LOGGING UTILIZATION RESEARCH IN THE PACIFIC NORTHWEST: RESIDUE PREDICTION AND UNIQUE RESEARCH CHALLENGES

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Abstract—Logging utilization research results have informed land managers of changes in utilization of forest growing stock for more than 40 years. The logging utilization residue ratio- growing stock residue volume/mill delivered volume- can be applied to historic or projected timber harvest volumes to predict woody residue volumes at varied spatial scales. Researchers at the University of Montana's Bureau of Business and Economic Research and USFS Southern Research Station are investigating variability in residue ratios across Montana, Idaho, Oregon, and Washington. This project has presented unique sample design challenges. The primary sampling unit is the logging site where trees are felled and removed from the forest. However, it is not possible to know in advance the total population of logging sites and it is therefore impossible to identify the sampling frame and conduct probabilistic design-based sampling. To meet this challenge, the authors designed a model-based sampling protocol that is yielding regional predictions of the residue ratio.

INTRODUCTION

The U.S.D.A. Forest Service's Forest Inventory and Analysis (FIA) Program provides information on the condition and changes in the timber resource throughout the western United States. The components of forest inventory change (i.e., growth, mortality, and removals) are captured by the FIA plot network. However, only through timber product output (TPO) mill surveys and logging utilization studies can removals for timber products be quantified and distinguished from inventory removals that are left in the forest or at the landing as logging residue (i.e., material that is cut or killed during commercial harvest but not utilized). TPO logging utilization studies are an effective and relatively simple way to make estimates of logging residue whether for potential biomass supply or as a component of removals.

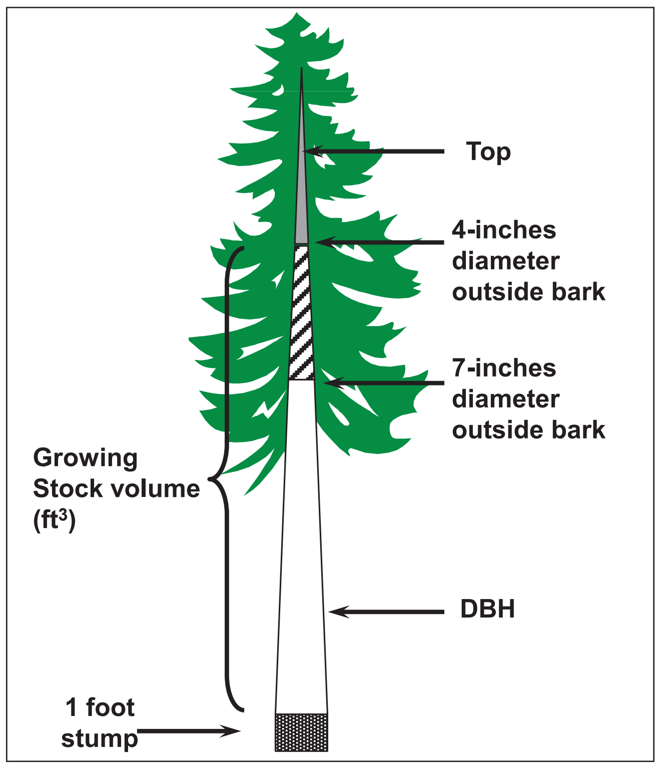

Figure 1—Individual tree growing stock. Growing stock includes live tree sections from the one-foot stump to the 4 inch outside bark top diameter.

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[2] Live trees ≥ 5 inches diameter breast height [d.b.h.]; 4.5 feet above ground on the uphill side, measured from a 1-foot stump height to a 4 inch diameter top outside bark [dob].

Logging utilization studies provide estimates of tree bole residue volumes without the need for detailed tree-level inventories (Morgan and Spoelma 2008). Study results include calculation of the growing-stock[1] (Fig. 1) residue ratio -- growing-stock logging residue volume divided by mill-delivered timber volume. The residue ratio can be used to quickly estimate growing-stock residue volumes by applying timber harvest volumes at stand, landscape, or state-levels (Morgan and Spoelma 2008). Bole, branch, and foliar biomass (i.e., non-growing stock portions of logging residue) can then be estimated with allometric equations. The residue ratio is used in the calculation of logging residue volumes published in the Timber Products Output (RPA-TPO) database (USDA FS 2015).

To answer land manager needs for updated information on logging residue production the authors investigated logging utilization in Montana, Idaho, Washington, and Oregon from 2008 through 2013. The study objective was to calculate the growing-stock logging residue factor as the ratio of means (Zarnoch et al. 2004) for the 4-state project area. Ratio values could be used to update county-level residue information in the RPA-TPO database.

