within the harvest unit. Over 150 vertebrate species use some form of down woody debris for habitat in the Douglas-fir forests of western Oregon (Hunter, 1990). The physical structure of down logs and branches provides protection and concealment from aerial predators as well as thermal cover. Fungi and other insects associated with decaying woody debris are important food sources for many larger animals.

There are many post-harvest forest residue assessments used to estimate the supply for biomass energy facilities. Perlak et al. (2005) estimated that 65% of the biomass is recoverable with current logging technology such as harvesters and forwarders. Gan and Smith (2006) assumed that 70% of the residues after harvests were available as feedstock for biomass energy. Their estimate was calculated using the allometric equations developed by the United States Department of Agriculture Forest Service's Forest Inventory and Analysis (FIA) data system. Kumar et al. (2003), estimated the available logging residue to be between 15% and 25% of total biomass present with residues accounting for approximately 0.247 dry metric tonnes per ha (DMt) of net residue per harvested hectare in Alberta, Canada. Likewise, Nurmi (2007) studied the impact of three different logging methods on the recovery of logging residues. These included felling and limbing on one side of the strip road, felling and limbing on both sides of the strip road and felling and limbing in the conventional manner, next to the stump, in an 11-ha harvest unit. They found that the recovered residues varied between 33.4 and 30.4 metric tonnes per hectare. The recovery rate was between 58% and 79% of the estimated total biomass. The highest volume of recoverable residues was produced when the limb material and residue were piled along both sides of the road following ground-based logging operations.

Kizha and Han (2015) estimated the harvest residues from two whole-tree harvesting operations from the redwood region of Humboldt County, California. The logging residues were collected and transported to a landing using shovels with a modified dump truck, hauling the material to a grinding site. No collection was performed beyond the landing from the cable operation. The biomass recovery rates for ground-based operations were 70% of the total harvest residues while cable logging recovery rates were 60% of the total harvest residues (Kizha and Han, 2015).

Forest biomass is a low value forest product in which the profitability of recovery operations is very dependent on unit layout, pile size, pile location and hauling distances. For example, if machinery is required to haul the material to a centralized landing for grinding, then the collection cost can be between $5.40 to $15.92/DMt depending on distance (Zamora-Cristales et al., 2013). Likewise, a mobile chipper may spend 17% of its operating time moving between piles that are located throughout the units (Zamora-Cristales et al., 2013). Chip vans are limited by landing space and the existing transportation systems resulting in inefficient hauling operations (Zamora-Cristales et al., 2013). Thus, the location of the piles may impact the technically available biomass.

This study aims to answer two questions: (1) how much residual material is placed in piles following logging after cable yarding or shovel logging? (2) How much of the residues are likely to remain on site following the collection if all piles are removed?

2. Materials and Methods

2.1. Study Area

Six units were selected to be sampled: two in the western foothills of the Cascade Mountains near Sweet Home, Oregon, two on the inland portion of Oregon's coastal range, and two on the coastal side of the coast range. Each of the units were on forestland owned by different private landowners who can recover $11 per bone dry tonne payment from the state government in Oregon for the renewable energy credits to encourage their development of biomass energy (Smith et al., 2012). The ground-based units were logged exclusively with shovels, which is becoming the dominating harvesting system on private timberlands in western Oregon. In the two Cascades units, one unit (High Deck) was harvested using ground based machinery and the other (Shot Pouch) using cable yarding. One unit (Numskull) on the inland side of the coastal range was shovel logged while the other (Fernhopper) employed a mixture of cable and shovel harvesting equipment.

The units on the west side of the Oregon coastal range (Four Way and Euchre Creek) were both logged with cable yarding equipment. These units represent the type of harvest units and timber stands that would likely supply raw material to a biomass conversion facility to generate the feed stock for aviation fuel in Oregon as they are representative of the type of terrain and timber harvested on a regular basis in western Oregon.

The stands were predominantly Douglas-fir (*Psuedotsuga menziesii*) with some grand fir (*Abies grandis)*, western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), red alder (*Alnus rubra*), and big leaf maple (*Acer macrophylla*). Table 1 summarizes the size, slope characteristics, and the harvesting system used in each unit.

