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Logging Utilization in Oregon and Washington, 2011–2015

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Cover photos: (upper left) harvester, by Eric Simmons; (upper right) logs, by Eric Simmons; (lower left) a crew member measures a tree in Skagit County, Washington, by Chelsea McIver, Oregon Department of Forestry; (lower right) logging operation in Pierce County, Washington, by Eric Simmons.

Abstract

A study of commercial timber harvesting activities in Oregon and Washington was conducted from 2011 through 2015 to characterize current tree utilization, 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 regional 5-year timber harvests. A two-stage sampling method was used to compute state-level utilization factors. Results of the study indicated that in Oregon, for every thousand cubic feet (MCF) delivered to the mill, harvesting removed 1,018 cubic feet (CF) of timber volume from growing stock, created 28 CF feet of growing-stock logging residue, and 10 CF of non-growing-stock material were delivered to the mill. This compared to 1,021 CF of growing-stock removals that created 29 CF of growing-stock logging residue and utilized 9 CF of non-growing-stock per 1 MCF of mill-delivered volume in Washington. Analyses showed that although utilization varies site to site, tree by tree, and as a result of logging practices, the overall effect of these variations on statewide removals factors can be minimal. Study results can inform land managers of residues available for bioenergy uses, provide data for woody biomass life cycle analyses, and estimate removals from growing stock.

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

Summary

Logging utilization studies, designed to quantify the amount of logging residue generated by commercial timber harvests, have not been conducted in Oregon and Washington since the 1980s. These older studies were based on measurements taken after product removal, quantifying volumes of logging residue left scattered throughout the site. Updated studies were needed in both states to reflect current harvesting practices and to directly associate logging residue volumes with harvest volumes and Forest Inventory and Analysis (FIA) inventory parameters, such as removals from growing-stock. Results indicated that, in Oregon, for every thousand cubic feet (MCF) delivered to the mill, 28 CF feet of growing-stock logging residue was created; and that in Washington, 29 CF of growing-stock logging residue was created per MCF of mill-delivered volume. Thus, removals factors for Oregon and Washington were very similar. Although utilization differed by site, by tree, and as a result of logging practices, this similarity between states demonstrates that the overall effect of these variations on statewide removals factors can be minimal. These findings can assist in quantifying the volume of logging residue that may be available, within certain economic constraints, for bioenergy, biofuels, or other products that could improve overall utilization of the timber resource.

Contents

Introduction

For various reasons, Pacific Northwest 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., dbh,[1] 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 yarding vs. ground-based skidding) may be of interest for planning purposes. The information developed from logging utilization studies can be useful in quantifying and describing portions of trees left on site after harvesting as logging residue, whether for potential biomass supply or as a component of removals from inventory.

Logging utilization studies identify material removed from forest inventory during commercial timber harvest activities, and they develop logging utilization factors. These factors quantify the amount of growing-stock[2] 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 used in the calculation of logging residue volumes in the Timber Products Output (TPO) database (http://srsfia2.fs.fed.us/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 historical or projected levels of timber harvest at various spatial scales to provide estimates of growing-stock removals from forest inventory. Logging utilization studies also characterize timber harvest activities and equipment and can provide estimates of the distributions of trees and volume harvested by species, size, and logging method.

When conducted in a consistent manner, these studies can provide a substantial amount of information about changes in timber harvesting practices and logging residue through time, as well as differences between states or regions. Recent logging utilization studies in Idaho (Simmons et al. 2014) and Montana (Morgan et al. 2005) have provided updated residue and harvesting information for the Inland Northwest. However, studies that link logging residue to TPO and FIA removals have not been conducted in Oregon or Washington. Older studies (e.g., Howard

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[1] Diameter at breast height (dbh) is the tree's diameter outside bark, measured at 4.5 feet above ground on the uphill side.

[2] 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.

Poletimber tree
(5.0–8.9 inches dbh)

Sawtimber tree
(≥ 9.0 inches dbh)

Top

4 inches (dob)

7 inches (dob) softwood trees;
9 inches (dob) hardwood trees

Growing stock
portion of tree

Sawtimber volume

Diameter at breast height

1-foot stump
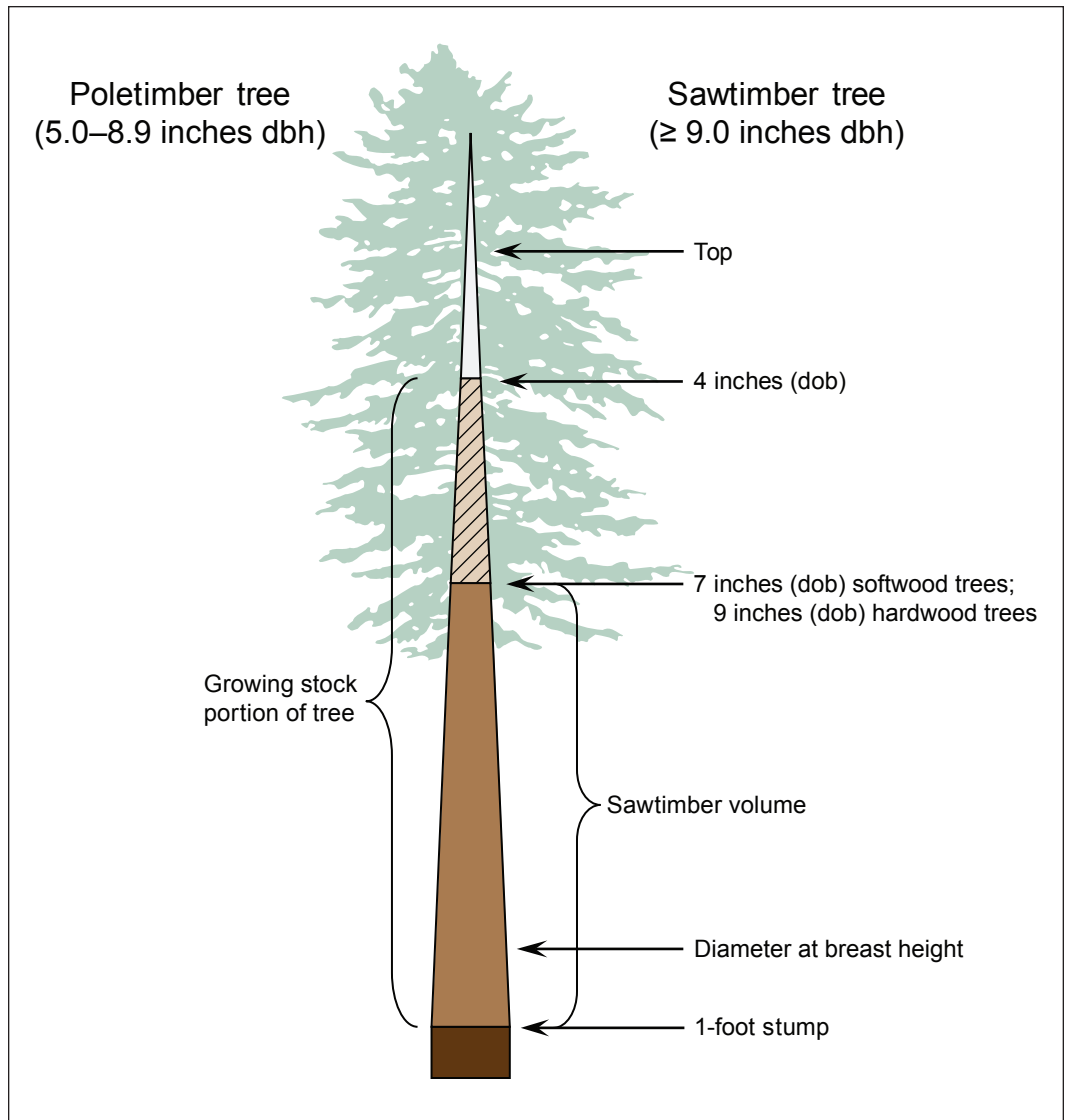
Figure 1—Sections of trees; dbh = diameter at breast height, dob = diameter outside bark.

