Rapid Sampling of Scattered and Piled Forest Harvest Residue:

A BIOMASS ENERGY FEEDSTOCK AND IMPORTANT ENVIRONMENTAL COMPONENT

Developing renewable energy markets are expected to increase demand for forest biomass. Forest residues generated by harvesting are one type of biomass identified as feedstock for second-generation biofuels, a type of renewable energy (Antizar-Ladislao and Turrion-Gomez, 2008). Forest biomass demand is expected to intensify and could have impacts on biodiversity, water quality and long-term site productivity (Björheden, 2010). Assessment of conditions on harvest sites with respect to biomass availability and retention will be critical to ensuring continuous feedstock supply and maintenance of sustainable forest management practices.

Forest harvesting residues (FHR) generally fall within two categories; residues that are scattered or residues that are piled. Scattered residues are randomly distributed coarse and fine woody debris. Piled residues consist of conglomerated coarse woody debris that may be randomly or systematically distributed. On a given site, harvest residues may be scattered or piled or both scattered and piled. Numerous techniques to sample harvest residues are available and each demand varied levels of effort, expense and expertise. One simple technique to rapidly sample scattered and piled harvest residues can be found using a combination of prism sweep (Bebber and Thomas, 2010) and slash pile sampling (adapted from Woodall and Monleon, 2007).

PRISM SWEEP SAMPLING

Prism sweep sampling (PSS) is a relatively accurate and efficient way to obtain volume estimates when sampling scattered forest harvest residues (See sidebar; Bebber and Thomas, 2003). PSS is a probability-proportional-to-size method that uses the same principles as point relascope or prism sampling and utilizes inexpensive and readily available equipment. Harvesting residues to be measured must be subtending by a prism angle where the midpoint diameter viewed from the point center is greater than the critical prism angle (Figure 1). If a piece of residue is determined as “in”, the length is measured.

Prism sweep sampling has some limitations. In order to collect a sample, there must be a clear line of sight from the point center to all pieces of forest harvest residue

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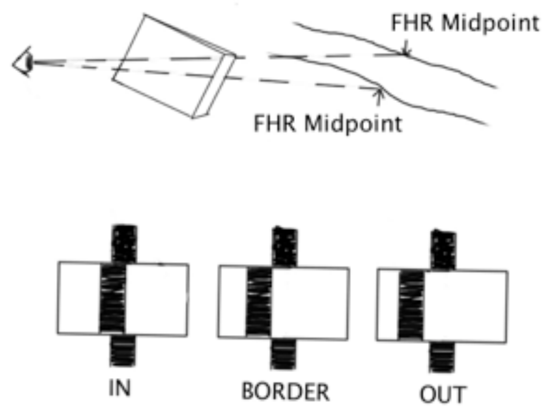

Figure 1. Sighting through a prism at the midpoint of a forest harvesting residue piece to determine if it is “in” and should be measured for length.

A Field Test for Relative Accuracy and Efficiency of Prism Sweep Sampling

Prism-sweep, line-intersect and fixed-radius plot sampling were used to estimate volume of forest harvesting residue within a recently clear-felled site in Johnston Country, North Carolina. Fifty sampling points were situated on a systematic grid and of these points twenty were randomly selected for sampling. Of those twenty points, thirteen were in a hardwood forest and seven were in a pine forest. At each randomly selected point, a sample was drawn using line-intersect, prism-sweep and 100-percent tally on 0.1-acre fixed radius plots. A two-person crew collected each sample. To assess relative accuracy of prism sweep sampling, the estimated population average for each sampling technique was compared (Table 1). Fixed radius plot sampling carried prohibitive costs regarding time to collect a sample, so only the efficiency of prism sweep and line-intersect sampling was measured (Table 2).

Table 1. Estimated green tons of forest harvest residues from twenty randomly selected sampling points using line-intersect, prism sweep and 0.1-acre fixed radius plot sampling.

	Sampling Technique		
	Line-Intersect	*Prism Sweep*	*0.1-Acre Plot*
Mean	25.97	21.04	22.32
Standard Error	3.10	2.51	1.60
Range	47.66	45.15	26.11
Confidence Limits (±)	6.49	5.25	3.36

Table 2. Minutes collecting a line-intersect or prism sweep sample using a two-person crew.

