USDA Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Pacific Northwest Research Station | Resource Bulletin PNW-RB-272 | October 2022

Logging Utilization in Alaska, 2016–2019

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This publication was produced in cooperation with the Bureau of Business and Economic Research, University of Montana, Missoula, Montana.

Cover photo: Export landing, Prince of Wales Island. Photo by Eric Simmons.

Abstract

Simmons, Eric A.; Berg, Erik C.; Morgan, Todd A.; Hayes, Steven W.; Christensen, Glenn A. 2022. Logging utilization in Alaska, 2016–2019. Resour. Bull. PNW-RB-272. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p. https://doi.org/10.2737/PNW-RB-272.

Commercial timber harvest sites in Alaska were studied between 2016 and 2019 to estimate growing-stock removals, characterize current tree utilization, characterize logging operations, and assist with estimating the amount of woody biomass left onsite after harvesting. Sample logging sites were selected within major geographic regions in proportion to 5-year timber harvest volumes. A two-stage sampling method (felled trees clustered within logging sites) was used to compute state-level utilization factors. Results indicated that for every 1,000 ft^3 delivered to the mill, harvesting removed 1,091 ft^3 of timber volume from growing stock; created 92 ft^3 of growing-stock logging residue; and yielded 2 ft^3 of non-growing-stock material that was delivered to the mill. The ratio of Alaska growing-stock residue to mill-delivered volume was three times larger than in other Northwest states. 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 associated with commercial timber harvesting.

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

Summary

Logging utilization studies, designed to quantify the amount of growing-stock removals and the logging residue generated by commercial timber harvests, have not previously been conducted in Alaska. Study findings were needed to directly associate logging residue volumes with harvest volumes and Forest Inventory and Analysis inventory parameters, such as removals from growing stock.

A two-stage sampling protocol (simple random two-stage or cluster sampling) was used to select logging sites and trees within sites for measurement (Levy and Lemeshow 1999). Sample sites were thus selected proportional to 5-year average timber harvest volumes. Logging sites with active harvesting of green trees for commercial products served as the stage 1 sampling units. The stage 2 sampling units consisted of randomly selected felled trees at each sample logging site. To qualify as a potential measurement tree, it had to be growing stock (live prior to harvest, ≥5.0 inches diameter at breast height (dbh), and meet minimum merchantability standards), and the entire stem, including the stump and top, had to be measurable (Morgan and Spoelma 2008, Woudenberg et al. 2010).

Results indicated that, in Alaska, 92 ft^3 feet of growing-stock logging residue was created for every 1,000 ft^3 of mill-delivered volume. Most of the growing-stock logging residue came from portions of the bole that were broken during felling and stumps cut higher than 1 ft above ground level. The ratio of Alaska growing-stock residue to mill-delivered volume was three times larger than that of other Northwest states. This finding is likely related to four major factors:

- Age-related defect
- End of utilization
- Stump height
- Timber products

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 associated with commercial timber harvesting.

Contents

Introduction

Alaska forest managers seek current information on the effects of timber harvesting on forest inventory. It is useful to know how postharvest woody residues affect fuel loads or create potential for woody biomass energy sources. Likewise, the characteristics of harvested trees (e.g., diameter at breast height [dbh],[1] total tree height, or species mix) and felling, yarding, and merchandising methods are also of interest for planning purposes. The information developed from logging utilization studies meets these information needs by characterizing felled tree attributes and logging methods, and by quantifying the volumes of tree sections left as logging residue after harvest.

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 amount of growing-stock[2] volume (fig. 1) removed from inventory and distinguish it as either timber products (e.g., sawlogs) delivered to mills or export landings, 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[3] maintained by the U.S. Department of Agriculture (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. Data from these logging studies can also be used to develop taper equations and to 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, logging utilization studies provide substantial information about changes in timber harvesting practices and logging residue through time and among states or regions. Recent pre-yarding (i.e., trees felled but not moved to landings) logging utilization studies provide updated residue

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

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

[3] Timber Product Output database: https://www.fs.usda.gov/srsfia/php/tpo_2009/tpo_rpa_int1.php (17 March 2020).

