TIMBER PRODUCTS OUTPUT (TPO):
FOREST INVENTORY, TIMBER HARVEST, MILL AND LOGGING RESIDUE- ESSENTIAL FEEDSTOCK INFORMATION NEEDED TO CHARACTERIZE THE NARA SUPPLY CHAIN

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BBER	Bureau of Business and Economic Research
BDT	bone dry ton: 2,000 pounds of wood at approximately zero percent moisture content
BLM	Bureau of Land Management
CF	cubic feet
dbh	diameter at breast height: tree diameter measured at 4.5 feet above ground
dob	diameter outside bark: tree diameter measured at any point along the bole
FIA	Forest Inventory and Analysis
IDEX	Integrated Design Experience
IDL	Idaho Department of Lands
IW	Interior West
MBF	thousand board feet
MCF	thousand cubic feet
MDF	medium-density fiberboard
MMBF	million board feet
MT-DNRC	Montana Department of Natural Resources and Conservation
NARA	Northwest Advanced Renewables Alliance
NIPF	non-industrial private forest
ODF	Oregon Department of Forestry
OSU	Oregon State University
PNW	Pacific Northwest
RMRS	Rocky Mountain Research Station
TPO	Timber Product Output
USFS	United States Forest Service
WA-DNR	Washington Department of Natural Resources
WMC	Western Montana Corridor
WSU	Washington State University
WWPA	Western Wood Products Association

EXECUTIVE SUMMARY

The University of Montana's Bureau of Business and Economic Research (BBER) Forest Industry Research Program participated in the NARA System Metrics Sustainable Production Team (a.k.a. the Sustainability Measurement Team), collecting and providing detailed measures of forest industry activity in the four-state NARA region. The primary data that BBER produced on the characteristics of timber harvest, logging residue, and mill residue were used by other NARA scientists to further analyze the financial and logistic availability of logging residue as a biojet feedstock and the potential viability of a biojet industry in the Pacific Northwest. These data have also been made broadly available to the public through the BBER's website, the Forest Inventory and Analysis Timber Product Output (FIA-TPO) online database, and by request.

Results from our research show that timber harvest levels and corresponding logging and mill residue quantities vary temporally and spatially across the NARA region. Mill residue is concentrated in counties with large timber-processing facilities and the vast majority is already utilized by the existing forest products industry as raw material for pulp, composite panels (e.g., MDF, particleboard), process heat and steam, or other products. Although substantial quantities of logging residue are generated annually in the region, they, like timber harvest, are not evenly distributed. The quantity of logging residue generally fluctuates with total timber harvest volume, and the amount of residue generated per unit of harvested volume is tending to decrease through time. The presence or absence of roundwood pulpwood removal also decreases/increases the amount of logging residue generated.

Timber Harvest:

Timber harvest volumes have varied across the four-state NARA region. Timber harvest is concentrated west of the Cascade Range in Oregon and Washington, and to a lesser extent in northern Idaho and western Montana. Private landowners are the most consistent and leading source of timber in all four states, despite high proportions of federal timberland ownership. During the U.S. housing bust and Great Recession (2007-2009), private lands timber harvest declined steeply in response to low demand for logs at domestic mills. However, substantial recovery of private lands harvest has been observed since 2010 in western Oregon and Washington and northern Idaho as a result of rising domestic new home construction and increased log exports to Asia. As domestic demand for housing and wood products, particularly lumber, continued to increase, private and state-owned timber harvests also rose. Timber harvest levels in Montana only partially recovered from the record lows of 2009, due to greater dependence on federal forests for timber supply, significant changes in private forest land ownership, and current forest inventory conditions, with substantial proportions of private lands in younger and smaller-diameter stands.