1973, 1981a, 1981b) described and quantified slash or logging residue per thousand board feet (MBF) 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[3] sources). This study, and others like it (Bentley and Johnson 2004, Morgan and Spoelma 2008, Simmons et al. 2014), make those direct connections among timber harvested for products, the associated logging residue, and the impacts on growing-stock inventory.

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

To update regional timber harvesting and logging residue information, a study of logging sites across Oregon and Washington was conducted from 2011 through 2015. This study was designed to quantify the creation of logging residue from commercial timber harvesting at the state level, and characterize harvested trees and harvesting activities within each state. The specific objectives were to:

- characterize each state's timber harvest by tree species and diameter at breast height (dbh);
- characterize each state's timber harvest operations by felling, yarding, and merchandising methods;
- compute current logging utilization factors for each state to express:
  - volumes of growing-stock logging residue generated per thousand cubic feet (MCF) of mill-delivered volume,
  - 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.

Recent Oregon and Washington Timber Harvests

There are nearly 41.5 million acres of nonreserved timberland[4] potentially available for timber harvest activities in Oregon and Washington (table 1). However, neither the timber resource nor harvesting activities are evenly distributed across the states. Wood-product markets and forest policy issues have influenced the geographic and ownership sources of harvested timber as well as annual harvest volumes.

Recent annual timber harvest volumes in Oregon and Washington combined have ranged from mid-decade highs of 8.3 billion board feet (BBF) Scribner in 2004 to more than a 50-year low of 5 BBF Scribner during 2009 (ODF 2015, WDNR 2015a). The ownership mix of the two states' timber harvest has remained fairly stable since 1995, with the majority of the harvest coming from private (industrial and nonindustrial) lands (figs. 2a and 2b). With the collapse of U.S. housing starts and markets for lumber, there was a marked decline in the volume and proportion of harvest from private lands after 2007. Harvests from state-owned lands increased, somewhat offsetting declines in private harvests. As federal harvest volumes declined in the 1990s, most dramatically in Oregon (Simmons et al. 2016), the geographic source of the two states' timber harvest made a pronounced shift to counties west of the Cascade Range, which currently account for 85 to 90 percent of the annual harvest volume in each state.

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[4] Timberland is defined as unreserved forest land capable of producing 20 cubic feet per acre per year of wood from trees classified as a timber species on forest land designated as a timber forest type.

