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# Logging Utilization in Montana, 2011–2016

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## Abstract

A study of commercial timber-harvesting activities in Montana was conducted during 2011 to 2016 to estimate growing-stock removals, characterize current tree utilization and logging operations, and assist with estimating the amount of woody biomass left onsite after harvesting. Sample logging sites were selected within major geographic regions proportional to 5-year timber harvest volumes. A two-stage sampling method was used to compute State-level logging utilization factors. Results of the study indicated that in Montana, for every 1,000 cubic feet (CF) delivered to the mill, harvesting removed 1,009 CF of timber volume from growing stock, created 30 CF of growing-stock logging residue, and sent 21 CF of non-growing-stock material to the mill. Logging site-level growing-stock logging residue production was predicted to decrease 65 percent when pulp products were harvested. Study results can inform land managers of residues available for biomass/bioenergy uses, provide data for life cycle analyses, and estimate removals from growing stock.

***Keywords:*** forest inventory, growing-stock removals, logging residue, removals factors, timber harvest

***Cover photo:*** E.A. Simmons, University of Montana, Bureau of Business and Economic Research.

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# Contents

# Introduction

Montana forest managers desire current information on the characteristics and effects of timber harvesting on forest inventory. They may wish to know how much woody material remains in the forest after commercial logging operations to understand fuel loads or to predict potential feedstock for woody biomass energy. Likewise, the characteristics of harvested trees (e.g., d.b.h.,[a] total tree height, or species mix) and harvesting methods (e.g., mechanical vs. hand-felling, merchandising at the stump vs. at the landing, or cable vs. ground-based yarding) may be of interest for planning purposes. The information developed from logging utilization studies can meet these needs by characterizing felled-tree attributes and logging methods and quantifying the volumes of tree sections left after harvest as logging residue.

Logging utilization studies identify material removed from forest inventory during commercial timber harvest activities and provide data used to compute logging utilization factors. These factors quantify the growing-stock[b] volume (fig. 1) removed from inventory and distinguish it as either timber products (e.g., sawlogs or pulpwood) delivered to mills, or as logging residue, which is left in the forest or at the landing (Morgan and Spoelma 2008). These logging utilization factors are

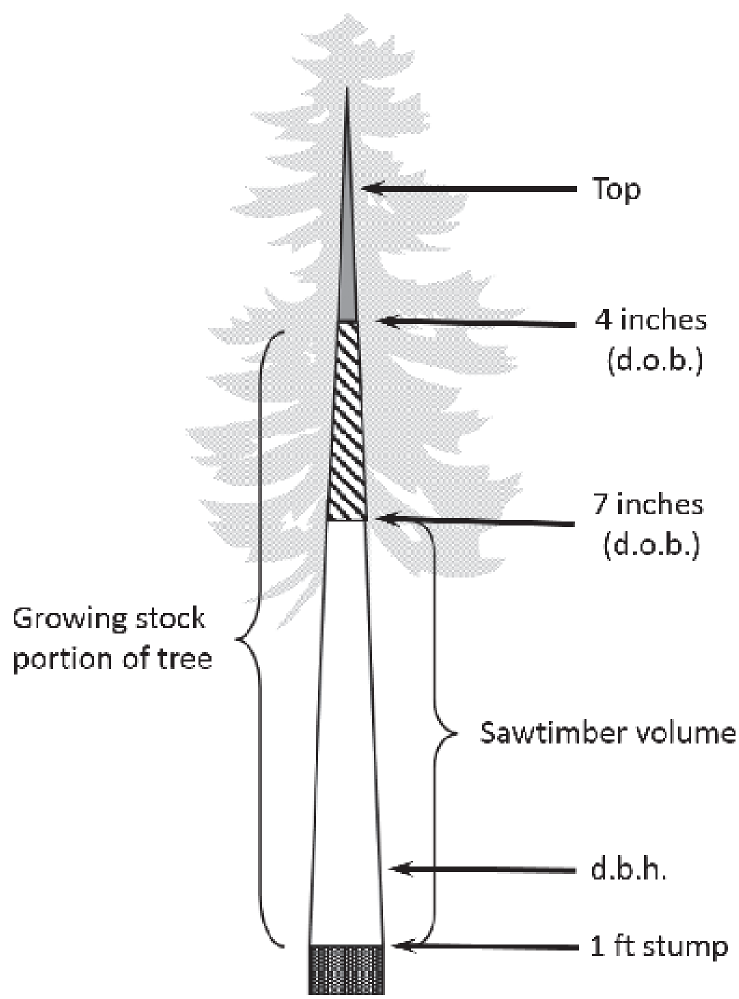


**Figure 1—**Growing stock sections of softwood trees.

used in the calculation of logging residue volumes in the Timber Products Output (TPO) database (https://www.fs.usda.gov/srsfia/php/tpo_2009/tpo_rpa_int1.php) maintained by the USDA Forest Service's Forest Inventory and Analysis (FIA) program. The factors can be applied to projected levels of timber harvest at regional or State-level spatial scales to provide estimates of growing-stock removals from forest inventory. Logging utilization studies also characterize timber harvest activities and equipment, and they can provide estimates of the distributions of trees and volume harvested by species, size, and logging method. Data from these studies can also be used to develop taper equations and better quantify characteristics of harvested trees, including stump heights and diameters, as well as lengths and small end diameters of utilized logs.

When conducted in a consistent manner, these studies provide substantial information about changes in timber harvesting practices and logging residue through time and among States or regions. Recent logging utilization studies provided updated residue and harvesting information for Idaho (Simmons et al. 2014) and Oregon and Washington (Simmons et al. 2016). However, the most recent Montana study is now more than 10 years old (Morgan et al. 2005). Older studies for nearby Oregon and Washington (e.g., Howard 1973, 1981a,b) described and quantified slash or logging residue per thousand board feet harvested; however, these studies did not directly associate the residue volume to harvest volumes and FIA inventory parameters (e.g., growing-stock vs. non-growing stock[c] sources). The current study, and others like it (Bentley and Johnson 2004; Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014, 2016), make those direct connections among timber harvested for products, the associated logging residue, and the impacts on growing-stock inventory.