	Sampling Technique	
	Line-Intersect	*Prism Sweep*
Mean	17.2	3.2
Standard Error	1.2	0.3
Range	15	5
Confidence Limits (±)	2.5	0.6

For this field test, prism sweep sampling yielded similar biomass estimates of forest harvesting residue when compared to line-intersect and fixed-radius plot sampling (Table 1). Prism sweep sampling, however, was nearly six times more efficient than line-intersect sampling (Table 2).

PREPARING FOR THE INVENTORY

This first step in a successful inventory is planning. Preparation will minimize time spent in the field and improve estimates determined from inventory data. To begin planning, you will need:

- a map or aerial photograph of the area to be sampled
- an estimate of the number of acres to be sampled
- a calculator

Before conducting the inventory, identify the number of sample points needed and their placement in the field. The number of sample points is based on a degree of confidence desired and the variation in the amount of harvest residue to be measured. You can estimate variation in harvest residue by taking a pilot sample. A pilot sample is a small sample taken prior to conducting a full inventory of a harvest area. Using information from the pilot sample, you can estimate variation for a given site by calculating the standard deviation or estimating standard deviation from the observed sample range (See Side Note). If taking a pilot sample is infeasible, estimate variation in forest harvest residue from previous inventories on similar sites or relevant publications. It is likely that scattered and piled residues for a given site will have unequal variance. In this case, use the group yielding the greatest variance when calculating the number of sample points to install.

Range Rule for Standard Deviation

The standard deviation and range indicates how spaced out the data are or how much variation is in the data. The range, which is easy to determine, is calculated by subtracting the minimum data value from the maximum value. The standard deviation, which is a more reliable measure of variation, is more involved to calculate then the range. There is no direct relationship between range and standard deviation, but there is a rule of thumb that can be useful in providing a rough estimate of the standard deviation based on the range. The range rule informs us that the standard deviation of a sample is approximately ¼ the range of the data.

S = (Maximum – Minimum) / 4

For example, *a pilot sample of the harvest area indicated the following per acre cubic foot volumes:*

Pilot Sample = {710,290,140,510,40,840,170,470,640,90,0,200,120,50,290,230}

$$S = \frac{840\,{ft^3}/{acre} - 0\,{ft^3}/{acre}}{4} = \frac{840\,{ft^3}/{acre}}{4} = 210\,{ft^3}/{acre}$$

The following calculation is used to determine the approximate number of sample points to install:

$$n = \left(\frac{S \cdot t}{E}\right)^2$$

Where,

n	is the number of sampling points to be installed based on a given confidence level,
S	is the standard deviation in the amount of scattered or piled harvest residue to be measured; one should use the group yielding the greatest variation,
t	is dependent on the desired confidence level; t=1.7 f or 90% confidence, t=2 for 95% confidence and t=2.6 for 99% confidence,
E	is the error of tolerance, and the person who requests the inventory specifies it. E is in the same units as S.

For example: A 50-acre recently harvested forest is to be sampled with an error tolerance ± 70 ft³/acre and a desired confidence level set at 95 percent. A pilot sample of the harvest area indicated a standard deviation of 64 ft³/acre for piled harvest residue and 210 ft³/acre for scattered harvest residue. Given that scattered harvest residue was observed to be relatively more variable than piled harvest residue, the number of sample points needed to conduct the inventory is calculated as:

S = 210 *ft³*/acre, t = 2; for a 95% confidence interval and E = ± 70 *ft³*/acre

$$n = \left(\frac{S \cdot t}{E}\right)^2 = \left(\frac{210\,ft^3/acre\ \times 2}{70\,ft^3/acre}\right)^2 = 36\ sampling\ points$$

Once the number of sample points has been calculated, determine their location in the field. On a map or aerial photo of the area to be inventoried, draw parallel lines that evenly cover the harvest area. The lines represent the approximate path to follow in sampling. The spacing of the lines and the distance between points will be based on the sampling intensity you are trying to achieve. Draw the lines perpendicular to drainage patterns to pick up variations caused by changes in topography. Locate sample points at regular intervals, which will produce the necessary number of sample points. Figure 2 depicts a typical layout of a sampling scheme.

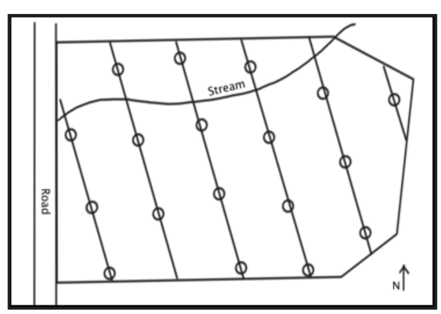

Figure 2. A typical layout of a sampling scheme.