Table 1—Timberland[a] by ownership class

Ownership class	Area[b]	Nonreserved[c] timberland
	Thousands of acres	*Percent*
Oregon:		
National forest	11,086	46.9
Undifferentiated private[d]	9,386	39.7
State	817	3.4
Bureau of Land Management	2,225	9.4
Other public	145	0.6
All owners	23,659	100
Washington:		
National forest	5,718	32.1
Undifferentiated private[d]	9,329	52.3
State	2,302	12.9
Bureau of Land Management	45	0.3
Other public	436	2.4
All owners	17,831	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 (Helms 1998).
[b] Oregon: 23,659 = 23.7 million ac, Washington: 17,831 = 17.8 millon ac.
[c] Forest land not withdrawn from harvest by statute or administrative regulation. Includes forest lands that are not capable of producing more than 20 cubic feet per acre per year of industrial wood in natural stands.
[d] Undifferentiated private includes industrial private, nonindustrial private, tribal, nongovernmental organization, and unincorporated local partnership/association/clubs.
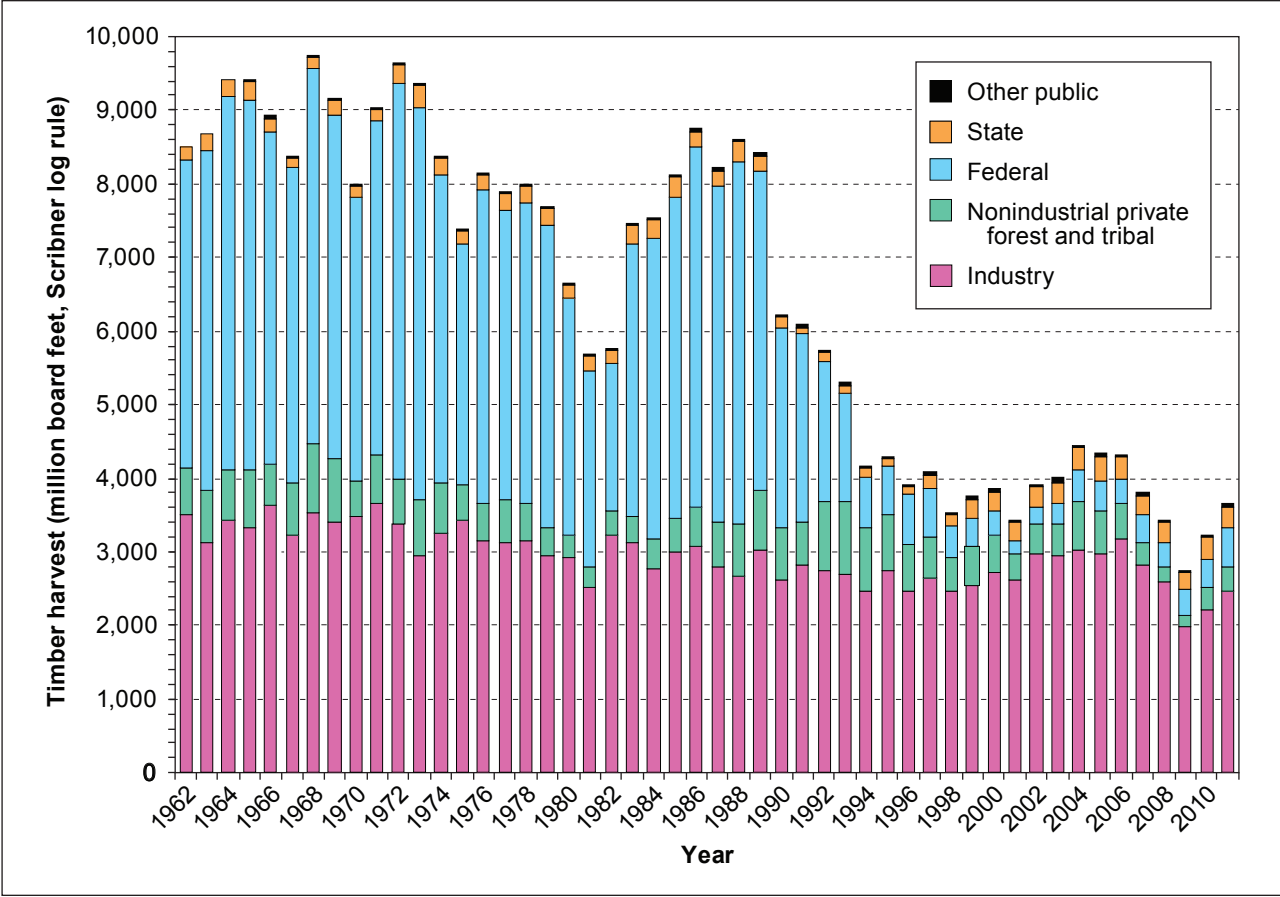Source: USDA FS (2015).

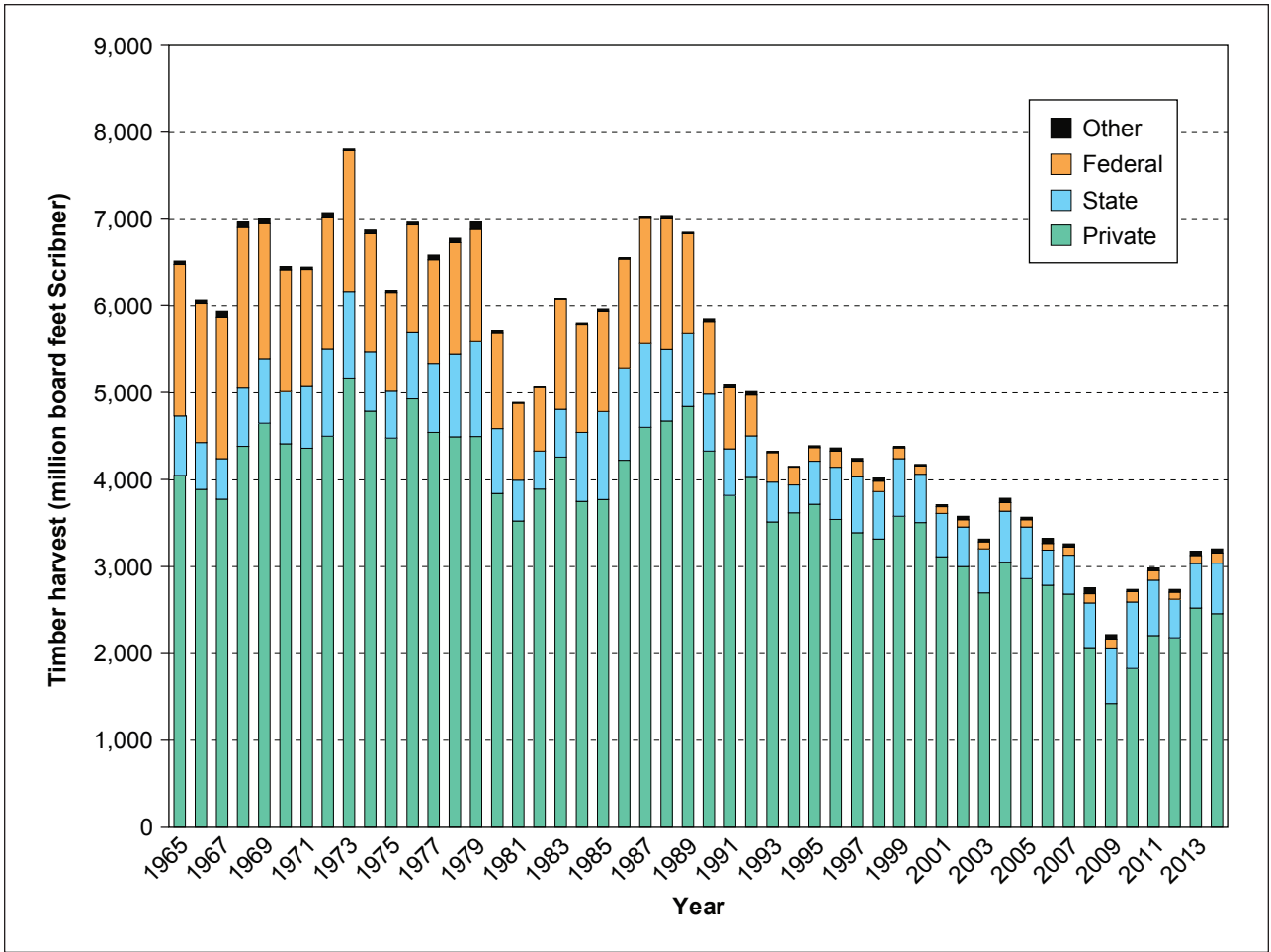Figure 2a—Oregon timber harvest, 1965–2014. Source: ODF (2015).