To update timber harvesting and logging residue information, a study of logging sites across Montana was conducted from 2011 through 2016. This study was designed to both quantify the creation of growing-stock logging residue from commercial timber harvesting at the State level and characterize harvested trees and harvesting activities within Montana. The specific objectives were to:

- characterize Montana timber harvest by landowner, geographic region, tree species, and diameter at breast height (d.b.h.);
- characterize timber harvest operations by felling, yarding, and merchandising methods; and
- compute current logging utilization factors to express:
- estimate volumes of growing-stock logging residue generated per 1,000 cubic feet (CF) of mill-delivered volume, and
- estimate proportions of mill-delivered volume coming from growing-stock vs. non-growing stock portions of harvested trees and total removals (i.e., timber product and logging residue) from growing stock.

# Methods

## Recent Montana Timber Harvests

There are over 19.8 million acres of non-reserved timberland[d] potentially available for timber harvest activities in Montana (Menlove et al. 2012; table 1). Timber resources and harvesting activities are concentrated west of the Continental Divide. Wood-product markets and forest policy issues have influenced the geographic and ownership sources of harvested timber as well as annual harvest volumes (McIver et al. 2013).

Recent annual timber harvest volumes in Montana have ranged from late 1980s highs of more than 1.3 billion board feet Scribner to less than 400 million board feet from 2009 through 2015 (Hayes and Morgan 2016). Most of Montana's timber has been harvested from private (industrial and nonindustrial) lands since the late 1970s, and there was a major decline in Federal harvest starting in the 1990s (fig. 2). With the collapse of U.S. housing starts and markets for lumber, there was a marked decline in private harvest after 2007. Since then, proportions of harvest among ownerships have varied substantially, with 14 to 30 percent coming from National Forests and 45 to 71 percent coming from private and tribal sources. Other sources, largely State and Bureau of Land Management, provided 16 to 26 percent of annual totals.

## Sample Design

The target population for this study was active logging sites in Montana where green (live) trees were being commercially harvested for conversion into wood products, primarily for lumber and veneer/plywood. Because of the need to measure harvesting impacts on growing-stock volume, only green-tree sites were targeted. Salvage sales, with many or most trees dead prior to harvest, were not included. Historically, 70 to 97 percent of Montana's annual timber harvest volume has been used for lumber and veneer/plywood production (Hayes and Morgan 2016; McIver et al. 2013). Other timber products (e.g., pulpwood, posts, and fuelwood) are commonly merchandised with sawlogs. Thus, sites were identified

**Table 1**—Montana timberland[a] by ownership class.

| Ownership class | Acres (thousands) | Percent of non-reserved timberland[a] |
|---|---|---|
| National Forest | 12,136 | 61.4 |
| Undifferentiated private | 5,849 | 29.6 |
| State | 919 | 4.6 |
| Bureau of Land Management | 841 | 4.3 |
| Other public | 22 | 0.1 |
| All owners | 19,767 | 100 |

[a]Timberland is forest land that is producing or capable of producing more than 20 cubic feet of wood per acre per year at culmination of mean annual increment and excludes reserved lands.