METHODS

The authors sought a sample protocol that would provide data needed to estimate the growing stock residue ratio for major Pacific Northwest regions. Because lists of all active logging sites (the primary sampling unit) did not exist researchers could not identify the sampling frame and compute regional values of the residue ratio with probabilistic design-based sampling (Lohr 2009). Model-based sampling offered alternative means of obtaining parameter estimates in lieu of design-based sampling and was used in the current study (Chambers and Clark 2012). The authors also compared design (without the use of a comprehensive list of logging sites) and model-based sampling outcomes.

Sterba (2009) outlined the need to stratify the population and adjust for disproportionate sample selection when conducting model-based sampling. These provisions were accounted for in the current study:

1. Stratification. The project area was stratified into 4 regions.
   a. Inland Empire. Northeastern Washington, northern Idaho, and western Montana.
   b. Blue Mountains. South-central Idaho, eastern Oregon, and southeastern Washington.
   c. Western Washington (west of the Cascade crest).
   d. Western Oregon (west of the Cascade crest).
2. Disproportionate sample selection. The authors corrected for over and under-sampling within strata by weighting the sample.

Stratified sampling, specifically sites stratified by region, was adopted as the sampling protocol**.** Numbers of sample logging sites per region were selected proportional to the 5-year timber harvest volume of each region (Table 1) (BBER 2015).

Table 1—Number of logging sites and trees sampled; 5 year timber harvest volume by region (BBER 2015); and sample weighting factors by region.

Region	Number of logging sites sampled	Number of trees sampled	5 year timber harvest volume -Scribner board foot	Weighting factors
Blue Mountains	7	173	2,855,205	0.087
Inland Empire	53	1324	6,400,383	0.194
Western Oregon	21	519	12,638,795	0.384
Western Washington	20	486	11,060,569	0.336
TOTAL	101	2502	32,954,952	

Researchers asked timberland managers to identify logging sites where live (i.e., growing-stock) trees were being harvested for commercial products and field crews could safely measure felled trees. Sample sites were selected without regard for logging systems employed, topography, tree species, or other attributes. Twenty to 32 live felled sample trees were measured at each of 101 logging sites. Field crews selected felled trees with a systematic sampling grid using randomized starting points. Species was recorded, outside bark diameter and section length measurements were taken at the cut stump height, at one foot above ground level (uphill side of the tree), at DBH, at the 4.0-inch diameter outside bark (DOB) point, and at the end-of-utilization. Each tree had diameter outside bark and section length measurements taken along the bole at intervals corresponding to the appropriate log lengths with a maximum section length of 16 feet. The percent cubic cull for each section was recorded and each bole section was identified as utilized (delivered to the mill) or unutilized (logging residue). Individual tree section cubic foot volumes were calculated using Smalian's formula and section volumes were summed for each tree by category (e.g., utilized vs. unutilized stump, bole, and upper stem sections of the trees); the residue ratio was calculated for each site as the sum of all growing stock residue cubic foot volume divided by total mill-delivered cubic foot volume for that site.

Design-based residue ratios of means and standard errors were computed using SAS PROC SURVEYMEANS (SAS 2013) (Table 2). Sample weights were derived from the five-year timber harvest volumes (Table 1). Ratios of means were also computed with SAS PROC GENMOD (SAS 2013) in a multilevel linear mixed model incorporating sample weights. Logging sites were nested within regions.

Because sample logging sites were not chosen at random from a comprehensive list of sites for design-based computations, a true "head to head" comparison of sampling methods was not possible. The authors created a simulated residue ratio of means population (1,000 replications using a mixed binomial and exponential distribution) to analyze potential bias created by not randomly selecting sample logging sites from a comprehensive list. Samples of 100 sites were repeatedly drawn from this simulated pseudo-population and analyzed with PROC SURVEYMEANS and GENMOD.

RESULTS

Residue ratios of means and standard errors were essentially identical for SURVEYMEANS and GENMOD using either simulated or real data. Bias (the project as a whole "true" simulated parameter estimate minus the "real" data parameter estimate) was less than 0.5 percent for both methods. The real data residue ratio distribution was skewed to the right with many observations less than 0.010 (Fig. 2). The project as a whole residue ratio of means equaled 0.027 or 27 cubic feet of growing stock residue per 1,000 cubic feet of mill-delivered volume (Table 2). Residue ratios of means varied little across regions with Blue Mountain (ratio = 0.032) and western Oregon (ratio = 0.030) sites exhibiting slightly higher values (Table 2).

Table 2—Design-based and model-based ratios of means and standard errors by region.