Mill Residue:

BBER's recent harvest and industry reports confirmed and better quantified preliminary observations: virtually all mill residue produced in the region is sold for a variety of industrial uses (primarily pulp and reconstituted board production) or used for internal energy purposes. Small quantities of unused mill residue were scattered among counties with relatively little forest industry. Mill residue production generally increased as primary product (i.e., lumber, veneer, etc.) outputs increased in response to improving economic conditions and increases in domestic new home construction. Bark has been the least utilized component of mill residue, but at 98 to 99 percent utilization in each state, it was still highly utilized.

Logging Residue:

BBER's logging utilization research clearly showed that logging residue as a fraction of mill delivered volume has continued to decline through time as land managers have progressively utilized more of each felled tree on commercial logging units. Improved technology, such as mechanized harvesting and processing, has resulted in more of each felled tree being utilized and allowed the utilization of smaller-diameter material.

Logging residue ratios (the sums of site-level growing-stock residue volume divided by mill delivered volume) varied little among the four NARA states, ranging 0.0240 to 0.0294 (24 to 29.4 cubic feet of growing-stock logging residue per 1,000 cubic feet of mill delivered volume). The likely cause for ratio conformity among states was a lack of variability in current utilization standards and logging systems, as the timber-using industry has dramatically downsized, moved away from harvesting old-growth timber, and shifted more to mechanized harvesting. Trees were often mechanically felled with stump heights less than one foot and small end utilized diameter of 4.0 to 6.0 inches throughout the four states.

BBER analysts found that more than half of the variation in the growing-stock logging residue ratio was related to method of harvest (i.e., by hand or mechanical) and presence/absence of pulpwood removal. The use of timber for pulpwood tended to reduce the volume of growing-stock logging residue generated and potentially available for other uses (e.g., biomass energy or biofuels).

The timber harvest, mill residue, logging residue, and other forest industry information provided by BBER for the NARA project and through the FIA's TPO database is the most current and consistent available. These data were used by several other NARA researchers and students for more in-depth and localized investigations of feedstock availability, biojet feasibility, life-cycle analysis, and sustainability around the region, including the Western Montana Corridor (WMC) and Mid-Cascades to Pacific (MC2P) analyses. By leveraging BBER's work on the NARA project and ongoing agreements with the FIA program, new data will continue to be developed and made available to the public. BBER can readily provide additional information about Idaho, Montana, and Oregon, and additional Washington information is available from WA-DNR. Firm level data are confidential, however, and cannot be released.

INTRODUCTION

Land managers and bioenergy specialists need definitive knowledge of woody biomass inventories and availability in the Pacific Northwest. This information is key to understanding the social, economic, and environmental impacts and sustainability of producing new wood-based energy products. To answer these needs, the Forest Industry Research Program at the University of Montana's BBER collected and provided a variety of information to help characterize the composition, quantities, and spatial distribution of several sources of woody biomass across the NARA four-state area.

The BBER and FIA programs at the Pacific Northwest (PNW) and Rocky Mountain Research Stations cooperated in the original collection and preparation of much of the information presented here. The BBER and FIA program have been studying the region's forest products industry since the 1970s. Work on this report was sponsored by the Northwest Advanced Renewables Alliance (NARA) supported by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30416 from the USDA National Institute of Food and Agriculture. This work covers tasks identified in the AFRI grant under SM-SP-7 "Supply Chain Analysis".

TASK 1: TIMBER HARVEST AND INVENTORY VOLUMES IN THE NARA FOUR-STATE AREA

Task Objective

Identify and provide primary timber harvest and standing Montana and Idaho timber inventory data to assess the woody biomass inventory in the four-state region. Coordinate new and existing Idaho and Montana ("eastside") inventory, harvest, and other data for use in "west-side" models.

This task originally consisted of gathering, summarizing, and sharing timber harvest and standing timber inventory data for use by our NARA colleagues. However, OSU scientists (e.g., Bailey and Latta) coordinated east and west-side forest inventory and growth and yield efforts, using FIA data for the entire NARA project area. No additional effort was needed from the BBER to acquire the forest inventory information. The BBER clarified this change in our 2012 accomplishment reports submitted to NARA.