Figure 2b—Washington timber harvest, 1965–2014. Source: WDNR (2015a).

Methods

The target populations for this study were active logging sites in Oregon and Washington where green (live) trees were being commercially harvested for conversion into wood products, including lumber and veneer/plywood, or for international export. Because of the need to measure harvesting impacts on growing stock, only green-tree sites were targeted. Salvage sales, with many or most trees dead prior to harvest, were not included. Historically, 90 to 95 percent of Oregon and Washington's annual timber harvest volume had been used for lumber and veneer/plywood production (Simmons et al. 2016, WDNR 2015b). Other timber products (e.g., pulpwood, posts, and fuelwood) are commonly merchandised with sawlogs. Thus, sites were identified 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 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 Oregon and Washington state levels (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 1996, Morgan and Spoelma 2008, Simmons et al. 2014). 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 ratio 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. So, sample sites were not selected at random, and ratios of means and standard errors were computed using design-based methods.

A two-stage sampling scheme 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 state) and owner-ships of potential sample logging sites (fig. 3). Timberland owners and sawmills in the two states 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.
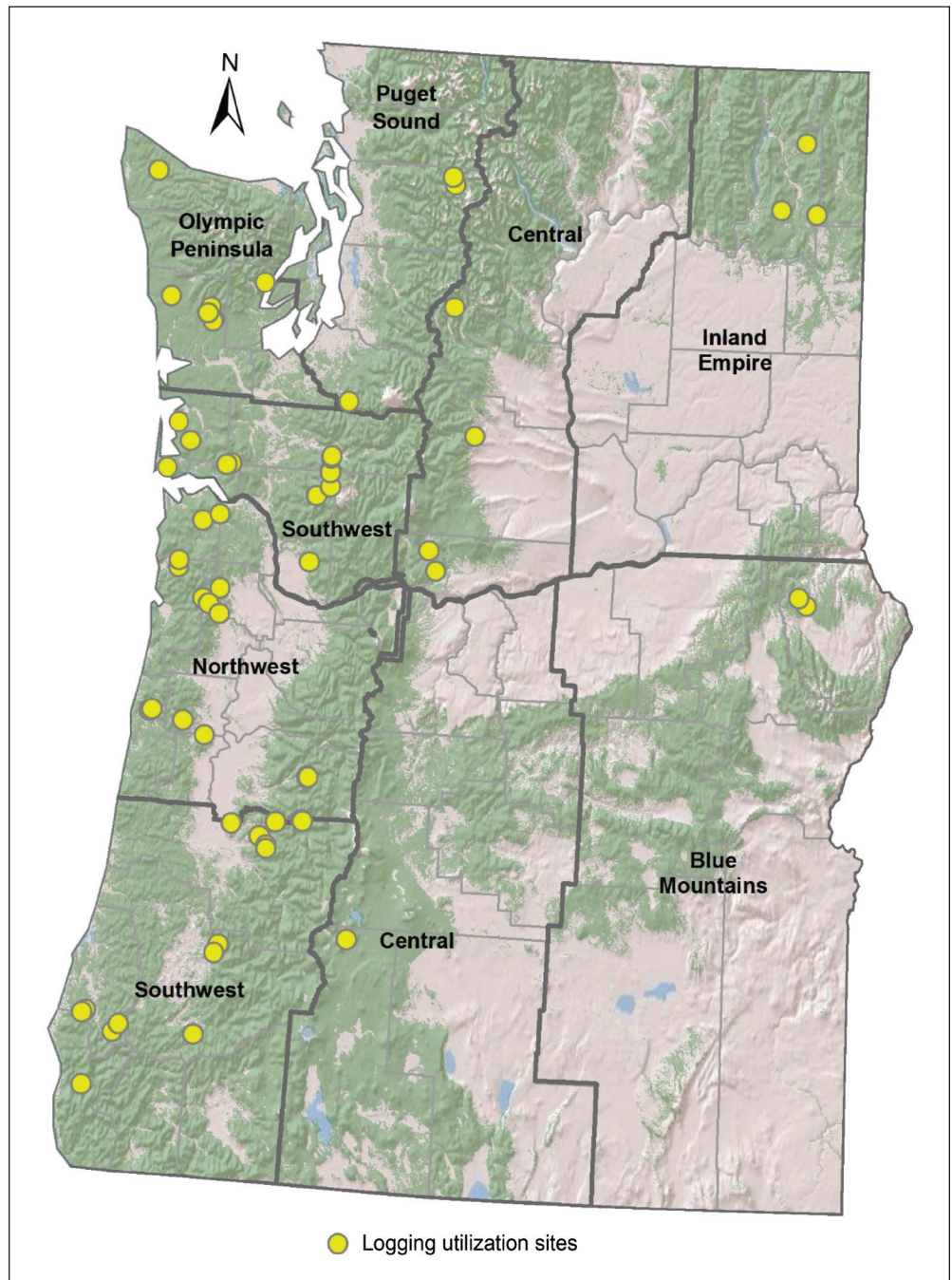

Figure 3—Logging utilization sample sites by region.

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 dbh ≥ 5 inches, and meeting minimum merchantability standards), and the entire stem, including the stump and top, had to be measureable (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, Idaho, and California garnered 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). 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.

Data Collection

Logging contractors or foresters at each selected 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 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, dbh, and primary product (e.g., sawlog, veneer log, etc.) information was recorded. Diameter and section length measurements were taken at the cut stump, at 1 foot above ground level (uphill side of the tree), at dbh, the end of the first 16-foot log, at the 7.0-inch diameter outside bark (dob), at the 4.0-inch dob point (end of growing stock), at the end-of-utilization, and at 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

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upper dob and length were recorded. The percent cubic cull for each section was also recorded and each bole 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 64 logging sites in both states (Oregon 34, Washington 30) from 2011 through 2015. These 64 active logging sites were spread across Oregon and Washington, and a total of 1,561 felled trees were measured.