Region	Design-based F3 ratio of means	Design-based F3 ratio of means standard error	Model-based F3 ratio of means	Model-based F3 ratio of means standard error
Blue Mountains	0.032	0.005	0.032	0.004
Inland Empire	0.024	0.003	0.025	0.003
Western Oregon	0.029	0.005	0.030	0.005
Western Washington	0.029	0.003	0.027	0.004
Total project area	0.029	0.003	0.027	0.002

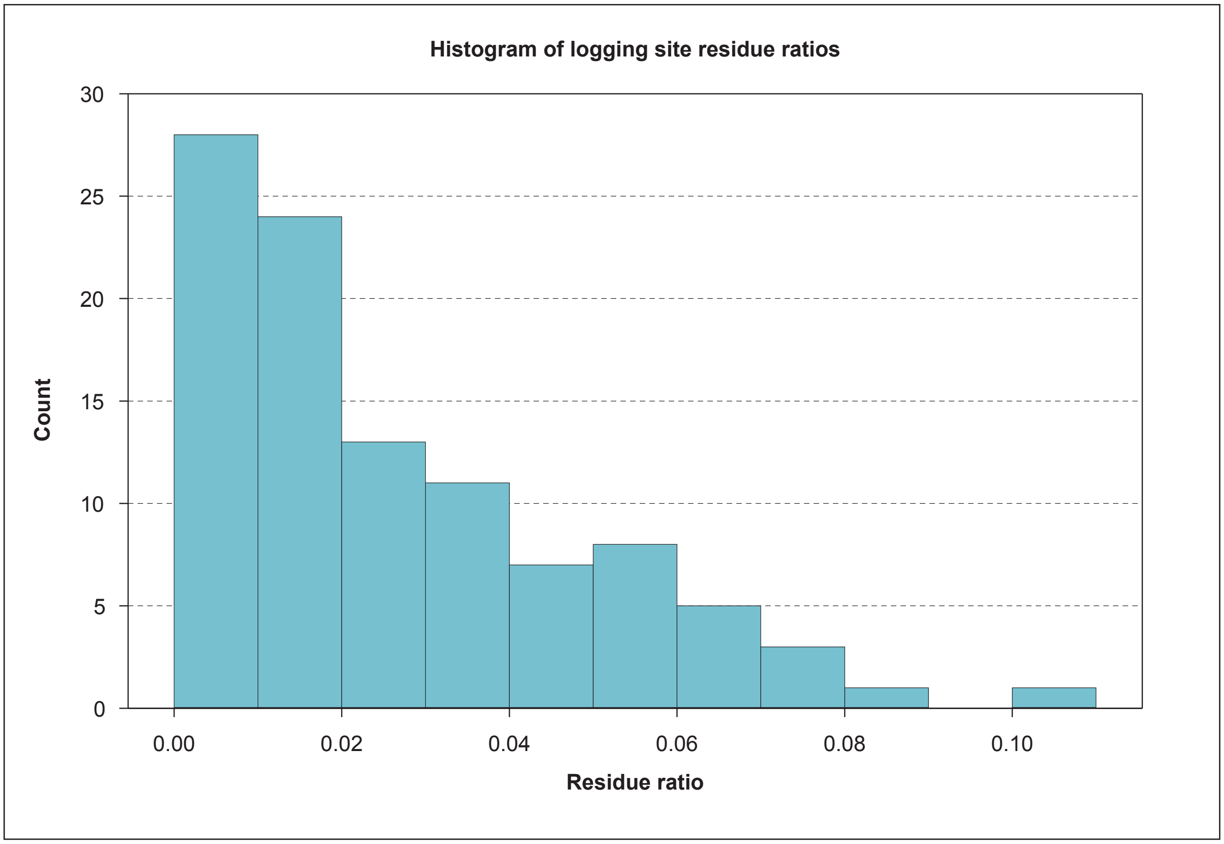

Figure 2—Histogram of logging site residue ratios (growing stock residue cubic foot volume/mill delivered cubic foot volume).

DISCUSSION AND CONCLUSIONS

Study findings concurred with other contemporary logging utilization research results: the residue ratio is now less than 4 percent of mill delivered volume. For example, Simmons et al. (2014) found that Idaho state (represented by the Inland Empire and Blue Mountain regions) ratio declined from 0.123 in 1965 to 0.024 in 2011. Because no similar Oregon or Washington pre-yarding (felled-trees measured before logs were yarded to a landing) studies were found, direct comparisons of this study's results to previous research in those states were not possible.

The lack of variability in residue ratios among Pacific Northwest regions (Table 2) was surprising. This finding likely stemmed from loggers employing similar utilization standards and harvesting systems within most logging sites regardless of location. Also, felled trees sampled in this study were consistently second or third growth timber with little defect.

Design and model-based sampling differ in statistical underpinnings and mathematical computation. However, design and model-based residue ratios and standard errors were found to be essentially identical. The authors suggest that researchers of future logging utilization studies could judiciously use either method to obtain estimates of the residue ratio. But statisticians disagree on the validity of model-based sampling (Lohr 2009). Having comprehensive lists of logging sites is clearly desirable, and if they are available scientists should use them in design-based sampling.

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