Table 1. Unit size, slope range, and harvesting systems for the six sample units

Unit	Area (ha)	Slope Range %	Logging System	
			Cable	Ground
Fernhopper	16.4	0-90	30%	70%
Numskull	28.4	0-60	100%	0%
Shot Pouch	27.0	15-60	0%	100%
High Deck	4.0	0-15	100%	0%
Four Way	24.6	40-70	0%	100%
Euchre Creek	13.4	5-100	0%	100%

2.2. Slash Pile Measurement

Every pile in each unit was measured to determine the footprint area and volume with a Nikon TruPulse cruising laser rangefinder linked via Bluetooth to a SXPad with the MapSmart software, achieving this way a 100% sampling rate. Long and Boston (2013) found that when they measured slash piles ranging from 29.2 to 1,775 cubic meters with both the TruPulse laser and the more complex and accurate terrestrial Lidar; A comparison of the two using the concordance correlation coefficient was 0.91 and this result suggest no significant difference between the two methods. However, the use of the laser is fraction of the cost and data collection time of the terrestrial Lidar measurements.

The pile volumes computed with the MapSmart TIN represent the shell that contains the residue; however, the solid-wood-to-space ratio is quite low. A biomass pile packing ratio of 0.2 developed by Hardy (1996) was applied to determine the weights of the residue for small-needle conifers such as Douglas-fir. Wright et al. (2010) showed similar results; they measured 63 conifer piles and computed a similar packing ratio of 0.19. A small sample performed as part NARA project showed a similar value, 0.19. Thus, for this study, the packing ratio of 0.20 suggested by Hardy (1996) was used to convert the shell-volume in the piles to the volume of actual material. A full sampling of the packing ratio requires each pile be collected and weighed individually, access to this data was not available for this study.

To determine the total volumes of residual scattered slash, the footprint area of all the piles needed to be removed from each unit's total area. The MapSmart footprint area calculation was found to be more accurate due to the inability of the operator to walk exactly at the base of the pile and the inherent lack of precision of the Trimble GeoExplorer.

2.3. Transects

Line transects were used to quantify the volume of slash remaining on the ground following harvesting, namely the residual volume (Warren and Olsen, 1964). In order to create an unbiased representative sample of each clear-cut, five transects were placed randomly through the unit for a total of approximately 300 meters as there was no prior estimation of the variability from previous studies. Using a string box to measure distance and establish a centerline of the transect and calipers to measure diameter of the woody material that intersects the line exceeding 0.635 cm was measured.

Only the solid wood that was generated from the immediate harvests was measured. On-site residues~~,~~ such as the residual brush or snags that had fallen from previously rotations due to its incorporation into the soils were not included in the forest residue estimates. Although~~,~~ bark has higher energy and nutrient values, it was not included in the measurements as the study's focus was on the solid wood as feedstock for jet fuel.

3. Results

3.1. Relationship of Pile Volume to Footprint Area

The relationship between pile volume (independent variable) and pile footprint area (dependent variable) proved to be very strong. One hundred and eleven piles from the High Deck, Shot Pouch, Four Way, and Euchre Creek units were used to find the following regression equation explaining 92.5% of the variation in pile footprint with pile size. This allows for the areas within the unit in that holds piles be deducted from the total harvest area with its statistical analysis contained in Table 2. The p-value shows that the slope is significantly different from zero.

$$PA\ (m^2) = 13.08 + 0.89\ X \qquad (1)$$

where,

X = gross pile volume in cubic meters

PA = pile area (m^2)

Table 2. Analysis of Variance for regression

	SS		*df*	MS
SSTOT	457937.47	457937.47	110	
SSR	450687.23	450687.23	1.00	450687.23
SSE	7250.24	7250.24	109	66.52
MSR	450687.23		1.00	
MSE	66.52			
R^2	0.98			
F* =	6775.62	p = 0.000		

3.2. Average Volume per Unit

The average volume of logging slash was of 152 m^3/ha. Of this, 25% to 58% remained scattered on the ground and the remainder in piles. In the cable harvested units, 53% of the forest residues were scattered on the ground. The mixed harvesting system had 46% were not piled and 33% of the material remained scattered on shovel logging units. An overview of the forest residues volume measurements is given in Table 3.

The total amount of harvest residues (scattered residual plus material in piles) varied from 40 m3/ha to 96 m3/ha. The average was 70 m3/ha. Figure 1 shows the total percent volume in piles for each harvest unit.