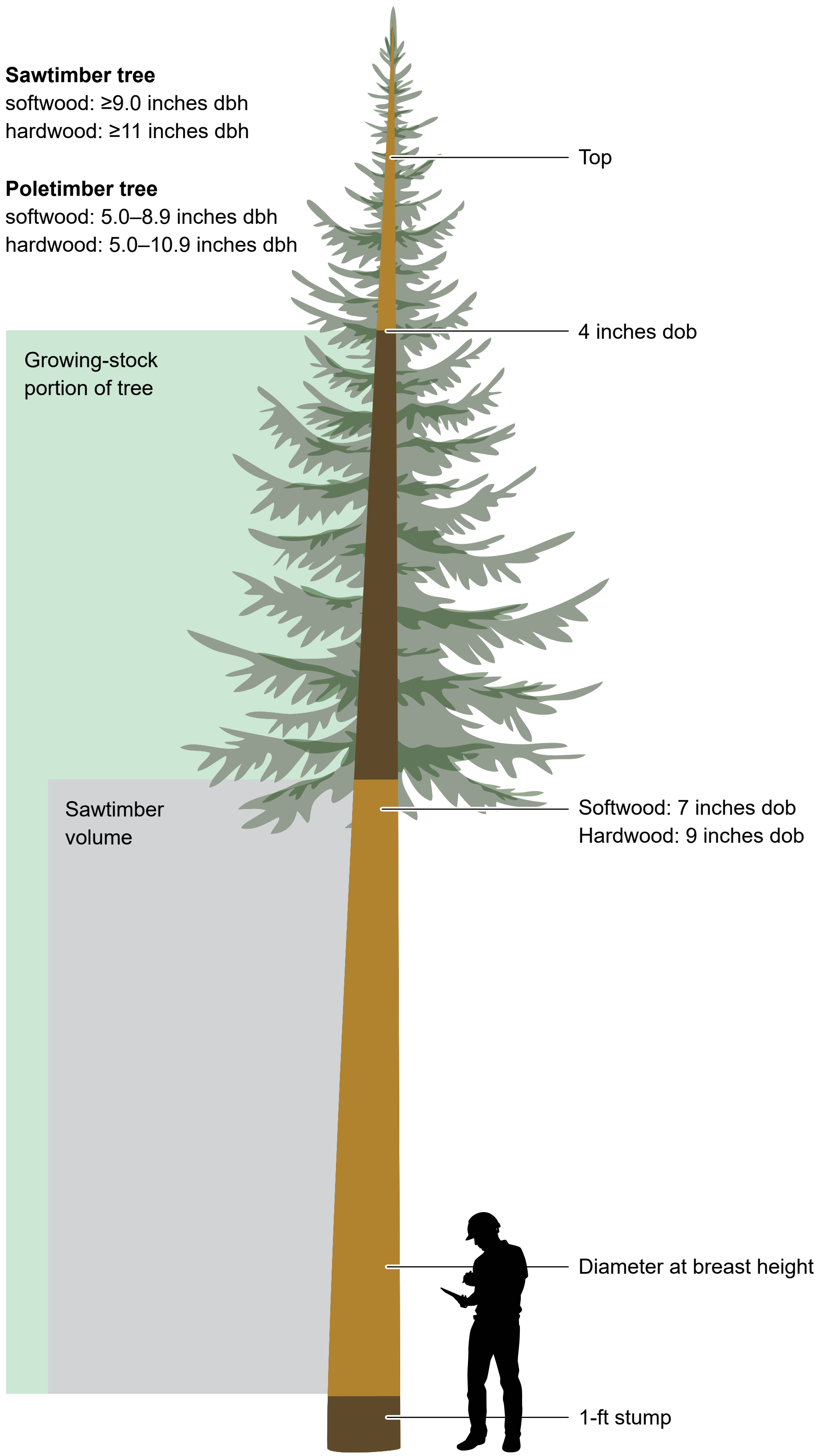

Figure 1—Growing stock and sawtimber sections of hard- and softwood trees.
dbh = diameter at breast height; dob = diameter outside bark.

and harvesting information for the lower four Northwest states: Idaho (Simmons et al. 2014), Oregon and Washington (Simmons et al. 2016), and Montana (Berg et al. 2018). However, comprehensive statewide pre-yarding logging utilization has never been investigated in Alaska. Howard and Setzer (1989) characterized post-yarding (i.e., where the trees have been removed from logging sites). Their research characterized all woody residues, including that from felled trees and down and dead woody material) residues in southeast Alaska, but their study did not directly associate the residue volumes to felled tree volumes and FIA inventory parameters (e.g., growing-stock vs. non-growing-stock[4] sources). The current study, and others like it (see Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014, 2016), make the direct connections among timber harvested for products, the associated logging residue, and the impacts on growing-stock inventory.

Logging utilization was investigated in active logging sites across Alaska from 2016 through 2019. This study was designed to quantify the creation of growing-stock logging residue from commercial timber harvesting at the state level and characterize harvested trees and harvesting activities within Alaska. To ensure that Alaska private landowner information remains confidential, detailed utilization findings are not reported by landowner or geographic region. Specific research objectives were as follows:

- Characterize Alaska timber harvest by tree species and dbh.
- Characterize timber harvest operations by felling, yarding, and merchandising methods.
- Compute current logging utilization factors to express three outcomes:
    - Volumes of growing-stock and sawtimber logging residue generated per 1,000 ft^3 of mill-delivered volume (the residue ratio or factor)
    - Proportions of mill-delivered volume coming from growing vs. non-growing stock, and sawtimber vs. non-sawtimber portions of harvested trees
    - Total removals (i.e., timber product and logging residue) from growing stock and sawtimber.

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

Methods

Alaska Timberlands and Recent Timber Harvests

The vast majority (nearly 79 percent) of Alaska's approximately 6.5 million ac of coastal timberlands[5] are managed by the federal government and are concentrated in the Tongass National Forest along coastal southeast Alaska in four resource areas (fig. 2). Further, 77 percent (110,893 million board feet [MMBF]) of all sawtimber is found on national forest lands (fig. 3) (Marcille et al. 2021). Alaska growing-stock volume is dominated by western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (55 percent) and Sitka spruce (*Picea sitchensis* (Bong.) Carrière) (25 percent); associated species include mountain hemlock (*T. mertensiana* (Bong.) Carrière), Alaska yellow cedar (*Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little), and western redcedar (*Thuja plicata* Donn ex D. Don) (Marcille et al. 2021). White spruce (*P. glauca* (Moench) Voss) and black spruce (*P. mariana* Britton, Sterns & Poggenb.) make up the majority of the softwood timber volume on interior Alaska's forested

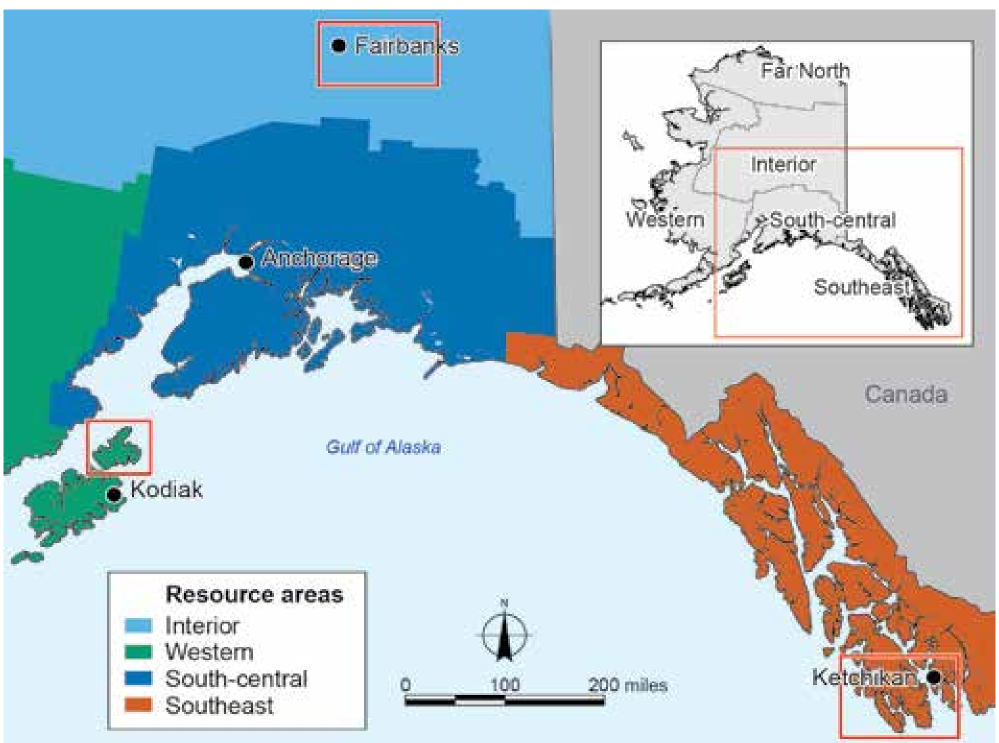

Figure 2—Alaska's resource areas and sample areas (highlighted map selections). Note: there were no logging sites sampled in the south-central resource area because of the relatively smaller volumes of timber harvested in that region.