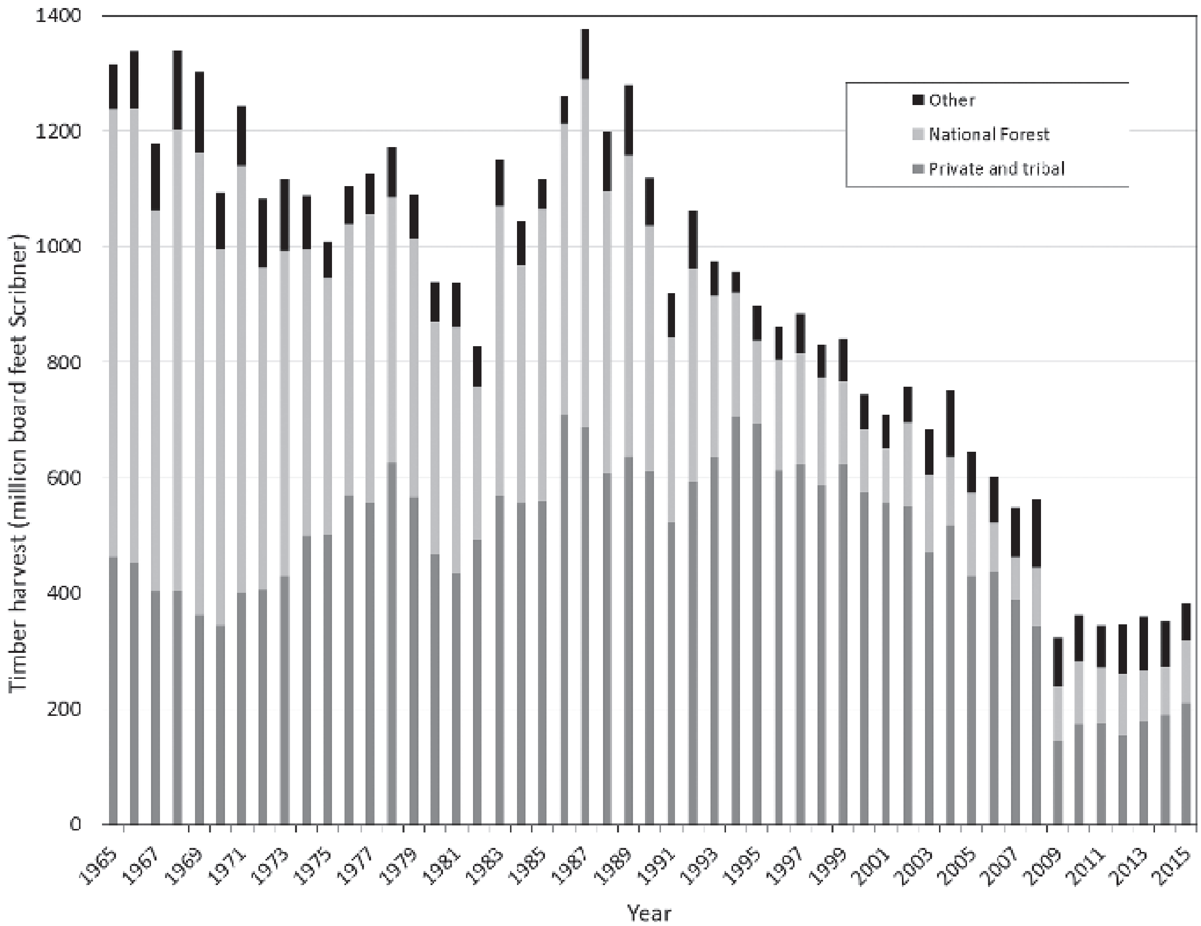


**Figure 2—**State of Montana timber harvest volume, 1965–2015 (source: Hayes and Morgan 2016).

where sawlogs and veneer logs were the primary products to be harvested, as these would account for the vast majority of annual harvest volume while also capturing some volume harvested for other products.

The authors sought a sample of felled trees within logging sites (the primary sampling unit) that would provide data to estimate logging utilization factors expressed as the ratios of means at the Montana State level (Zarnoch et al. 2004). Ideally, the sampling protocol should yield ratios and attendant standard errors computed in the same manner as other logging utilization investigations to ensure comparability of results. Most State-level logging utilization investigations have reported factors and standard errors using design-based methods without selecting sample sites at random from a list of all active logging sites, i.e., the sampling frame (McClain 1992; Morgan and Spoelma 2008; Simmons et al. 2014, 2016). As Morgan and Spoelma (2008) described, it is not possible to know in advance the full population of logging sites in a State for a given year and simply draw a sample of those sites to measure. But without a sampling frame to draw samples at random, design-based sampling could bias parameter estimates and compromise any ability to make population inferences (Lohr 2009). Berg et al. (2015) analyzed the potential bias in design-based sampling without the use of a sampling frame and found that the computed design-based residue factors exhibited less than 0.5 percent bias. In the current study, as in other investigations, the authors could not obtain a list of all active sites; sample logging sites were not selected at random.

A two-stage sampling protocol was then used to select logging sites and trees within sites for measurement (Levy and Lemeshow 1999). The number of logging sites in an area (e.g., county or multi-county region) was assumed to be proportional to harvest volume. Sample sites were thus selected proportional to 5-year timber harvest volumes. Logging sites with active harvesting of green trees for commercial products served as the stage 1 sampling units. Annual timber harvest summaries (BBER 2016) provided the geographic location (i.e., county) and ownerships of potential sample logging sites (fig. 3). Timberland owners and sawmills were contacted periodically throughout the study to identify when and where logging activities would be occurring and to request access to logging sites to conduct measurements.

The stage 2 sampling units consisted of felled trees at each selected logging site. To qualify as a potential measurement tree, it had to be growing stock (live prior to harvest, with a d.b.h. greater than or equal to 5.0 inches, and meeting minimum merchantability standards), and the entire stem, including the stump and top, had to be measurable (Morgan and Spoelma 2008; Woudenberg et al. 2010).

Sample sizes for stage 1 and 2 sample units were guided by standard errors achieved in previous utilization studies. Zarnoch et al. (2004) found that standard errors for utilization ratios dropped substantially by increasing the number of measured logging sites from 10 to 20. Previous logging utilization studies in Montana,