3.3. Pile Volume

Pile sizes and distribution varied widely between the units. Units with gentle terrain and more road access had more piles that were smaller than the harvest units on the steeper slopes. The steep units that used centralized landings for cable yarding had only a few, but very large piles as seen in Table 4. Figure 1 shows the dispersed pattern of piles after a shovel operation with ample road access. Figure 2 shows the distribution of piles in the Fernhopper unit, a unit with both cable and shovel operations. The logging system had the largest impact on amount of available biomass with a 13% difference in pile volume between shovel operations and cable operations. There was no apparent pattern for the location of the units as no difference was detected among the Cascades, Willamette Valley and Oregon Coast.

Table 3. Summary of residual and piled biomass volume estimates by harvesting system

	Gross Pile (shell volume) Volume (m^3)	Solid wood Pile Volume (m^3)	Pile Area (ha)	Adj. Unit Area (ha)	Residual Volume (m^3/ha)	Total Biomass (m^3)	Percent In Piles
Mixed							
Fernhopper-WV	6671	1334	0.38	16.4	72	2487	53.6%
Shovel							
Numskull-WV	15635	3127	1.23	28.4	79	5273	59.3%
High Deck-CAS	2232	457	0.19	4.0	40	609	75.0%
System Average							62.6%
Cable							
Shot Pouch-CAS	9407	1879	0.73	27.0	96	4399	42.7%
Four Way-OC	7426	1485	0.27	24.6	85	3542	41.9%
Euchre-OC	3711	742	0.35	13.4	47	1356	54.8%
System Average							46.5%
Overall Average							54.5%

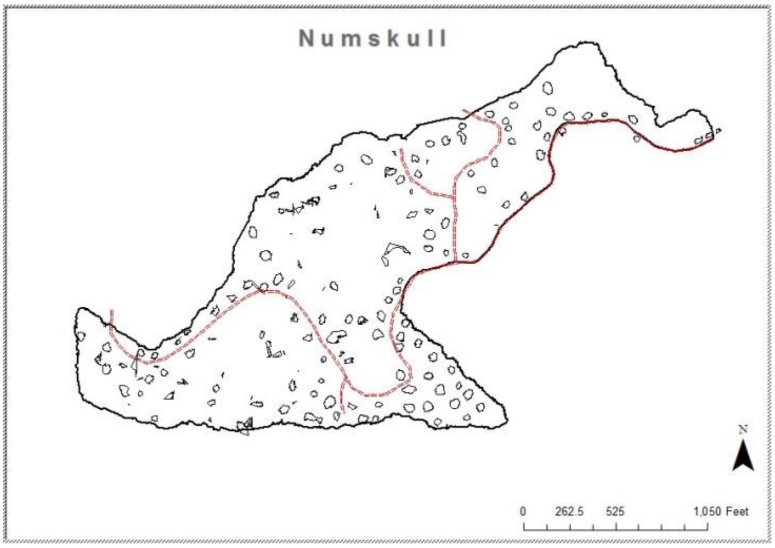

Figure 1. Numskull Unit boundary and piles as an example of pile distribution after a ground-based operation

Table 4. Summary of the slash piles measured in each unit by harvest system

Unit	Pile Count (N)	Average Shell Volume (m^3)	Average solid Wood Volume (m^3)
Mixed			
Fernhopper-Willamette Valley	18	370	74.0
Shovel			
Numskull Willamette Valley	153	103	20.5
High Deck Cascades	34	67	13.5
Cable			
Shot Pouch Cascades	74	127	25.4
Four Way Oregon Coast	3	2475	491.1
Euchre Oregon Coast	1	3711	742.2