[5] Timberland is defined as unreserved forest land capable of producing 20 ft^3 per acre per year of wood from classified timber species on forest land designated a timber forest type (USDA FS 2006).

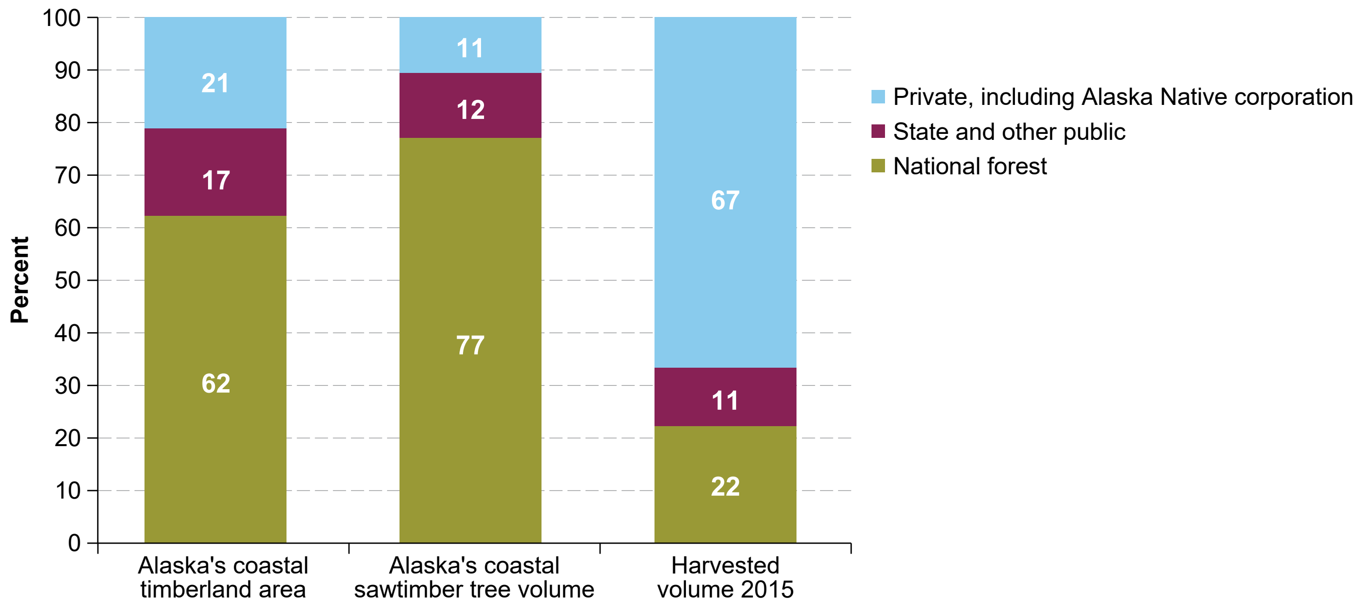

Figure 3—Characteristics of Alaska’s coastal timberlands and timber harvest by ownership class, 2015. Sources: Marcille et al. 2021, USDA FS 2020.

ecosystems. Recent annual timber harvest volumes in Alaska have declined from a high of nearly 400 MMBF Scribner in 2000 to <34 MMBF in 2017, primarily in response to a decline in available timber for harvest on federal lands (fig. 4). Native corporation lands have provided the majority of Alaska’s timber harvest over the past 30 years (fig. 3), and most of this (75 percent in 2015) has been exported (Marcille et al. 2021).

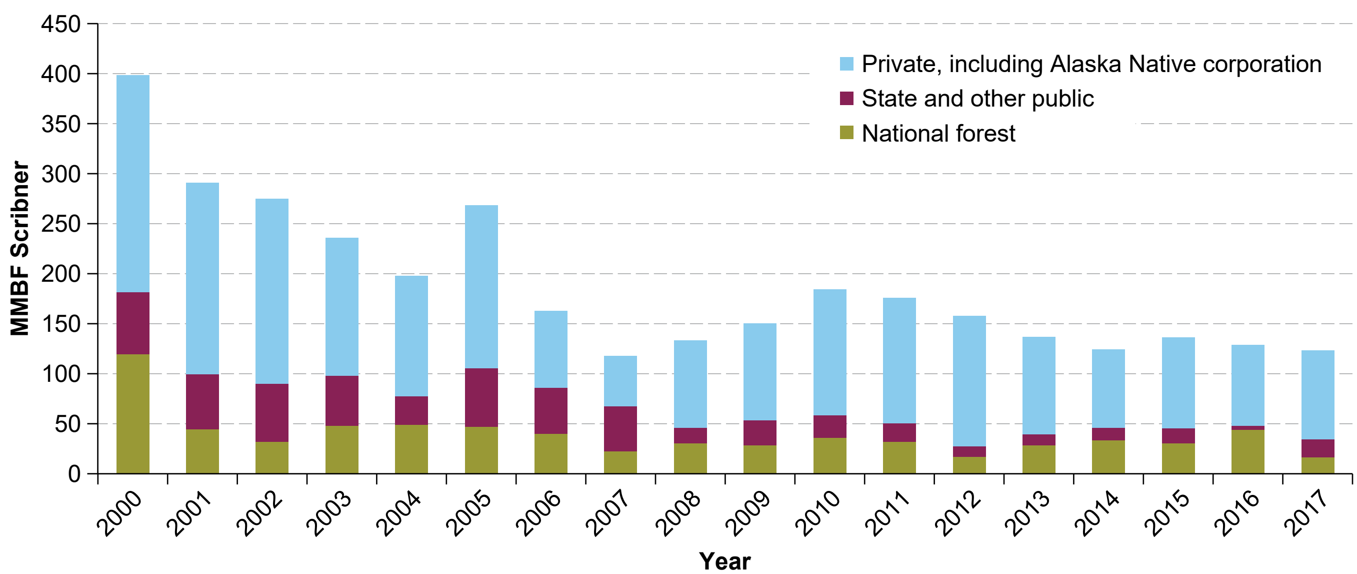

Figure 4—Alaska timber harvest by land ownership, 2000–2017. MMBF = million board feet. Sources: Alexander 2012, BBER 2016, Berg et al. 2014a, Brackley et al. 2009, Marcille et al. 2021, USITC 2016, Zhou 2013, Zhou and Warren 2012.