Data Analysis

Following the methods of Morgan and Spoelma (2008) and Simmons et al. (2014), cubic volumes for more than 16,700 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 residue factors, standard errors, and 95-percent confidence intervals (CIs) were computed at the state level for Oregon and Washington based on the two-stage sampling design using the ratios of means estimator (Zarnoch et al. 2004) obtained from SAS PROC SURVEYMEANS (SAS 2013).[5] Characteristics of the felled trees, harvest operations, and utilization factors were then summarized and compared with historical Oregon and Washington logging utilization studies and with recent studies from other Western states.

Results and Discussion
Characteristics of Logging Sites and Operations

Because the majority of commercial logging in both states occurs in the regions west of the Cascades, most of the sample sites were located in these regions (table 2). Limited availability of logging sites in the Central region of Oregon (fig. 3) and the Puget Sound region of Washington resulted in fewer sites being measured relative to average harvest volumes in those regions. Likewise, the proportion of federal (Forest Service and Bureau of Land Management) sites in Oregon and nonindustrial private forest sites in Washington were somewhat lower than average harvest proportions for those ownerships (table 3).

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[5] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 2—Percentage of 5-year-average harvest and sample sites by region

Region	Harvest	Sample
	- - - - - - - *Percent* - - - - - - -	
Oregon:		
Northwest	47	50
Southwest	40	41
Central	7	3
Blue Mountain	6	6
Total	100	100
Washington:		
Southwest	38	40
Olympic Peninsula	28	30
Puget Sound	19	13
Central	6	7
Inland Empire	9	10
Total	100	100

Table 3—Percentage of 5-year-average harvest and sample sites by ownership

Ownership	Number of sites	Percentage of sites	Percentage of harvest
Oregon:			
Industry	24	70	65
Nonindustrial private forest	2	6	9
State and other public	6	18	10
Federal	2	6	16
Total	34	100	100
Washington:			
Industry	11	36	27
Nonindustrial private forest	11	37	48
State and other public	5	17	20
Federal	3	10	5
Total	30	100	100

Note: Washington nonindustrial private forest (NIPF) includes large private timber investment management organizations (TIMOs).

Harvesting methods included hand or mechanical felling and merchandising, as well as sites with a mix of the two (table 4). Mechanical felling methods included the use of equipment with accumulating heads such as a "hot saw" or feller-buncher. Hand felling and merchandising was done with chainsaws. Yarding operations were accomplished with cable or ground-based systems depending on topography or prescription. Cable systems were typically towers with motorized carriages. Ground-based skidding included the use of shovels,[6] rubber-tired skidders, and 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) delimbers and dangle-head processors.

In Oregon, hand felling occurred on 53 percent of the sites, whereas in Washington 53 percent of sites were felled mechanically. Cable yarding was used on 53 percent of the sites in Oregon and 27 percent of the sites in Washington. This was primarily due to a greater number of sites with steep slopes in Oregon. In both states, tree-length skidding predominated. Ground-based skidding with shovels (i.e., shovel logging) was common, especially on industrial private lands, in Oregon and Washington. The processing or merchandising of trees at landings with mechanical systems was employed on all but two of the 64 sites in this study. Complete merchandising with chainsaws was observed on just one site in each state. However, some of the largest trees were bucked once—at the end of the first (butt) log—on several cable sites.

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Characteristics of Felled Trees

The trees analyzed in Oregon ranged from 5.0 to 31.3 inches dbh; Washington trees ranged from 5.0 to 37.2 inches dbh (table 5). Half of the trees measured in Oregon were ≤ 14.0 inches dbh, but they accounted for about 18 percent of the utilized volume and 23 percent of growing-stock logging residue. Roughly one-half of the utilized volume and total logging residue in Oregon came from trees < 18.0 inches dbh. As in Oregon, 50 percent of the harvested trees in Washington were ≤ 14.0 inches dbh. These trees accounted for about 16 percent of the mill-delivered volume and just 13 percent of growing-stock logging residue volume. About one-half of Washington's utilized volume was produced by trees < 18.0 inches dbh, the same as in Oregon. However, more logging residue came from larger diameter trees in Washington, particularly in the 24 to 34 inch dbh classes. This finding is different than

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[6] Shovel: typically an excavator with a boom and grapple used to move felled trees from within a unit to a landing for processing or to load log trucks. When this system is used, the operation is referred to as "shovel logging."

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

Ownership	Felling			Yarding		Skidding		Merchandizing location		Merchandizing method	
	Hand[a]	Mechanical	Mixed	Ground	Cable	Tree length	Log length	In unit	At landing	Hand[a]	Mechanical
	— Number of sites —										
Oregon (34 sites):											
Federal	1	1	0	1	1	2	0	0	2	1	1
State	6	0	0	0	6	6	0	0	6	0	6
Nonindustrial private forest	1	0	1	2	0	2	0	0	2	0	2
Industrial private	10	11	3	13	11	24	0	0	24	0	24
Total	18	12	4	16	18	34	0	0	34	1	33
Washington (30 sites):											
Federal	2	1	0	1	2	1	2	1	2	0	3
State	2	2	1	3	2	5	0	0	5	1	4
Nonindustrial private forest	1	6	4	8	3	11	0	0	11	0	11
Industrial private	0	7	4	10	1	11	0	0	11	0	11
Total	5	16	9	22	8	28	2	1	29	1	29

[a] With chainsaws.