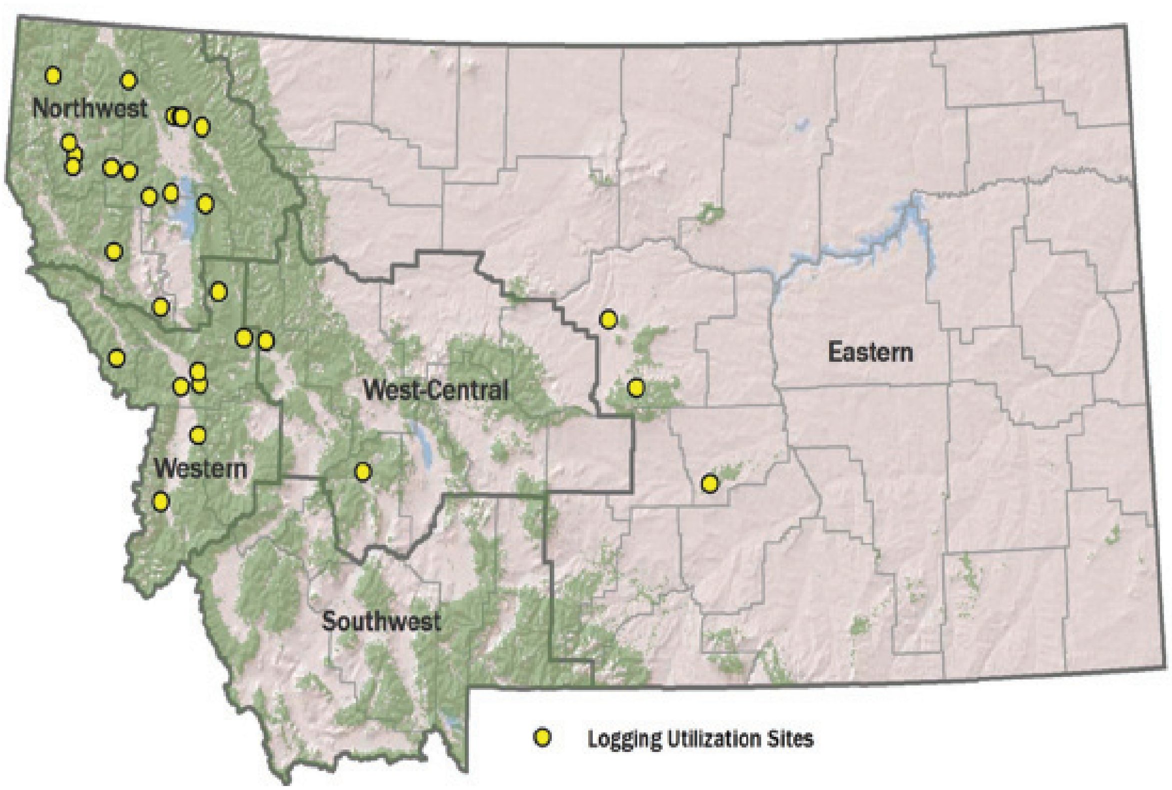


**Figure 3—**Sampled logging sites, 2011–2016.

Idaho, and California achieved low standard errors by measuring 25 to 35 trees on each of 30 to 35 logging sites (Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014, 2016). Further, logging utilization studies conducted by the USDA Forest Service Southern Research Station (Bentley and Johnson 2004; Zarnoch et al. 2004) suggested that a sample of 30 to 50 logging sites with 20 to 35 felled trees measured at each logging site would be sufficient to determine State-level utilization factors. Based on these guidelines, the authors decided to sample 20 to 30 felled trees located within each of 30 to 35 active logging sites throughout the State of Montana.

## Data Collection

Logging contractors or foresters at each selected logging site were contacted 3 to 5 days prior to site visits to confirm access and outline protocols to ensure field crew safety. At each logging site they provided information on tree species, products merchandised, and preferred and acceptable log lengths delivered to receiving mill(s). Field crews recorded this information along with the date, county, land ownership class, felling method, yarding/skidding method, log merchandising location and method, logging contractor name, equipment in use, and receiving mill(s).

Field crews selected felled trees meeting the specified requirements at random. Individual trees or tree piles accumulated for skidding were scattered throughout the logging site, depending on the operation and equipment used. A unique identification number was assigned to each measurement tree, and species, d.b.h., and primary product (sawlog, veneer log, etc.) information were recorded. Diameter and section length measurements were taken at: the cut stump, 1 foot above ground level (uphill side of the tree), d.b.h., the end of the first 16-foot log, the 7.0-inch diameter outside bark (d.o.b.), the 4.0-inch d.o.b. point (end of growing stock), the end-of-utilization, and the tip of the tree. Each tree had diameter (in 0.1-inch increments) and section length (in 0.1-foot increments) measurements recorded with a maximum section length of 16 feet. Thus, for each bole section, lower and upper d.o.b. and length were recorded. The percent cubic cull for each bole section was also recorded and each section was identified as utilized (delivered to the mill) or unutilized (logging residue). When evident, the timber product type for each utilized section was also recorded. A minimum of 20 felled live trees were measured at each of 30 logging sites from 2011 to 2016 (most frequently 25 trees per site). These 30 active sites were spread across Montana, and a total of 757 felled trees were measured.

## Data Analysis

Following the methods of Morgan and Spoelma (2008) and Simmons et al. (2014, 2016), cubic volumes for individual tree sections were calculated using Smalian's formula (Avery and Burkhart 1994). Section volumes were summed for each tree by category (e.g., utilized vs. unutilized stump, bole, and upper stem sections of the trees), and utilization factors were calculated for each tree and site. Logging utilization factors, standard errors, and 95-percent confidence intervals (CIs) were computed at the Montana State level based on the two-stage sampling design using the ratios of means estimator (Zarnoch et al. 2004) obtained from SAS PROC SURVEYMEANS (SAS 2013). Residue factors were also calculated for individual species, species groups, and for each tree d.b.h. class. Characteristics of the felled trees, harvest operations, and utilization factors were then summarized and compared with historical Montana logging utilization studies and with recent studies from other western States.

# Results and Discussion

## Characteristics of Logging Sites and Operations

Because most commercial logging occurs west of the Continental Divide, most of the sample sites were located in these regions. Limited availability of logging sites in west-central and southwestern Montana (fig. 3) resulted in fewer sites being measured relative to average harvest volumes in those regions (table 2). Likewise, the proportion of Federal (Forest Service and Bureau of Land Management) sampled sites was somewhat lower than the proportion of Federal harvest from 2011–2015 (table 3). Because ownership and geographic region were

**Table 2**—Montana percent of 5-year average timber harvest and percent and number of sample sites by region.

| Region | Percent of harvest[a] (2006–2010) | Percent of harvest[a] (2011–2015) | Percent of sample | Number of sites |
|---|---|---|---|---|
| Northwest | 50 | 55 | 53 | 16 |
| Western | 20 | 16 | 27 | 8 |
| West-central | 14 | 14 | 10 | 3 |
| Eastern | 11 | 9 | 10 | 3 |
| Southwest | 5 | 7 | 0 | 0 |
| Total | 100 | 100 | 100 | 30 |

[a]Five-year mean timber harvest Scribner volume; source: BBER 2016.

**Table 3**—Montana percent of 5-year average harvest and sample sites by ownership.

| Ownership | Percent of harvest[a] (2006–2010) | Percent of harvest[a] (2011–2015) | Percent of sites | Number of sites |
|---|---|---|---|---|
| Industry | 33 | 26 | 33 | 10 |
| NIPF and tribal | 31 | 23 | 20 | 6 |
| Federal and other public | 26 | 37 | 23 | 7 |
| State | 10 | 14 | 23 | 7 |
| Total | 100 | 100 | 100 | 30 |

[a]Five-year mean timber harvest Scribner volume (source: BBER 2016).

shown to be weakly related to the residue factor in a recent Pacific Northwest logging utilization study (Berg et al. 2016), under or oversampling by ownership and region should not bias the current study's calculated utilization factors.