Sample Design

The target population for this study was active logging sites in Alaska where green (live) trees were being commercially harvested. Because this study sought 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. 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 Alaska state level (Zarnoch et al. 2004). Ideally, logging utilization studies should be based on random sampling of logging sites. However, 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 (McLain 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. Further, without a sampling frame from which to draw samples at random, design-based sampling could bias parameter estimates and compromise any ability to make population inferences (Lohr 2009).

Using simulation methods, Berg et al. (2015) analyzed the potential bias in design-based sampling without the use of a sampling frame and found that computed design-based ratios of logging residue to mill-delivered cubic volume (the residue factor) in the lower four Northwest states exhibit <0.5 percent bias. Because Alaska's site-level growing residue factor distribution followed the same exponential decay pattern (the essential component of the simulation methods) as logging sites in the lower four Northwest states (fig. 5), and sample sites were not selected based on timber size or other tree or site attributes, we concluded that Alaska sample sites were selected without known bias. In the current study, as in other investigations, the authors could not obtain a list of all active sites; thus, sample sites were not selected at random, and ratios of means and standard errors were computed using design-based methods.

A two-stage sampling protocol (simple random two-stage or cluster sampling) 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., borough or multi-borough or census area region) was assumed to be in proportion to harvest volume. Sample sites were thus selected proportional to 5-year average timber harvest volumes. Logging sites with active harvesting of green trees for commercial products served as the stage 1 sampling units. Timber-harvest summaries (BBER 2015–2018) provided the geographic location and ownerships of potential sample logging sites. 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.

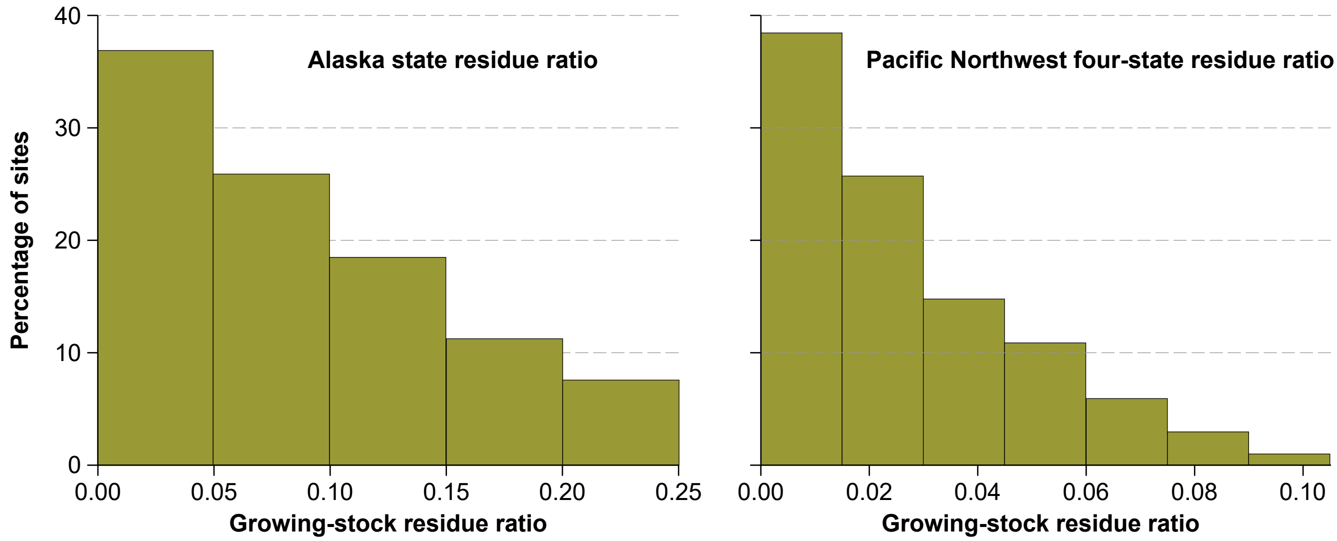

Figure 5—Percentage of occurrence by ratio of means, growing-stock residue volume (cubic foot) per mill-delivered volume (cubic foot) for Alaska and the lower four Northwest states combined. Greater occurrence of the lowest ratios and similar pattern of distribution in Alaska to other Northwest states confirms assumption of an unbiased sample of sites.

The stage 2 sampling units consisted of randomly selected felled trees at each sample logging site. To qualify as a potential measurement tree, it had to be growing stock (live prior to harvest, ≥5.0 inches dbh, and meet minimum merchantability standards), and the entire stem, including the stump and top, had to be measurable (Morgan and Spoelma 2008, Woudenberg et al. 2010).

Researchers desired a sampling protocol that would yield <20 percent standard error of the estimate for the growing-stock residue ratio. To meet this target, sample sizes for stages 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, with at least 10 sampled trees per site. Previous logging utilization studies in Montana, Idaho, Oregon, Washington, and California yielded low standard errors (<20 percent of the estimate) by measuring 20 to 35 trees on each of 25 to 35 logging sites (Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014, 2016). Based on these guidelines, the authors decided to sample 10 to 25 felled trees within each of 25 to 30 active logging sites throughout the state of Alaska.