Table 5—Distribution of trees, mill-delivered volume, and growing-stock logging-residue volume in cubic feet, by dbh class

dbh class (inches)	Number of trees	Percentage of sample trees	Cumulative percentage	Percentage of mill delivered volume	Cumulative percentage	Percentage of growing-stock logging residue	Cumulative percentage
				Cubic feet		*Cubic feet*	
Oregon (835 trees):							
6	17	2.0	2.0	0.2	0.2	0.1	0.1
8	84	10.1	12.1	1.9	2.1	4.4	4.5
10	125	15.0	27.1	5.8	7.9	8.3	12.8
12	139	16.6	43.7	9.7	17.6	10.5	23.3
14	138	16.5	60.2	13.5	31.1	13.1	36.4
16	107	12.8	73.1	14.5	45.6	9.5	46.0
18	82	9.8	82.9	14.1	59.7	12.3	58.3
20	59	7.1	89.9	12.8	72.6	10.7	69.0
22	30	3.6	93.5	7.6	80.2	7.5	76.5
24	20	2.4	95.9	6.3	86.5	4.2	80.7
26	14	1.7	97.6	5.0	91.5	8.9	89.6
28	15	1.8	99.4	6.1	97.5	5.9	95.5
30	4	0.5	99.9	1.8	99.4	2.7	98.2
32	1	0.1	100	0.6	100	1.8	100

Table 5—Distribution of trees, mill-delivered volume, and growing-stock logging-residue volume in cubic feet, by dbh class (continued)

dbh class (inches)	Number of trees	Percentage of sample trees	Cumulative percentage	Percentage of mill delivered volume	Cumulative percentage	Percentage of growing-stock logging residue	Cumulative percentage
Washington (726 trees):							
6	11	1.5	1.5	0.2	0.2	0.4	0.4
8	65	9.0	10.5	1.9	2.1	1.5	1.9
10	91	12.5	23.0	3.9	5.9	3.6	5.5
12	137	18.9	41.9	9.7	15.6	7.7	13.2
14	123	16.9	58.8	12.2	27.8	7.8	21.0
16	112	15.4	74.2	15.5	43.3	11.0	32.0
18	59	8.1	82.4	10.5	53.8	6.9	38.9
20	46	6.3	88.7	10.4	64.2	13.7	52.6
22	16	2.2	90.9	4.5	68.7	3.3	55.9
24	15	2.1	93.0	5.5	74.3	2.7	58.6
26	15	2.1	95.0	5.6	79.8	11.4	70.0
28	12	1.7	96.7	5.4	85.3	6.0	75.9
30	8	1.1	97.8	4.1	89.4	8.9	84.8
32	7	1.0	98.8	4.5	93.9	6.6	91.5
34	6	0.8	99.6	3.9	97.8	6.6	98.0
36	2	0.3	99.9	1.4	99.3	1.1	99.1
38	1	0.1	100	0.7	100	0.9	100

dbh = diameter at breast height.
Note: Percentages may not sum to 100 because of rounding.

in Oregon and is inconsistent with studies in other Western states, where smaller trees tended to produce proportionally more residue per cubic foot of mill-delivered volume than larger trees (Morgan and Spoelma 2008, Simmons et al. 2014).

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco); western hemlock (*Tsuga heterophylla* (Raf.) Sarg.); hardwoods, primarily red alder (*Alnus rubra* Bong.); and true firs (*Abies spp.*) were the four most sampled and harvested tree species in Oregon (table 6). These species accounted for 96 percent of the mill-delivered volume from Oregon sites in this study and 92 percent of the 2013 harvest as reported by Simmons et al. (2016). In Washington, these species accounted for 93 percent of the mill-delivered volume in this study and 92 percent of 2014 log consumption as reported by the Washington Department of Natural Resources (WDNR 2015b). The mill-delivered volume of pines (*Pinus* spp.) measured in the sample of logging sites from both states was somewhat lower than reported pine volumes from other sources. This was likely a result of the small number of sites located east of the Cascades in both Oregon and Washington, where pine species are more commonly harvested (Simmons et al. 2016, WDNR 2015b). Hardwoods and true firs exhibited higher residue ratios (growing-stock logging residue as a percentage of mill-delivered volume) than other species groups in both Oregon and Washington.

Statewide Logging Utilization Factors

Logging utilization removals factors are statewide ratios of removals volumes versus mill-delivered volumes (Morgan and Spoelma 2008, Simmons et al. 2014). Removals factors calculated in this study indicated that commercial timber harvesting in Oregon removed 1,018 CF of growing-stock volume for each 1,000 CF delivered to the mill: 990 CF of growing stock was utilized, plus 28 CF of growing stock was left in the forest or at the landing as logging residue (table 7). In addition, 10 CF of non-growing-stock material from stumps cut below 1-foot in height and tops (utilized beyond the 4-inch dob) that went to the mill. Washington removals factors were very similar to those found in Oregon. For each 1,000 CF delivered to the mill, 1,021 CF of growing stock was removed, with 991 CF utilized and 29 CF left on site as logging residue. And, an additional 9 CF of non-growing-stock material was delivered to the mill.

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) found that breakage accounted for more than 90 percent of individual tree growing-stock residue in a four-state logging residue investigation. Relatively little logging residue came from stem sections near the end of growing stock (i.e., the 4-inch dob). 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

Most of the growing-stock logging residue volume came from portions of the bole that were broken during felling and stumps cut higher than 1.0 foot above ground level.

Table 6—Proportion of felled trees, harvest, delivered volume, total logging residue, and residue per cubic foot delivered volume by species

Species	Number of sample trees	Percentage of harvests in Oregon (2013) and Washington (2014)	Percentage of mill-delivered volume	Percentage of total logging residue	Residue as a percentage of mill-delivered volume
Oregon:					
Douglas-fir	586	69.5	73.3	57.2	2.2
Western hemlock	146	11.2	17.2	22.6	3.7
Hardwoods	40	3.5	2.4	10.8	12.7
True firs	33	8.0	3.2	5.8	5.1
Other softwoods	18	3.0	2.4	2.1	2.4
Pines	12	4.8	1.6	1.4	2.5
All species	835	100	100	100	2.8
Washington:					
Douglas-fir	382	60.3	61.8	52.4	2.5
Western hemlock	199	24.2	24.5	26.8	3.2
Other softwoods	62	4.1	5.0	5.3	3.2
True firs	40	3.8	4.3	7.0	4.7
Hardwoods	33	3.6	2.7	7.3	8.0
Pines	10	4.0	1.8	1.2	2.1
All species	726	100	100	100	2.9

changes in small-end utilized diameters (e.g., 4.0 inches dob versus 6.0 inches dob) yielded small differences in residue volume, residue ratios increased exponentially as small-end-utilized diameters increased.