Harvesting methods included hand or mechanical felling and merchandising, as well as sites with a mix of the two (table 4). Mechanical felling machines were typically equipped with circular "hot saws" and accumulating heads that enabled them to both fell and bunch trees for yarding. Hand-felling and merchandising were done with chainsaws. Yarding operations were accomplished with cable- or ground-based systems depending on topography or prescription. Cable logging was typically conducted with two-drum skyline yarders equipped with gravity-fed carriages. Ground-based yarding was mostly accomplished with rubber-tired skidders (rarely with bulldozers) equipped with either a grapple or a winch with chokers. Trees were skidded both tree- and log-length. Mechanical merchandising methods included the use of stroke (slide-boom) de-limbers and dangle-head processors.

Timber was hand-felled on 37 percent of all sampled sites. Cable yarding was used on 17 percent of the sites. Timber was skidded log length on only four of the 30 sites; tree-length skidding predominated. Timber was frequently mechanically felled and bunched in piles and skidded with rubber-tired skidders. Timber was processed or merchandised at landings on all but five of the 30 sites in this study.

## Characteristics of Felled Trees

Sampled trees ranged 5.0 to 29.0 inches d.b.h. with a median d.b.h. of 10.8 inches. About one-half of the measured trees were greater than 11.0 inches d.b.h., but they accounted for only 21 percent of the utilized volume and 31 percent of the growing-stock logging residue (table 5). Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.), and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) were the three most frequently sampled and harvested tree species (table 6). They accounted for 74 percent of the mill-delivered volume from Montana sites in this study and 78 percent of the 2014 harvest as reported by Hayes and Morgan (2016). The percentage of lodgepole pine volume (6.2 percent) sampled was markedly less than reported harvested (16.0 percent) in 2014 (Hayes and Morgan 2016). This difference was largely due to the sample including only green-tree sites, whereas recent lodgepole pine harvest in Montana has included salvage logging after bark beetle mortality. Ponderosa pine exhibited the highest residue factor of any species (3.9 percent). The residue factor for the pooled group of "other" softwoods—western redcedar (*Thuja plicata* Donn ex D. Don), western white pine (*Pinus monticola* Dougl. ex D. Don), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)—was only 1.5 percent, the least of any species.

**Table 4**—Number of sampled sites by logging methods and ownership class.

| | Felling | | | Yarding | | Skidding | | Merch location | | Merch method | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ownership | Hand[a] | Mechanical | Mixed | Ground | Cable | Tree length | Log length | In unit | At landing | Hand[a] | Mechanical |
| | *Number of sites* | | | | | | | | | | |
| Federal and other public | 3 | 4 | | 4 | 3 | 7 | | | 7 | | 7 |
| State | 3 | 3 | 1 | 7 | | 4 | 3 | 3 | 4 | 1 | 6 |
| NIPF and tribal | 2 | 4 | | 6 | | 5 | 1 | 2 | 4 | 2 | 4 |
| Industrial Private | 3 | 7 | | 8 | 2 | 10 | | 10 | | | 10 |
| Total | 11 | 18 | 1 | 25 | 5 | 26 | 4 | 5 | 25 | 3 | 27 |

[a] With chainsaws.

**Table 5**—Montana distribution of trees, mill-delivered volume, and growing-stock logging residue volume, cubic feet (CF) basis, by d.b.h. class; 757 trees nested within 30 sites.[a]

| d.b.h. class (inches) | Number of trees | Percent of sample trees | Cumulative percent | Percent of mill delivered CF volume | Cumulative percent of mill delivered CF volume | Percent of growing-stock logging residue CF volume | Cumulative percent of growing stock logging residue CF volume |
|---|---|---|---|---|---|---|---|
| 6 | 48 | 6.3 | 6.3 | 1.2 | 1.2 | 2.9 | 2.9 |
| 8 | 187 | 24.7 | 31.0 | 8.1 | 9.3 | 13.2 | 16.1 |
| 10 | 153 | 20.2 | 51.3 | 11.6 | 20.9 | 14.9 | 31.0 |
| 12 | 114 | 15.1 | 66.3 | 12.3 | 33.2 | 14.1 | 45.1 |
| 14 | 95 | 12.5 | 78.9 | 15.1 | 48.3 | 18.6 | 63.6 |
| 16 | 64 | 8.5 | 87.3 | 14.1 | 62.4 | 14.4 | 78.1 |
| 18 | 42 | 5.5 | 92.9 | 12.0 | 74.4 | 9.3 | 87.4 |
| 20 | 31 | 4.1 | 97.0 | 13.1 | 87.6 | 6.9 | 94.3 |
| 22 | 15 | 2.0 | 98.9 | 7.0 | 94.5 | 3.5 | 97.8 |
| 24 + | 8 | 1.1 | 100.0 | 5.5 | 100.0 | 2.2 | 100.0 |

[a]Percentages may not sum to 100 due to rounding.

**Table 6**—Number of sampled trees, percent of Montana 2014 Statewide timber harvest volume, percent of sampled tree mill delivered volume, percent of total logging residue volume, and residue per cubic foot (CF) delivered volume by species.

| Species | Number of sampled trees | Percent of 2014 Montana timber harvest volume (MBF, Scribner)[a] | Percent of sampled tree mill delivered CF volume | Percent of total logging residue CF volume | Residue as a percent of mill delivered CF volume |
|---|---|---|---|---|---|
| Douglas-fir | 324 | 41 | 48.1 | 46.4 | 2.9 |
| Ponderosa pine | 142 | 21 | 19.7 | 25.5 | 3.9 |
| Lodgepole pine | 114 | 16 | 6.2 | 7.5 | 3.6 |
| Western larch | 85 | 8 | 7.8 | 6.9 | 2.6 |
| True fir | 57 | 7 | 12.0 | 10.6 | 2.6 |
| Other softwoods | 35 | 7 | 6.2 | 3.1 | 1.5 |
| All species | 757 | 100 | 100 | 100 | 3.0 |

[a]Source: Hayes and Morgan 2016.