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, crews provided information on tree species, products merchandised, and preferred and acceptable log lengths delivered to receiving mills. Field crews recorded this information along with the date, borough, 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, diameter at breast height, and primary product type (e.g., sawlogs) were recorded. Diameter and section-length measurements were taken as follows:

- At the cut stump
- 1 ft above ground level (uphill side of the tree)
- Diameter at breast height
- At the end of the first 16-ft log
- At the 7-inch diameter outside bark (dob)
- At the 4-inch dob point (end of growing stock)
- At end of utilization
- At the tip of the tree

Each tree had diameter (in 0.1-inch increments) and section length (in 0.1-ft increments) measurements recorded with a maximum section length of 16 ft. Thus, for each bole section, lower and upper dob and length were recorded. The percentage of 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 10 felled live trees were measured at each of 27 logging sites from 2016 to 2019 (most frequently 20 trees per site). These 27 active sites were spread across the southeast, western, and interior Alaska resource areas consistent with the sample design prescripts for selecting site locations based on proportion of timber harvest (fig. 2). A total of 438 felled trees comprising 4,699 individual tree sections 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 residue factors (or ratios), standard errors, and 95-percent confidence intervals (CIs) were computed at the 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).[6] Residue ratios were also calculated for individual species and for each tree diameter class. Characteristics of the felled trees, harvest operations, and utilization factors were then summarized and compared with recent studies from other Western states.

Results and Discussion

Characteristics of Logging Sites and Operations

Logging utilization sample sites were located according to 5-year-average timber harvest by region (table 1). Because most commercial logging occurred in the southeast and western resource areas, most of the sample sites were located in these regions (fig. 2). To keep private landowner data confidential, detailed findings by region and ownership will not be reported. However, because ownership had been shown to be only minimally related to the residue factor in a recent Pacific Northwest logging utilization study (Berg et al. 2016), any substantive loss in research findings is unlikely.

Harvesting methods included felling and merchandising either mechanically or by hand, as well as a combination of the two (fig. 6). 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 and prescription. Cable logging was typically conducted with three-drum skyline yarders equipped with motorized carriages. Ground-based skidding included the use of shovels[7] and rubber-tired

Table 1—Percentage of 5-year-average harvest and sample sites by Alaska resource area

Resource area	Harvest	Sample
	Percent	
Southeast	61	59
South-central/western[a]	30	33
Interior	10	7
Total	100	100

Note: Columns may not sum due to rounding.
[a] Resource areas combined to avoid disclosure.

[6] 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.

[7] 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."

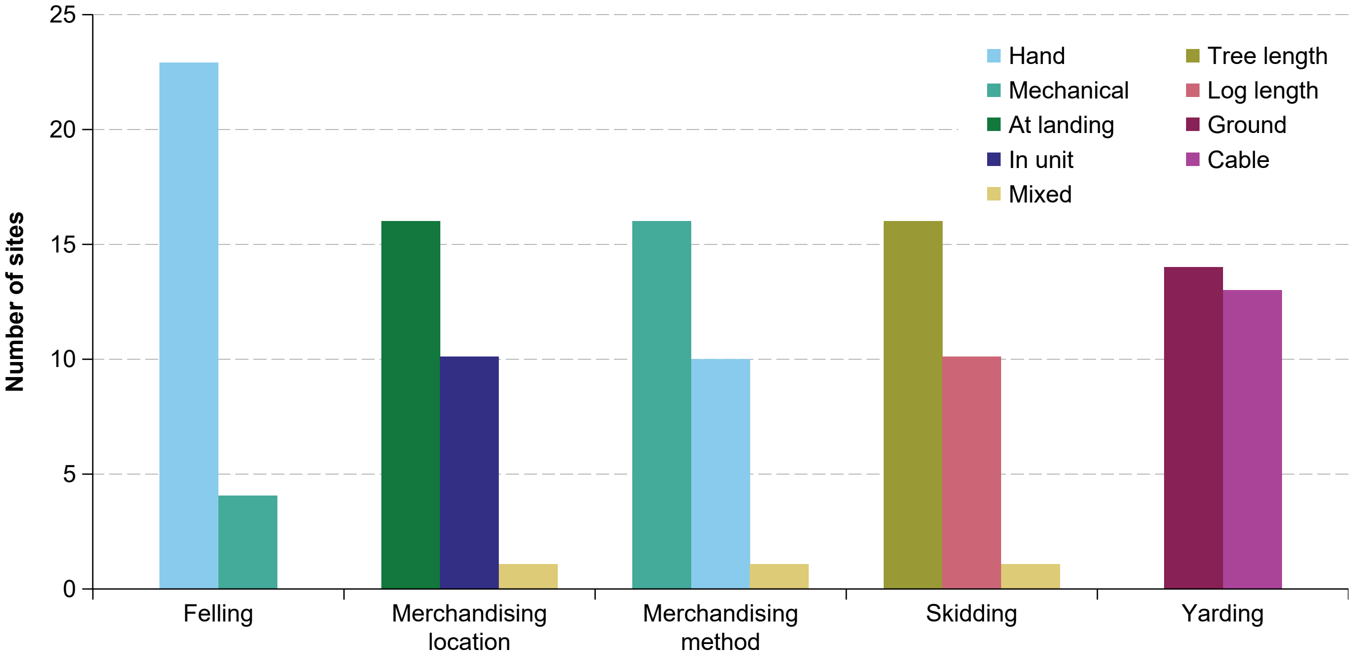

Figure 6—Frequency of logging methods employed on Alaska sampled sites.

skidders; timber was rarely skidded 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. Timber was hand-felled on 85 percent of all sampled sites. Cable yarding was used on 48 percent of the sites. Timber was yarded log-length on 10 of the 27 sites, tree-length skidding being predominant. Timber was processed or merchandised at landings on 59 percent of all sampled sites.

Characteristics of Felled Trees

Sampled trees ranged from 7.2 to 58.8 inches dbh with an average of 20.7 inches overall (standard error = 0.8 inch). Approximately one-half of the measured trees were ≤18.7 inches dbh, but they accounted for only 19 percent of the utilized volume and approximately 15 percent of the growing-stock logging residue (table 2). Trees in the largest diameter classes combined (36 and ≥38 inches dbh) contained the highest proportion of utilized and residue volumes (19.4 and 28.1 percent, respectively). Sitka spruce and western hemlock were the most frequently sampled and harvested tree species (table 3), accounting for 77 percent of the mill-delivered volume from Alaska study sites in this study and 82 percent of the 2015 harvest (Marcille et al. 2021). Western redcedar exhibited the highest residue ratio of any species (14.6 percent) and Sitka spruce the lowest (5 percent).