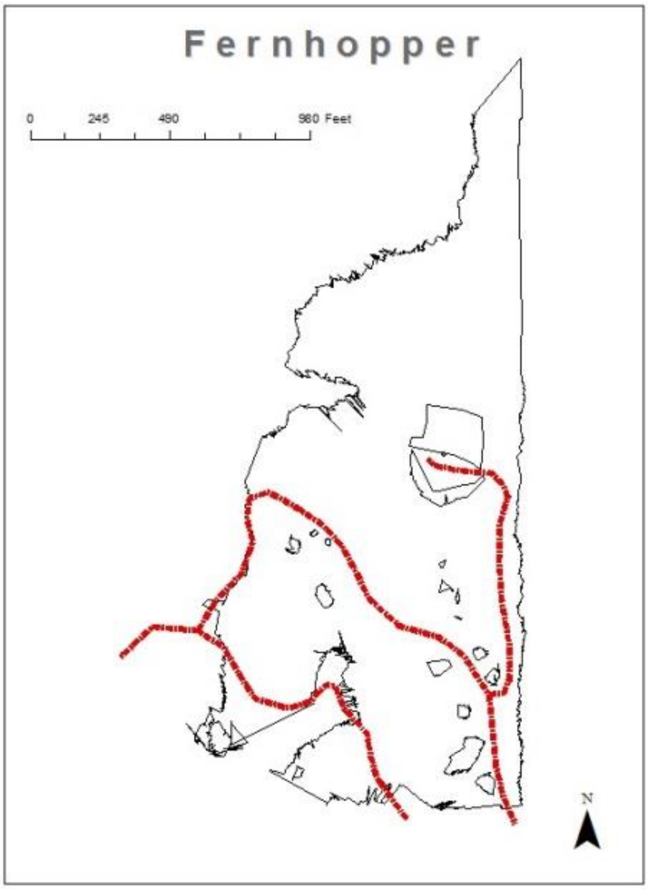

Figure 2. Unit boundary and pile locations in the Fernhopper unit with mixed system (70% cable and 30% shovel logging)

3.4. Residual Biomass

Most of the residual volume came from moderately sized limbs. The fine woody material, less than 25 mm in diameter, was much more plentiful by number but lacked the mass. Likewise, the large woody material was too rare to produce large volume. Figure 3 shows the average volume for each piece size class from all six units. The standard deviation of the line-intersect sampling transects is sensitive to the presence of large woody material as well as the overall volume of residual material. Intersecting a few pieces of larger material had an impact of the volume estimates. Sixty-nine percent of the scattered slash by volume was about 5 cm and smaller while only 2% of the volume was greater than 15 cm in diameter resulting in a standard deviation that was 11% of the average volume estimate. Conversely, the High Deck unit had a relatively small volume of fine and course woody material and large woody material scattered about randomly resulting in a standard deviation that was 34% of the average volume estimate.

4. Discussion

The results from our study showed that the ground-based logging system had a larger percentage of the logging residue in piles than the cable logging units and these results agree with the findings of Kizha and Han (2015) that showed similar figures of about 10% more material available from the ground-based operations. Additionally, two of cable logging sites had more residual slash per hectare than the shovel logging, but there was a large amount of variation among the units.

The British Columbia energy project (Akhtari et al., 2013) estimated the available feedstock to be 80% of the total biomass. Likewise, in Alberta, (Kumar et al., 2003) assumed the availability to be 70%. Our findings show that for most cases these are overestimations of supply when applied to Oregon private lands. However, our sample size was small. Our highest value for biomass availability was 75% in the High Deck unit. This unit was our closest match to the two availability estimates given by Akhtari et al. (2013) of 80% and Kumar et al., (2003) of 70%. The uncertainty in the packing ratio is the next area of work to be completed reduce the uncertainty in these estimates.