Once the number of sample points is determined and a sampling scheme identified, you are ready to begin the inventory. The following procedure is based on a two-person team, but a single person can accomplish it.

CONDUCTING THE INVENTORY

To begin an inventory, you will need to gather a few pieces of equipment and locate the first sampling point. The equipment needed for the inventory includes the following.

- BAF 10 Wedge Prism
- Measuring Tape (25- or 50-foot length)
- Map or aerial photo with sampling scheme laid out.
- Compass
- Pin flag
- Data sheets (See examples at end of the document)

Sampling Scattered Forest Harvesting Residue:

1. Place a pin flag marking the sampling point.

2. With the compass, determine the direction you are facing. This will be the starting and ending point as you rotate 360^{o} around the sampling point as marked with the pin flag.

3. The procedure used for sampling with the prism is similar to the typical technique used for determining in-trees in standard forestry measurements. Stand with the prism over the sampling point. Hold the prism approximately ten inches from your eye and at a right angle to the axis of the length of the residue (Figure 1). With one eye closed, begin sighting harvest residue, counting only those pieces whose midpoint is offset by the prism. These pieces are considered “in” (Figure 1) and their total length is measured to the nearest inch. As you rotate 360o around the prism, hold the prism over the sampling point.

4. Move to the next sampling point and repeat the sampling procedure beginning at step one.

Sampling Piled Forest Harvesting Residue:

Woodall and Monleon (2007) describe a method to sample slash piles for the US Forest Service Forest Inventory and Analysis. The method by Woodall and Williams has been adapted in this publication to sample piled FHR within recently clear-felled forests. As mentioned before, piles of FHR may be randomly or systematically distributed across a harvest area. Randomly distributed piles of FHR are piles that are dispersed in no set pattern across the site. Systematically distributed residue piles are piles that are not dispersed across the site but are clustered for example near roadsides. The guidance in this publication is for harvest sites with randomly distributed residue piles. If a harvest area can be characterized as a site with systematically distributed residue piles, consider surveying all piles on the site. Failure to distinguish between sites with randomly or systematically distributed residue piles could result in biased estimation of forest harvesting residue for a given site.

5. Survey the area surrounding the sampling point for residue piles. If the center of a residue pile falls within 24 feet of the sampling point, as marked by the pin flag, use the following protocol:

   a) Estimate the proportion of each pile that falls within 24 feet of the sampling point. The proportion is between 0 and 1 and is recorded as a decimal to the nearest tenth (0.1, 0.2, 0.3, etc.). Record this on a data sheet under the column labeled “MP.”

   b) Next, estimate the packing density of each pile that falls within 24 feet of the sampling point. The proportion is between 0 and 1 and is recorded as a decimal to the nearest tenth (0.1, 0.2, 0.3, etc.). Record this on a data sheet under the column labeled “Packing Density.”

Packing Density is a measure of how dense a pile of FHR is considering the amount of wood and airspace in the pile. Some examples of packing density for three different piles are shown in Figure 3.

Figure 3. Three examples of packing density for piled forest harvesting residue.

c) Find the shape code that best represents the residue pile (Figure 4). Based on the code selected, the required residue pile dimensions should be measured and recorded along with the shape code under the respective columns on the data sheet.

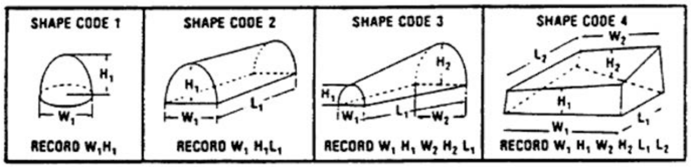

Figure 4. Shape code and measurements for harvesting residue piles (Woodall and Monleon, 2007).

d) Move to the next sampling point and repeat the sampling procedure beginning at step one.

Calculating an Average Estimate of Scattered Forest Harvesting Residue Volume

The cubic-foot volume of scattered forest harvest residues is calculated using the following equation based on the sum of measured lengths of tallied residue pieces for each plot, the prism basal area factor, and number of sample points taken.

$$\widehat{\widehat{V_S}} = \frac{\sum_{i=1}^{n} L_i}{n} \times BAF$$

Where,

n is the number of sampling points installed,

$\sum_{i=1}^{n} L_i$ is the sum of the lengths of all “in” piece of scattered forest harvesting residue and,

BAF is the basal area factor of the prism used in the inventory.