Of particular note is the difference between sampled trees and the 2015 state-level harvest volume by species. Sitka spruce represented only 47 percent of total

Table 2—Alaska distribution of sampled trees, mill-delivered volume, and growing-stock residue volume (cubic feet) by diameter class

Diameter class	Number of sample trees	Percentage of sample trees	Cumulative percentage of sample trees	Percentage of mill-delivered volume	Cumulative percentage of mill-delivered volume	Percentage of growing-stock logging residue volume	Cumulative percentage of growing-stock logging residue volume
Inches dbh							
8	11	2.5	2.5	0.1	0.1	1.0	1.0
10	20	4.6	7.1	0.6	0.8	1.2	2.2
12	33	7.5	14.6	1.7	2.4	1.9	4.1
14	53	12.1	26.7	4.1	6.5	4.0	8.1
16	48	11.0	37.7	5.3	11.8	3.8	11.8
18	57	13.0	50.7	8.2	20.0	5.1	16.9
20	29	6.6	57.3	5.3	25.3	3.1	20.0
22	38	8.7	66.0	8.2	33.5	6.3	26.3
24	44	10.0	76.0	11.2	44.8	9.4	35.7
26	29	6.6	82.6	9.4	54.2	9.1	44.8
28	18	4.1	86.8	7.0	61.2	9.7	54.6
30	15	3.4	90.2	6.9	68.1	3.0	57.6
32	8	1.8	92.0	4.2	72.3	2.1	59.6
34	13	3.0	95.0	8.2	80.6	12.3	71.9
36	9	2.1	97.0	8.7	89.3	5.8	77.7
38+	13	3.0	100.0	10.7	100.0	22.3	100

dbh = diameter at breast height.

Table 3—Number of sampled trees with percentages of 2015 timber harvest, mill-delivered volume, total logging residue volumes, and residue per cubic foot of mill-delivered volume by species

Species	Number of sampled trees	Percentage of 2015 timber harvest volume (MBF Scribner)[a]	Percentage of mill-delivered volume	Percentage of total logging residue volume	Residue as a percentage of mill-delivered volume
Sitka spruce	181	71	47	25	5
Western hemlock	147	11	30	43	13
Western redcedar	54	10	18	28	15
White spruce	42	6	3	2	6
Alaska yellow cedar	11	1	2	1	6
Other	3	2	0	0	8
All species	438	100	100	100	9

MBF = 1,000 board feet.

[a] Source: Marcille et al. 2021.

sampled tree cubic foot volume but 71 percent of 2015 board foot harvest volume. Western hemlock accounted for 30 percent of sampled tree volume compared to 11 percent of state-level harvest. The likely cause of this disparity is large site-specific differences in species composition among logging sites, which are particularly common in southeast Alaska.

Statewide Logging Utilization Factors

Logging utilization removal factors are statewide ratios of removal volumes vs. mill-delivered volumes (Morgan and Spoelma 2008, Simmons et al. 2016). Removal factors for Alaska indicated that for each 1,000 ft^3 (MCF) delivered to a mill, commercial timber harvesting removed 1,091 ft^3 of growing-stock volume and 92 ft^3 of growing stock was left in the forest or at the landing as logging residue (table 4). A crucial sample design target was met with the current study: the computed Alaska residue factor standard error was 13.8 percent, less than the targeted 20 percent.

Table 4—Alaska logging utilization removal factors

Removals factors	Lower bound (95% CI)	Estimate (ratio of means)	Upper bound (95% CI)	Standard error	Cubic feet per mill-delivered MCF
Growing-stock removals factors:					
(F1) Non-growing stock product delivered to mills (utilized non-growing stock ÷ total utilized)	0.000	0.002	0.003	0.001	2
(F2) Growing-stock product delivered to mills (utilized growing stock ÷ total utilized)	0.997	0.999	1.000	0.001	999
(F3) Growing-stock logging residue (unutilized growing stock ÷ total utilized)	0.066	0.092	0.118	0.013	92
(F4) Removals from growing stock (utilized + unutilized growing stock) ÷ total utilized)	1.064	1.091	1.118	0.013	1091
Sawtimber removals factors:					
(F5) Non-sawlog products delivered to mills (utilized non-sawlog ÷ total utilized)	0.001	0.003	0.006	0.001	3
(F6) Sawlog product delivered to mills (utilized sawlog ÷ total utilized)	0.994	0.997	0.999	0.001	997
(F7) Sawlog logging residue (unutilized sawlog ÷ total utilized)	0.049	0.076	0.103	0.013	76
(F8) Sawlog removals from sawtimber (utilized sawlog + unutilized sawlog) ÷ total utilized)	1.044	1.072	1.100	0.014	1072

CI = confidence interval; MCF = 1,000 ft^3.

Three of the four sawtimber removals factors were slightly lower than their growing-stock counterparts (table 4) because only the sawlog portion of each sawtimber tree (fig. 1) was included in sawtimber factor calculations (sawlog data only in the F6, F7, F8 ratio numerators). The exception was F5 non-sawtimber product delivered to mills, which was 50-percent greater than F1 non-growing stock product delivered to mills largely because log section volumes between the 7-inch dob sawtimber limit and the 4-inch dob growing-stock limit are included in the F5 numerator. Based on informal conversations with the Bureau of Business and Economic Research (BBER) field crews, most land managers have indicated that growing-stock factors are more helpful than sawtimber factors in meeting their postharvest residue estimation needs. However, the sawtimber factors can inform sawlog-focused managers of important changes in forest inventories.

Most of the growing-stock logging residue came from portions of the bole that were broken during felling and stumps cut higher than 1 ft above ground level. Berg (2015) and Wilson et al. (1970) found that breakage accounted for >90 percent of individual tree growing-stock residue. Relatively little logging residue came from stem sections near the end of growing stock (i.e., 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 changes in small-end utilized diameters (e.g., 4 vs. 6 inches dob) yielded small differences in residue volume, residue ratios climbed rapidly as small-end utilized diameters increased. This finding relates to the definition of the residue ratio: growing-stock residue volume divided by mill-delivered volume. The residue ratio spiked as the small-end diameter increased because the ratio numerator (residue volume) increased while the denominator (mill-delivered volume) decreased. Cull material (e.g., rot) was not identified as logging residue. Cull material reduced mill-delivered volumes (i.e., denominators), which therefore yielded higher residue ratios; this cull material's impact on the residue ratio was particularly acute in the largest diameter classes.