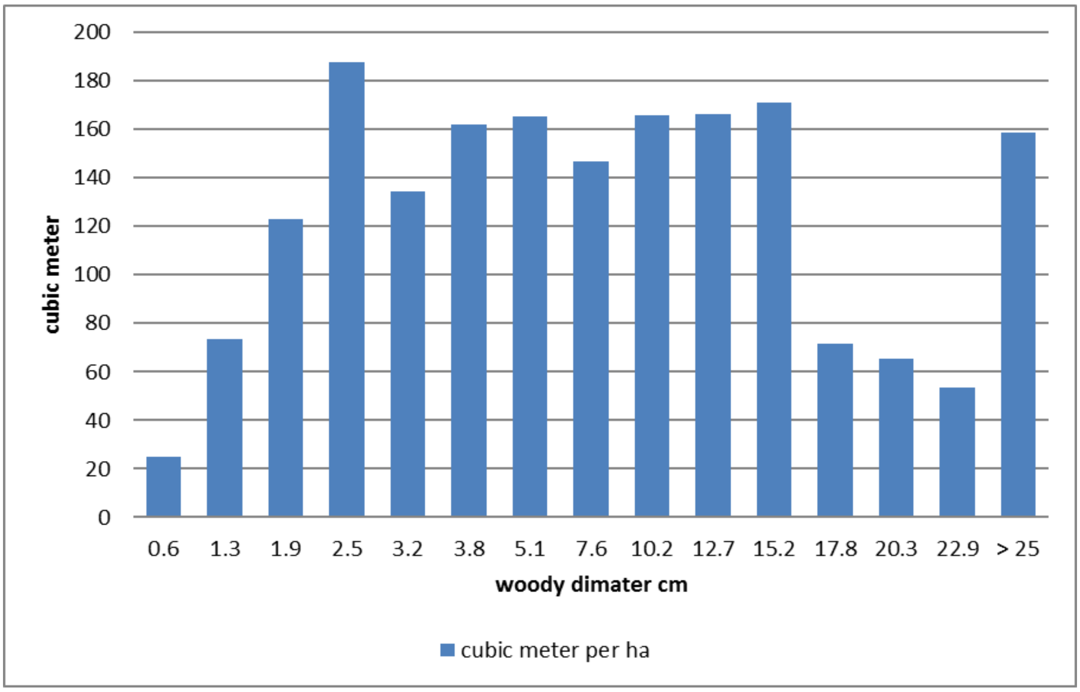

Figure 3. Average volume per piece size of scattered residual material in all six study units

The biomass estimates from the single logging system units were well below previously cited biomass volume availability estimates, especially for cable harvested units (41-59% of total biomass in piles). The average percentage of biomass piled after cable, mixed and shovel, and logging system was 46%, 54%, and 67%, respectively. A more reasonable biomass availability estimate may be between 45% and 70% depending on the severity of the terrain and the specific harvesting system is one of the results of this study.

The volume of woody material remaining scattered over the site after harvest met the best management practices standard established by The Forest Guild in four out of the six units. On moderate terrain with ground based logging only, the High Deck unit did not meet the recommended best management practices level of 30% retention suggested by the Forest Guild; this unit only had 25% of the total slash scattered on site. Likewise, the Euchre Creek unit was the only cable yarding unit which did not meet the recommended level of 50% residual scattered slash on steeper slopes (45% of the harvesting residue remained on the site outside the piles). This assumes that all the volume in piles will be removed or burned on site. Conversely, both the Shot Pouch and Four Way units (57% and 58%) exceeded the recommended 50% recommended by the Forest Guild. The Fernhopper and Numskull units exceeded the 30% benchmark with 46.4% and 40.6% respectively.

The fear of total removal of woody material from logging operations can be alleviated as these units demonstrated that much of the material remains on site. However, there may not be enough large material left on-site for future habitat structure. Only 6% of the total residual volume was over 30 cm in diameter (large woody material) and only 21% of the residual biomass could be classified as coarse woody debris (residual material that is 15 to 30 cm in diameter). This result doesn't mean the sites were completely void of large woody debris because only the biomass from the most recent harvest was measured. The older biomass that was in more advanced stages of decay was not quantified as the goal was to consider the residual material that resulted from harvesting operation. However, with current practices, the critical, large woody material in the future may not be prevalent enough on the forest floor to meet 5% ground cover recommended by the Forest Guild.

The distribution of slash and the inherent difficulty in collecting, chipping, and transporting forest biomass within common economic constraints might make the availability estimates in this study too high; especially in the ground based shovel operations as the cost to transport the piles to the landing may exceed the revenue from the pile. In cable yarding or in whole tree ground skidding operations, central or roadside landings are focal points for harvest residue accumulation. Conversely in current practice, shovel logging promotes a large distribution of numerous piles throughout the unit because the harvest residue is left scattered throughout the unit, rather than tending towards centralized points. The economic feasibility of chipping those piles that are not near the road may be low (Zamora-Cristales et al., 2013). Therefore, the harvesting process from layout to slash piling should be evaluated as to its effect on the final biomass availability. Future work is recommended.

5. Conclusion

The results of this study showed that the previous estimates of available residues in piles, may overestimate available residues by at least 20%. The volume of harvest residues piles was dependent on logging system. Cable yarding left nearly 60% of total slash as logging residue that remained on site. Shovel operations may leave as little as 39 % on site. A more reasonable biomass availability estimate may be between 45% and 70% depending on the severity of the terrain and the specific harvesting system. The lower end is for cable yarding while ground-based systems will be higher.

The results of this study show that the harvest volume varies by harvesting system with more of the material placed into piles from ground-based systems as opposed to cable-based logging systems. The residual volume, that material not in piles, meet the Forest Guild Society guidelines for material remaining on site in 5 of the six harvest units, but there is a concern of the lack of large material that remains on these sites as this large wood debris is a key habitat element for many species.

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