## Statewide Logging Utilization Factors

Logging utilization factors are Statewide ratios of removals volumes versus mill-delivered volumes (Morgan and Spoelma 2008; Simmons et al. 2016). Logging utilization factors for Montana indicated that for each 1,000 CF delivered to the mill: 21 CF of non-growing stock (stumps cut below 1-foot in height and tops utilized beyond the 4-inch d.o.b.) material was utilized, 979 CF of growing stock was utilized, 30 CF of growing stock was left in the forest or at the landing as logging residue, and commercial timber harvesting removed a total of 1,009 CF of growing-stock volume (table 7).

Most of the growing-stock logging residue came from portions of the bole that were broken during felling and stumps cut higher than 1.0 foot above ground level. Berg (2014) and Wilson et al. (1970) found that breakage accounted for more than 90 percent of individual tree growing-stock residue. Relatively little logging

**Table 7**—Montana logging utilization removals factors.

| Removals factors | Lower bound (95% CI) | Estimate(ratio of means) | Upper bound (95% CI) | Standard error | Cubic feet (CF) per 1,000 CF mill-delivered |
|---|---|---|---|---|---|
| Non-growing stock product delivered to mills (utilized non-growing stock divided by total utilized) | 0.015 | 0.021 | 0.027 | 0.003 | 21 |
| Growing-stock product delivered to mills (utilized growing stock divided by total utilized) | 0.973 | 0.979 | 0.985 | 0.003 | 979 |
| Growing-stock logging residue (unutilized growing stock divided by total utilized) | 0.020 | 0.030 | 0.040 | 0.005 | 30 |
| Removals from growing stock (utilized plus unutilized growing stock) divided by total utilized | 0.996 | 1.009 | 1.021 | 0.006 | 1,009 |

residue came from stem sections near the small end of growing-stock (i.e., the 4.0 inch d.o.b.), because there is less volume in the smaller diameter (upper) portions of the bole compared to stump sections. However, Berg et al. (2016) found that although changes in small-end utilized diameters (e.g., 4.0 inches d.o.b. vs. 6.0 inches d.o.b.) yielded small differences in residue volume, the residue factor climbed rapidly as small-end utilized diameters increased. Cull material (cull wood is not logging residue) reduced mill-delivered volumes, which therefore yielded higher residue factors.

The growing-stock residue factor dropped rapidly from the 6.0 to 8.0 inch d.b.h. classes then continued to decline slowly to the largest diameter classes (fig. 4). Overall, smaller trees tend to produce proportionally more residue per cubic foot of mill-delivered volume than larger trees (Morgan and Spoelma 2008; Simmons et al. 2014). However, unlike in Montana, sampled trees in Idaho, Oregon, and Washington all exhibited some increases in the residue factor in the largest diameter classes (Simmons et al. 2014, 2016).

The relationship of the logging-site residue factor with logging-site level variables was explored with one-way, single factor analyses computed with SAS PROC HPMIXED (SAS 2013). As in the Berg et al. (2016) Pacific Northwest four-State investigation (which included Montana), the current study's Montana residue factor was strongly related to whether or not pulp products were removed from logging sites ($P$ = 0.001). The predicted least squares mean residue factor was 0.051 (standard error = 0.007) for sites where pulp products were not removed, and 0.018 (standard error = 0.006) for sites where pulp products were removed. Harvesting pulpwood improved overall utilization and reduced the predicted growing-stock residue factor by 65 percent. Unlike findings of the four-State study, the Montana residue factor was not related to felling method (i.e., hand, mechanical, or a mix of the two methods; $P$ = 0.580). In the four-State study, felling-caused breakage

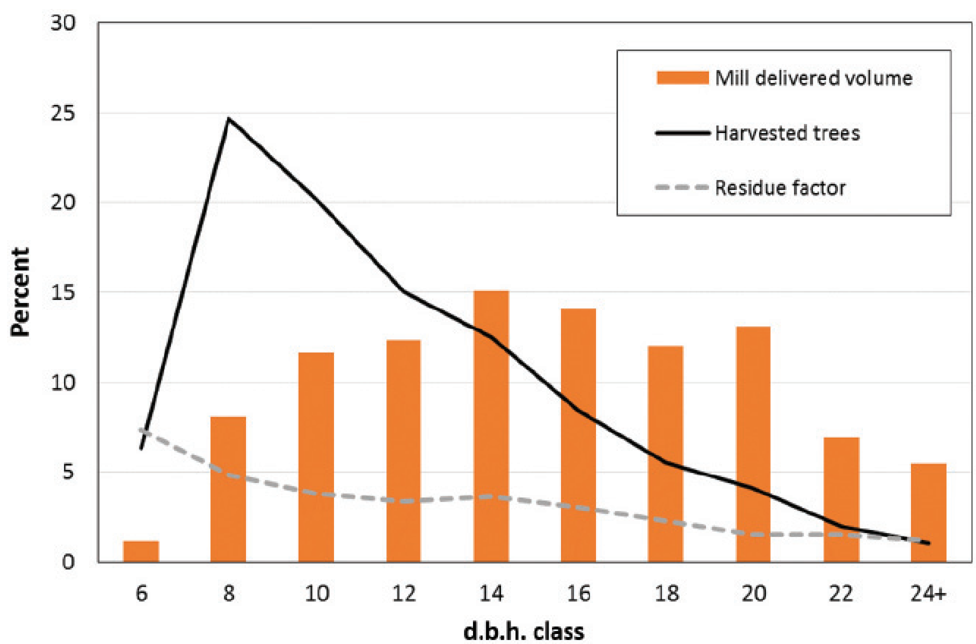


**Figure 4—**Montana State-level harvested trees, mill delivere volume, and residue factor percentages by d.b.h. class.

**Table 8**—Montana growing stock removals factors for each cubic foot of green material delivered to mills, 1965, 1988, 2002, 2011–2016.[a]

| Factor | 1965 | 1988 | 2002 | 2011–2016 |
|---|---|---|---|---|
| Non-growing stock product delivered to mills | <0.005 | <0.005 | 0.011 | 0.021 |
| Growing-stock product delivered to mills | 0.997 | 0.999 | 0.989 | 0.979 |
| Growing-stock logging residue | 0.163 | 0.122 | 0.092 | 0.030 |
| Removals from growing stock | 1.160 | 1.121 | 1.081 | 1.009 |

[a]Sources: McLain 1992; Morgan et al. 2005; Wilson et al. 1970.

spiked in several Pacific coast hand-felled and mixed-methods sites (Berg et al. 2016; Simmons et al. 2016). Field crews did not observe extensive hand or mixed-method felling-caused breakage in Montana. Residue factors were not related to the Montana geographic regions (west, northwest, west-central, eastern) where logging sites were located ($P$ = 0.259). These findings conform to those of the four-State study (Berg et al. 2016) and suggest that Montana residue factors were not related to the diversity in tree form caused by regional site quality differences.