In figure 7, standard 2-inch diameter classes were grouped to make the figure less cluttered (i.e., 10-inch dbh class = trees 7.0- to 10.9-inch dbh). The growing-stock residue ratio dropped rapidly from the 10- to the 22.0-inch diameter class groups, then increased progressively to the largest diameter classes (fig. 7). This residue ratio vs. diameter response in Alaska mirrors those of Idaho, Oregon, and Washington. However, in Montana, researchers found that the residue ratio gradually declined with increasing diameter, with no spike in the largest diameter classes (Berg et al. 2018; Simmons et al. 2014, 2016).

Much of the rapid decline in the smaller diameter class residue ratios was largely an artifact of cubic volume computation: the residue ratio denominator—mill delivered volume—was small in the 10-inch dbh class group of trees

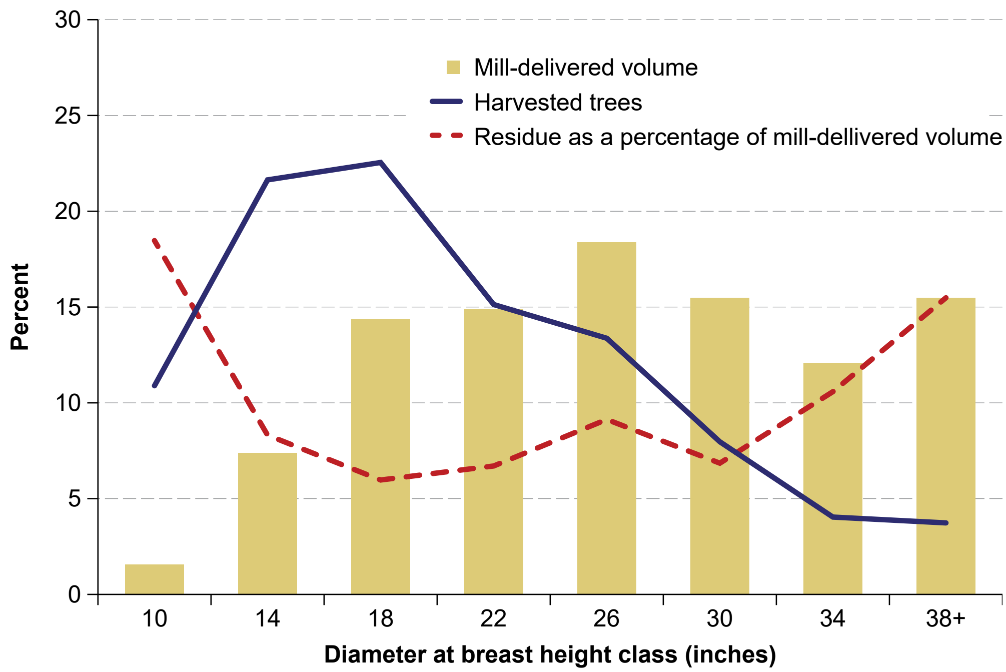

Figure 7—Percentage of mill-delivered volume, harvested trees, and growing-stock residue ratio (cubic feet of growing-stock residue per cubic feet of mill-delivered volume) by diameter class.

but increased rapidly as tree diameter went from the 10- to the 16-inch dbh group, resulting in exponential reductions in the residue ratio (fig. 7). 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).

Unlike the four-state study findings of Berg et al. (2016), the Alaska residue ratio was not related to felling method (p = 0.46 computed with SAS PROC SURVEYREG [SAS 2013]) in part because at the vast majority of logging sites, timber was hand-felled (85 percent); timber was felled mechanically in only four sites, precluding any meaningful statistical comparison. In the four-state study, felling-caused breakage spiked in several Pacific coast hand-felled and mixed-methods sites (Berg et al. 2016, Simmons et al. 2016). Field crews observed extensive felling-caused breakage in Alaska.

Because pre-yarding logging utilization had not been previously researched in Alaska, it was not possible to characterize changes in logging utilization factors over time. However, Howard (1981), Howard and Fiedler (1984), and Howard and Setzer (1989) reported post-yarding logging utilization residue ratios in Alaska and other Western states in the 1980s as cubic feet of wood plus bark residues per thousand board feet Scribner of harvested timber. Howard's post-yarding research is not directly comparable to the current pre-yarding research; however, his work does provide insights on state-level residue production. For public land clearcut sites, Howard's post-yarding utilization ratio (cubic feet residue per thousand board feet harvested) was highest in Alaska among all Northwest states (Alaska: 97 ft^3/MBF, Montana: 95 ft^3/MBF, Idaho: 87 ft^3/MBF, western Oregon: 47 ft^3/MBF, western Washington: 44 ft^3/MBF). Although a direct comparison among states is problematic owing to varied timber composition and conditions, site differences, stand age, and product removal, Howard's ranked findings somewhat dovetail with current Western state comparisons. Alaska exhibited the highest state-level pre-yarding residue ratio of 0.092 in this current study, a substantially higher ratio when compared to recent findings in the lower four Northwest states, Idaho, Montana, Oregon, and Washington (fig. 8) (Berg et al. 2018; Simmons et al. 2014, 2016). Further, Alaska's individual site-level residue ratios ranged from 0.02 to 0.24, while the other Northwest states' ratios ranged from < 0.01 to 0.10 (Berg et al. 2016). This suggests Alaska's logging residue ratios have been greater than those in the lower four Northwest states for at least the past 30 years.