For example: Consider 89 “in” scattered forest harvest residue pieces were found on 28 sample points. The sum of measured lengths for the “in” pieces was 763 feet. For this inventory a 10 basal area factor prism was used. Given this information, the estimated average volume of scattered harvest residues is:

$$\widehat{\widehat{V_S}} = \frac{\sum_{i=1}^{n} L_i}{n} \times BAF = \frac{763}{28} \times 10 = 27.25 \times 10 = 272.5\ ft^3/acre$$

Calculating an Average Estimate of Piled Forest Harvesting Residue Volume

To estimate the average volume in cubic feet per acre of piled forest harvest residue over all plots, individual plot-level estimates must be calculated. The first step in calculating a plot-level estimate is to find the net cubic-foot volume of individual piles. Net cubic-foot volume estimates for a given residue pile can be found using the shape-code equations from Woodall and Monleon (2007) given below:

Table 3. Equations for determining net cubic-foot volume of residue piles based on shape code

Shape code	net volume equationa (cubic feet)
1	$\left(\pi HW^2/8\right)(PD)$
2	$\left(\pi HWL/4\right)(PD)$
3	$\left(\pi L\left[(H_1W_1)+\sqrt{H_1W_1H_2W_2}+(H_2W_2)\right]/12\right)(PD)$
4	$\left(\left[(L_1+L_2)(W_1+W_2)(H_1+H_2)\right]/8\right)(PD)$

[a] H,W, L refer to pile dimensions (in feet) according to shape code and PD is packing density

Once the volume of individual piles has been calculated, estimate the volume per acre for each sample point using the equation below:

$$\widehat{\widehat{V_p}} = \frac{\sum_{i=1}^{n}\left(v_{p_i} \times \delta_i\right)}{n} \times 24$$

Where,

n is the number sampling plots installed,

v_{p_i} is the net cubic foot volume of the ith sampled residue pile and,

δ_i is the proportion of the ith sampled residue pile falling within the plot.

For example: Consider you sampled 2 piles on 2 plots over a total of 28 sample plots. The shape of both piles best matches shape code 2, so you measured height, length, and width of each pile. Pile one measured 7.5 feet in height, 10 feet in length, and 5 feet in width. Pile two measured 3 feet in height, 10 feet in length, and 4 feet in width. The packing density for piles one and two is estimated at 60% and 45%, respectively. Approximately 75% of both piles fell within the sampling plot.

With this information, the estimated net volume of each pile is,

$$v_{p_1} = ((\pi HWL)/4) \cdot PD = ((\pi \cdot 7.5 \cdot 5 \cdot 10)/4) \cdot 0.6 = 176.71 \, {}^{ft^3}/_{acre}$$

$$v_{p_2} = ((\pi HWL)/4) \cdot PD = ((\pi \cdot 3 \cdot 4 \cdot 10)/4) \cdot 0.45 = 42.41 \, {}^{ft^3}/_{acre}$$

The estimated average volume of piled forest harvest residue over all plots is,

$$\hat{\bar{V}}_p = \frac{\sum_{i=1}^{n} \left(v_{p_i} \times \delta_i\right)}{n} \times 24 = \frac{[(176.71 \cdot 0.75) + (42.41 \cdot 0.75)]}{28} \times 24 \; = 140.86 \, {}^{ft^3}/_{acre}$$

CONCLUSION

Any inventory of scattered and piled forest harvesting residue requires planning and considerable effort. A combination of prism sweep sampling and modified slash pile sampling is one way to minimize effort while obtaining relatively accurate volume estimates. Knowing how much forest harvesting residue is being retained on a given site is an important first step that landowners, natural-resource professionals, and others must take towards ensuring sustainable forest management.

Acknowledgements

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SOME DATA SHEETS TO GET YOUR INVENTORY STARTED

Scattered Forest Harvest Residue Tally Sheet

Data Collector ____________________ Location __________________________ Date ________ Page _______

Sampling Point	FHR Length (feet)	Sampling Point	FHR Length (feet)	Sampling Point	FHR Length (feet)

Piled Forest Harvest Residue Tally Sheet

Data Collector ____________________ Location ___________________________ Date ________ Page _______

Sampling Plot	**H1** (feet)	**H2** (feet)	**W1** (feet)	**W2** (feet)	**L1** (feet)	**L2** (feet)	**MP** (0-1)	**Shape Code** (1-4)	**Packing Density** (0-1)