Montana residue factors declined at an accelerating rate and the utilization of non-growing stock increased from 1965 to 2016 (McLain 1992; Morgan et al. 2005; Wilson et al. 1970; table 8). The rate of decline of the growing-stock residue factor was particularly acute from 2002 to 2011–2016, dropping more than 70 percent in less than 15 years. The reduction in Montana residue factors through time mirrors the same pattern found in Idaho. However, the rate of decline in Montana has been more rapid than in Idaho (Simmons et al. 2014). Some of the decline in Montana logging residue factors likely reflects progressive reductions in small-end utilized diameters through time; for example, the 2002 Montana mean individual tree small-end utilized diameter was 5.5 inches compared to 4.4 inches in the current 2011–2016 study. Reduced log availability, increased use of smaller diameter material, changing markets, and increased use of technology and mechanization in logging and milling infrastructure have contributed to reductions in residue factors through time (Simmons et al. 2014).

Results of this study can also be used to characterize utilization of the entire bole of the harvested tree. In Montana, 3.9 percent of the entire harvested bole volume (i.e., portions of the tree from the cut stump to the tip of the tree, excluding branches) remained in the woods as logging residue. Of this total residue, 1.0 percent was derived from non-growing stock tree tops above the 4.0 inch small end diameter. A total of 96.1 percent of the entire bole was delivered to the mill, which includes 2.0 percent non-growing stock (fig. 5). This information can benefit forest managers who do not use the FIA distinctions of growing-stock and non-growing-stock tree components.

This investigation provides land managers with practical logging residue information: the Statewide residue factor (i.e., 30 CF of growing-stock logging residue per 1,000 CF of mill-delivered volume) can be coupled with bole, top, and limb component functions (e.g., Woodall et al. 2011) to assemble comprehensive estimates of post-harvest woody biomass residues. Knowing whether or not pulp

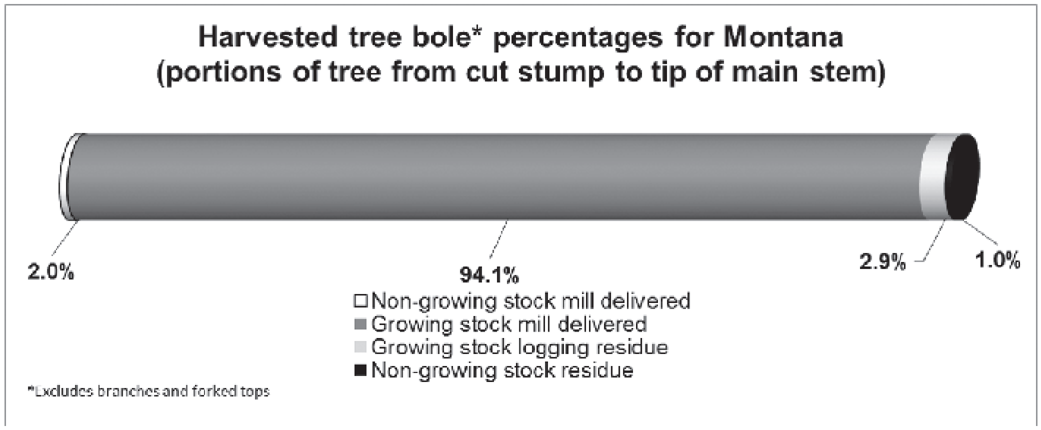


**Figure 5—**Utilization of entire tree boles.

products will be removed from planned logging sites can inform managers of probable *site-specific* residue factors.

Logging utilization study data have already been used for a wide variety of applications, including the characterization of felled-tree stump heights (Simmons et al. 2015), small-end utilized diameters (Berg 2014; Simmons et al. 2015), and the availability of logging residue as a feedstock source for bio-jet fuel (Morgan 2015). A biomass estimator tool has been proposed (Berg et al. 2014) that predicts total felled-tree woody biomass residue, including tops and limbs. Much more can be done. For example, Peltola et al. (2011) used detailed measurements of tree section diameters and lengths retrieved from a log processor to develop residue prediction equations. Log processor data could yield detailed taper functions and utilization data and serve as a test bed for comparison of processor versus traditional field sampling methods.

# Conclusions

This investigation characterized the variability in Montana logging methods and felled-tree attributes including growing-stock utilization. Study results will be used to update the RPA-TPO database, which will provide land managers with State-level information that can help them understand the impacts of commercial timber harvesting on growing-stock inventories, woody residue volumes, and biomass, carbon dynamics, and life cycle analyses.

### Endnotes

a. Diameter at breast height (d.b.h.) is the tree's diameter outside bark, measured at 4.5 feet above ground on the uphill side.

b. Growing stock is defined as all live trees of commercial species that meet minimum merchantability standards or have the potential to meet these merchantability standards. In general, these trees have at least one solid 8-foot section; they are reasonably free of form defect on the merchantable bole; and 26 percent or more of the tree's volume is merchantable.

c. Non-growing-stock sources include wood from below the 1-foot stump height and from tops above the 4-inch diameter outside bark.

d. Timberland is defined as unreserved forest land capable of producing 20 cubic feet per acre per year of wood at culmination of mean annual increment from trees classified as a timber species on forest land designated as a timber forest type.