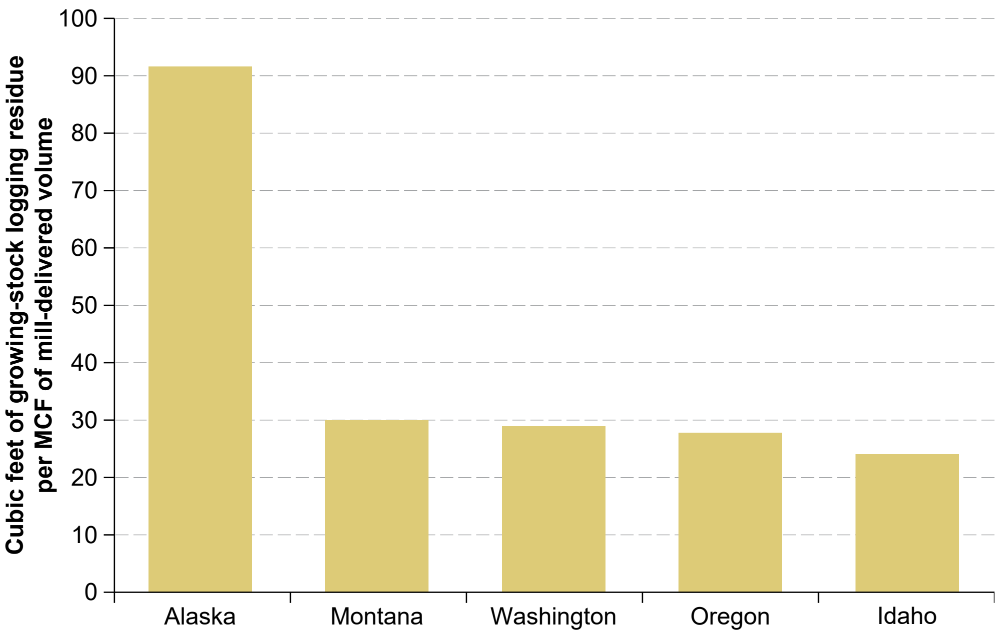

Figure 8—Residue ratios among all Northwest states. MCF = 1,000 ft^3.

Alaska's pre-yarding residue ratio was more than three times greater than residue ratios for the other Northwest states. This finding is likely related to four major factors:

1. **Age-related defect:** Although age is not sampled in logging utilization studies, tree age was likely a factor. Because the vast majority of trees sampled in the lower four Northwest states were located within second- and third-growth plantations, they had less defect characteristic of older trees. In Alaska, many of the largest trees, particularly cedar species, had long butts cut and left onsite as a result of defect typical of older trees (Hennon and Mulvey 2014).
2. **End of utilization:** The diameter of the tree where bole utilization ends can increase residue ratios considerably. The mean small-end utilized diameter (SED) in Alaska was 8.17 inches compared to mean SEDs ranging from 4.5 to 5.0 inches in sampled trees in the lower four Northwest states. The SED has previously been shown to be the most important variable contributing to the residue ratio (Berg et al. 2016).
3. **Stump height:** The height at which trees are cut can leave portions of growing-stock volume attached to stumps in the unit as logging residue. The mean stump height in Alaska was 1.38 ft, compared to mean stump heights of approximately 0.5 ft in the other states. In the lower four Northwest states, <10 percent of sampled stumps were >1 ft in height, compared to 45 percent in Alaska.
4. **Products:** Although pulp was frequently harvested in the lower four Northwest states, no pulp was used in Alaska. Removing pulp logs substantially lowers the logging-site-level residue factor (Berg et al. 2016).

Results of this study can also be used to characterize utilization of the entire bole of the harvested tree without regard to growing stock or sawtimber definitions. In Alaska, 8.9 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, 0.5 percent was derived from non-growing-stock tree tops >4-inch small-end diameter. A total of 91.1 percent of the entire bole was delivered to the mill, including 0.1 percent non-growing stock (fig. 9). This information could benefit forest managers who do not use the FIA distinctions of growing-stock and non-growing-stock tree components.

This investigation provides land managers practical logging residue information: the statewide growing-stock residue factor can be coupled with bole, top, and limb component functions to assemble comprehensive estimates of postharvest woody biomass residues (e.g., Woodall et al. 2011). Logging utilization study data have already been used for a wide variety of applications, including the

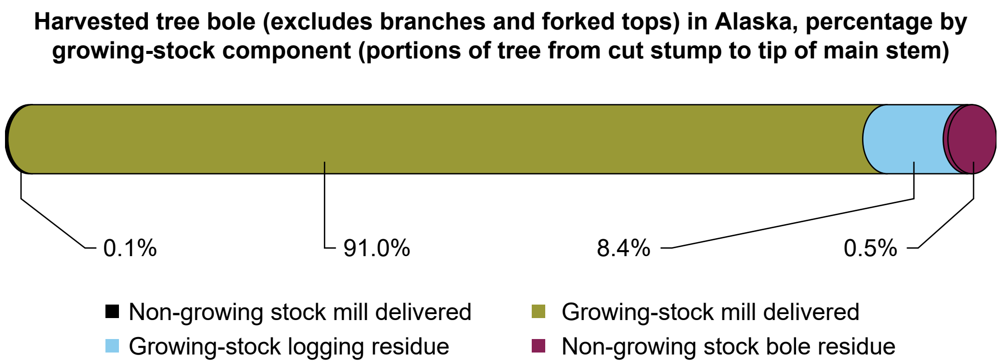

Figure 9—Percentage of sampled volume by growing-stock components in whole felled trees, Alaska.

characterization of felled-tree stump heights (Simmons et al. 2015), small-end utilized diameters (Berg 2014b, Simmons et al. 2015), and the availability of logging residue as a feedstock source for bio-jet fuel (Morgan 2015, 2016). Much more could be done; for example, Alaska land managers have expressed interest in using study results to characterize how logging residue hinders tree planting and other postharvest silvicultural operations.

Conclusions

This investigation characterizes the variability in Alaska logging methods and felled-tree attributes, including growing-stock utilization. Study results will be used to update the Resources Planning Act Timber Product Output database, which will provide land managers state-level information to help them understand the impacts of commercial timber harvesting on growing-stock inventories, woody residue volumes and biomass, and carbon dynamics.

Land managers can use this study's results to predict postharvest residue factors. 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 lifecycle analyses.

Acknowledgments

The authors gratefully acknowledge the financial support of the USDA Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis program in Portland, Oregon (Joint Venture Agreement 15-JV-11261979-073). Other cooperators included the Sealaska Timber Company; Ouzinkie Native Corporation; Natives of Kodiak, Inc.; Koncor Forest Products; USDA Forest Service, Tongass National Forest; and Alaska Department of Natural Resources, Division of Forestry. Without the access to logging sites, assistance from personnel, and other resources of our cooperators, this analysis could not have been accomplished.

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