The amount of growing-stock residue generated per unit of mill-delivered volume (i.e., the growing-stock residue factor) differed between Oregon and Washington in some diameter classes (fig. 4). In Washington, the residue factor for trees in the 6-inch diameter class was over six times higher than in Oregon. This difference resulted from more pulpwood utilization at some Oregon sites, and may have been related to different minimum log-length specifications for pulp products in Oregon versus Washington. Although the low residue factor for 6-inch dbh trees in Oregon was contrary to findings in other states (e.g., Simmons et al. 2014), it was consistent with findings by Berg et al. (2016) that harvesting pulpwood improved overall utilization and reduced the growing-stock residue factor.

The growing-stock residue factor for trees in the 24- to 30-inch dbh classes was 33 percent higher in Washington than in Oregon. Much of this difference was attributable to three sites in Washington where larger trees had been felled across

The growing-stock residue factor for trees in the 24- to 30-inch dbh classes was higher in Washington because three sites had larger trees felled across bunch piles, creating considerable damage to—and residue from—the larger trees.

Table 7—Logging utilization removals factors

Removals factors	Lower bound (95% CI)	Estimate (ratio of means)	Upper bound (95% CI)	Standard error	Cubic feet per mill-delivered MCF
Oregon:					
Non-growing-stock product delivered to mills (*utilized non-growing stock ÷ total utilized*)	0.0051	0.0102	0.0153	0.0025	10
Growing-stock product delivered to mills (*utilized growing stock ÷ total utilized*)	0.9847	0.9898	0.9949	0.0025	990
Growing-stock logging residue (*unutilized growing stock ÷ total utilized*)	0.0209	0.0278	0.0348	0.0034	28
Removals from growing stock ((*utilized + unutilized growing stock) ÷ total utilized*)	1.0096	1.0176	1.0257	0.0040	1,018
Washington:					
Non-growing stock-product delivered to mills (*utilized non-growing-stock ÷ total utilized*)	0.0056	0.0090	0.0123	0.0016	9
Growing-stock product delivered to mills (*utilized growing stock ÷ total utilized*)	0.9877	0.9910	0.9944	0.0016	991
Growing-stock logging residue (*unutilized growing stock ÷ total utilized*)	0.0206	0.0294	0.0382	0.0043	29
Removals from growing stock ((*utilized + unutilized growing stock) ÷ total utilized*)	1.0088	1.0204	1.0320	0.0057	1,021

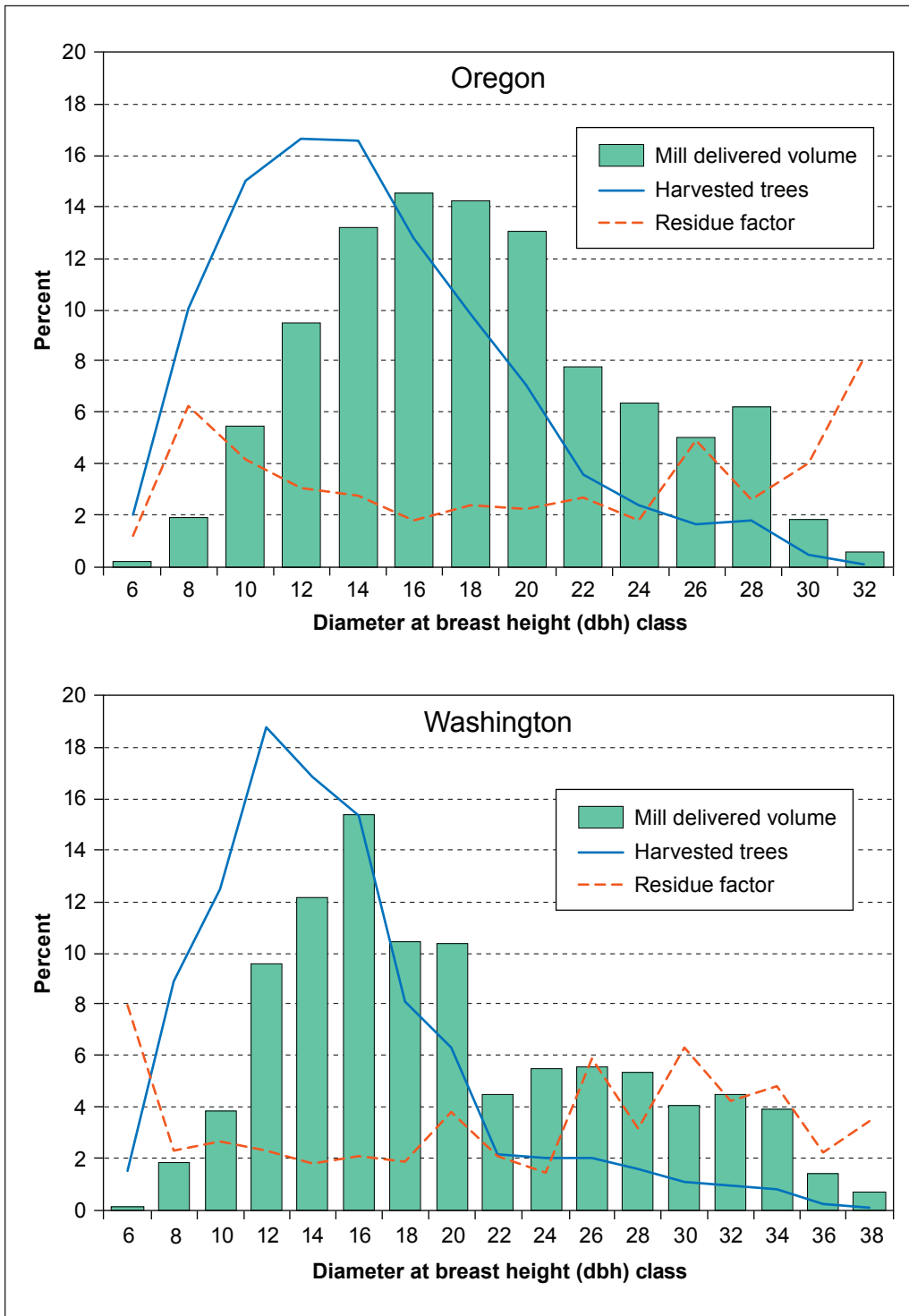CI = confidence interval; MCF = thousand cubic feet.