## References


Avery, T.E.; Burkhart, H.E. 1994. Forest measurements. 4th ed. New York: McGraw-Hill. 408 p.

Bentley, J.W.; Johnson, T.G. 2004. Eastern Texas harvest and utilization study, 2003. Resour. Bull. SRS-RB-97. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 28 p.

Berg, E.C. 2014. Causes of felled-tree residue creation and characterization of stump heights and small-end utilized diameters. Analyses completed for the Northwest Advanced Renewables Alliance. Unpublished report on file with: University of Montana, Bureau of Business and Economic Research, Gallagher Business Building, 32 Campus Drive #6840, Missoula, MT 59812-6840.

Berg, E.C.; Morgan, T.A.; Simmons, E.A.; [et al.]. Logging utilization: Decision support tools for land managers. Poster presented at the Northwest Wood-based Biofuels + Co-products Conference, Seattle, WA. April 28–30, 2014. www.bber.umt.edu/pubs/forest/util/DecisionSupportToolsForLandManagers2014.pdf

Berg, E.C.; Morgan, T.A.; Simmons, E.A.; [et al.]. 2015. Logging utilization research in the Pacific Northwest: Residue prediction and unique research challenges. In: Stanton, S.M.; Christensen, G.A., comps. Pushing boundaries: New directions in inventory techniques & applications. Forest Inventory and Analysis (FIA) symposium 2015. Gen. Tech. Rep. PNW-GTR-931. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 384 p.

Berg, E.C.; Morgan, T.A.; Simmons, E.A.; [et al.]. 2016. Predicting logging residue volumes in the Pacific Northwest. Forest Science. 62(5): 564–573.

Bureau of Business and Economic Research [BBER]. 2016. Harvest and industry: Harvest by county Web tool. Missoula, MT: University of Montana. http://www.bber.umt.edu/FIR/H_Harvest.asp. (20 November 2016).

Hayes, S.W.; Morgan, T. 2016. Montana's forest products industry and timber harvest, 2014. http://www.bber.umt.edu/FIR/H_States.asp. (20 November 2016).

Howard, J.O. 1973. Logging residue in Washington, Oregon, and California: Volume and characteristics. Resour. Bull. PNW-RB-44. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.

Howard, J.O. 1981a. Ratios for estimating logging residue in the Pacific Northwest. Res. Pap. PNW-RP-288. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.

Howard, J.O. 1981b. Logging residue in the Pacific Northwest: Characteristics affecting utilization. Res. Pap. PNW-RP-289. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 41 p.

Levy, P.S.; Lemeshow, S. 1999. Sampling of populations: Methods and applications. 3rd ed. New York: Wiley Inc. 525 p.

Lohr, S.L. 2009. Sampling: Design and analysis. 2nd ed. Boston, MA: Brooks/Cole, Cengage Learning. 596 p.

McIver, C.P.; Sorenson, C.B.; Keegan, C.E.; [et al.]. 2013. Montana's forest products industry and timber harvest, 2009. Resour. Bull. RMRS-RB-16. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 42 p.

McLain, W.H. 1992. Logging Utilization—Montana, 1988. Resour. Bull. INT-RB-78. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 9 p.

Menlove, J.; Shaw, J.D.; Thompson, M.T.; [et al.]. 2012. Montana's forest resources, 2003–2009. Resour. Bull. RMRS-RB-15. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 140 p.

Morgan, T.A. 2015. Developing timber product output (TPO) harvest residue information. NARA webinar presented November 19, 2015. https://youtu.be/wp2z5YKukLQ.

Morgan, T.A.; Spoelma, T.P. 2008. California logging utilization: 2004. Western Journal of Applied Forestry. 23(1): 12–18.

Morgan, T.A.; Spoelma, T.P.; Keegan, C.E., III; [et al.]. 2005. Montana logging utilization, 2002. Res. Pap. RMRS-RP-52. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 12 p.

Peltola, S.; Kilpeläinen, H.; Asikainen, A. 2011. Recovery rates of logging residue harvesting in Norway spruce (*Picea abies* (L.) Karsten) dominated stands. Biomass and Bioenergy. 35: 1545–1551.

SAS. 2013. SAS version 9.4. Cary, NC: SAS Institute Inc.

Simmons, E.A.; Berg, E.C.; Morgan, T.A.; [et al.]. 2014. Logging utilization in Idaho: Current and past trends. Gen. Tech. Rep. RMRS-GTR-318. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Simmons, E.A.; Berg, E.C.; Scudder, M.G. 2015. NARA Logging Utilization. Poster presented at NARA annual meeting; 2015 September 15–17; Spokane, WA. www.bber.umt.edu/pubs/forest/util/NARALoggingUtilPoster2015.pdf

Simmons, E.A.; Morgan, T.A.; Berg, E.C.; [et al.]. 2016. Logging utilization in Oregon and Washington, 2011–2015. Resour. Bull. PNW-RB-268. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Wilson, A.K.; Green, R.E.; Choate, G. 1970. Logging residues on sawlog operations, Idaho and Montana. Res. Pap. INT-RP-77. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Woodall, C.W.; Heath, L.S.; Domke, G.M.; [et al.]. 2011. Methods and equations for estimating aboveground volume, biomass, and carbon for trees in the U.S. forest inventory, 2010. Gen. Tech. Rep. NRS-GTR-88. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 30 p.

Woudenberg, S.W.; Conkling, B.L.; O'Connell, B.M.; [et al.]. 2010. The Forest Inventory and Analysis database: Database description and users' manual version 4.0 for Phase 2. Gen. Tech. Rep. RMRS-GTR- 245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 336 p.

Zarnoch, S.J.; Bentley, J.W.; Johnson, T.G. 2004. Determining sample size for tree utilization surveys. Res. Pap. SRS-RP-34. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 11 p.

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