Figure 4—Distribution of mill delivered volume, harvested trees, and residue per cubic foot of mill-delivered volume by tree diameter at breast height (dbh).

bunch piles of smaller trees, creating considerable damage to—and residue from—the larger trees as well as the trees in the piles. Compared to trees of the same diameter at other sites in Washington, the growing-stock logging residue factor was almost twice as high for these three sites. These findings suggest that, although statewide residue factors may have been similar, differences in product utilization and logging practices clearly affected logging residue quantities at individual sites.

Results of this study can also be used to characterize utilization of the entire bole of the harvested tree. In Oregon, 3.5 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, and 96.5 was delivered to the mill (fig. 5). Washington's harvested tree bole utilization was nearly identical. This information can benefit forest managers who do not use the FIA distinctions of growing-stock and non-growing-stock tree components.
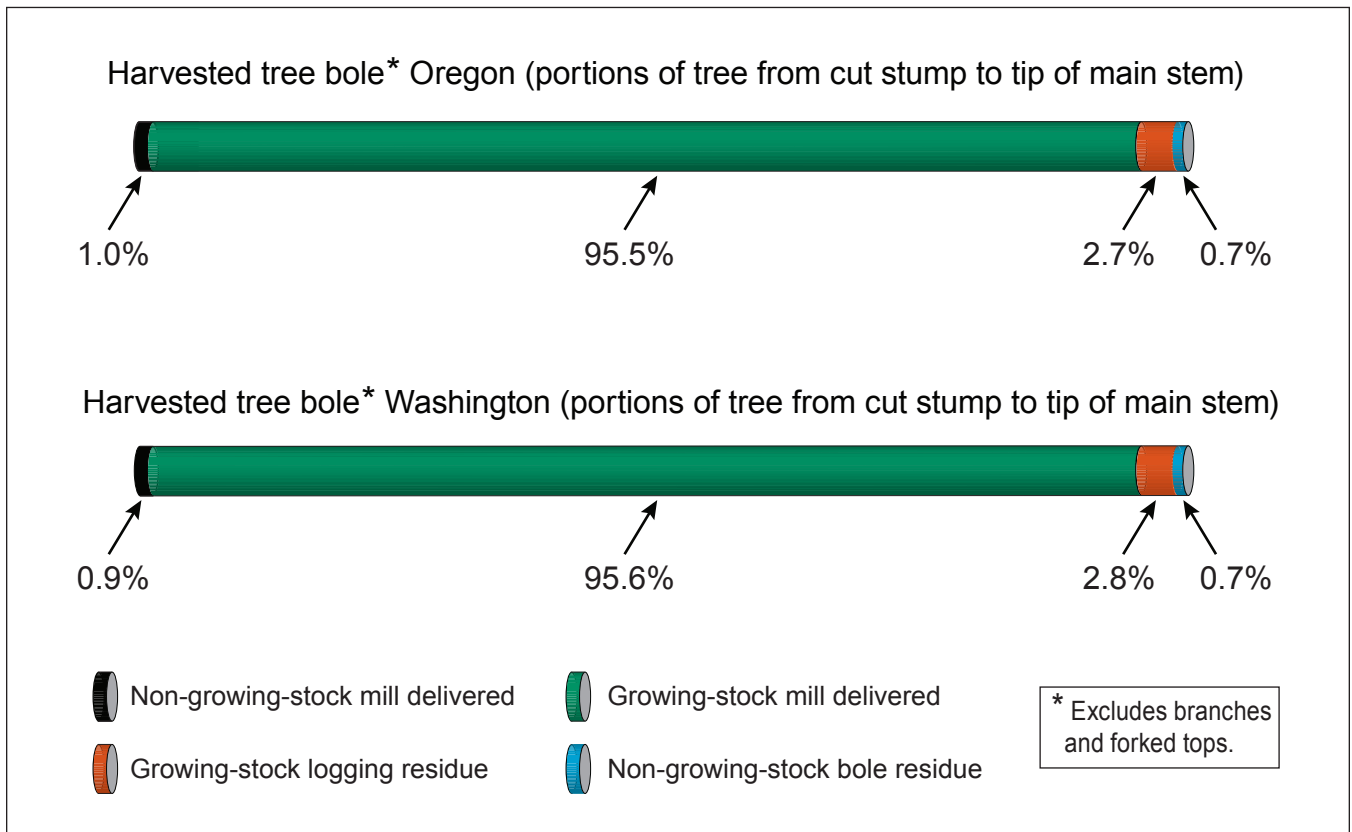
Harvested tree bole* Oregon (portions of tree from cut stump to tip of main stem)

1.0%   95.5%   2.7%   0.7%

Harvested tree bole* Washington (portions of tree from cut stump to tip of main stem)

0.9%   95.6%   2.8%   0.7%

Non-growing-stock mill delivered   Growing-stock mill delivered   * Excludes branches and forked tops.

Growing-stock logging residue   Non-growing-stock bole residue

Figure 5—Harvested tree bole utilization.

Conclusions

Logging utilization studies can help land managers understand the impacts of commercial timber harvesting on growing-stock inventories, woody residue volumes, and carbon dynamics. Variables including logging method, species, tree size (i.e., dbh), defect, and the presence/absence of a pulp market can have profound impacts on the production of logging residue (Berg et al. 2016, Simmons et al. 2014).

The sampling design used in this study appears to have captured the range in variability of recent Oregon and Washington logging sites and harvested trees. Site locations, as reflected in geographic distribution and species mix in the sample, closely approximated timber harvest information reported in both states (Simmons et al. 2016, WDNR 2015a). Results also suggest that the sampling scheme did well at capturing information on the more frequently harvested species, but perhaps not as well with the less frequently harvested species.

This study produced removals factors for Oregon and Washington that enabled calculation of growing-stock logging residue quantities based on current, local harvesting practices. Removals factors for Oregon and Washington were nearly identical, even though utilization differed site to site, tree by tree, and as a result of logging practices, demonstrating that the overall effect of these variations on statewide removals factors, when all the data are combined, can be minimal. These residue factors can aid land managers in estimating the quantities of logging residue removed from growing stock and potentially available for bioenergy uses, while also providing information for woody biomass life cycle analyses.

Removals factors for Oregon and Washington were nearly identical, even though utilization differed site to site, tree by tree, and as a result of logging practices, demonstrating that the overall effect of these variations on statewide removals factors, when all the data are combined, can be minimal.

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