BBER focused on collecting and providing timber harvest data for the four-state region in three formats:

- annual harvest by county and ownership reported in board foot Scribner measure;
- periodic timber harvest by county, ownership, species, and product type reported in board foot Scribner;
- periodic TPO removals by county, ownership, species, product type, and source (i.e., sawtimber, poletimber, and non-growing stock) reported in cubic feet and FIA standard units.

Methodology

Timber harvest information reported by BBER was generated through a combination of sources. The annual harvest by county and ownership data reported through the BBER's online Harvest by County Tool: www.bber.umt.edu/FIR/H_Harvest were gathered from multiple agencies (e.g., USFS, BLM, ODF, WA-DNR, IDL, and MT-DNRC), which use different data collection methods and time periods (e.g., state or federal fiscal year, calendar year, or quarterly reports). The more detailed harvest and TPO removals information for the individual states were developed through periodic statewide censuses of primary forest products manufacturers (e.g., McIver et al., 2013; Simmons et al., 2014a; Simmons et al., 2016; Washington DNR, 2015b). The censuses also included data from firms in adjacent states that utilize raw material from the target state in the census year. Although great effort was made to collect data from every primary facility that operated during a census year, facilities that were not surveyed may have been added in a subsequent census. Both "Eastside Scribner" (short log) and "Westside Scribner" (long log) rules are used for timber measurement in Oregon and Washington (Fonseca, 2005). Log volumes are presented as they were reported by the participating facilities and agencies; no distinction or standardization was made between the two Scribner log rules.

The Forest Industries Data Collection System (FIDACS) was developed by the BBER in cooperation with the FIA programs in the Rocky Mountain and PNW Research Stations to collect, compile, and report data from primary forest products manufacturers. Primary forest products firms were identified through the use of various phone directories, industry associations, Internet searches, and through previous censuses. The questionnaires were distributed by mail, fax, or email and are administered over the telephone or during on-site visits of timber processing facilities. A single questionnaire was completed for each wood-processing facility and included the following information:

- Plant production, capacity, and employment
- Volume and size of raw material received, by county and ownership
- Species mix and proportion of standing dead timber received
- Finished product volumes, types, sales value, and market locations
- Utilization and marketing of manufacturing residue

Other information sources (Ehinger, 2012, Random Lengths, 1976–2013, WWPA, 1964–2015, Elling, 2015) along with prior survey data were used to estimate attributes for firms that did not participate in mill censuses. Additional information from federal, state, and private sources was used to verify estimates.

Information collected through FIDACS is stored by the University of Montana's BBER. Because of the substantial detail on the industry and its timber use, there is a time lag between the date of the census and publication. To make this information available to the public at the earliest opportunity, summary tables and highlights are made available online as they are compiled and reviewed. (www.bber.umt.edu/fir). Additional information is available by request. However, individual firm-level data are confidential and will not be released.

Results

The BBER has provided annual 2002 through 2014 timber harvest data (in MBF Scribner) by county and ownership for the entire four-state region (Figure TPO-1.1), which is available through the BBER's online Harvest by County Tool: www.bber.umt.edu/FIR/H_Harvest.asp. This timber harvest information has facilitated updating models of potentially available feedstock, and measures of sustainability (e.g., growth-to-harvest ratios). Several NARA researchers, e.g. Darius Adams and Greg Latta, Natalie Martinkus, Indroneil Ganguly, and the IDEX student groups, have used the BBER's timber harvest data to analyze feedstock availability.

State-level harvest information below has been summarized from BBER's harvest by county tool; BBER's forest industry reports for Idaho (Simmons et al. 2014a), Montana (McIver et al. 2013), and Oregon (Simmons et al. 2016); and WA-DNR harvest and industry reports (Washington DNR 2015a and b).

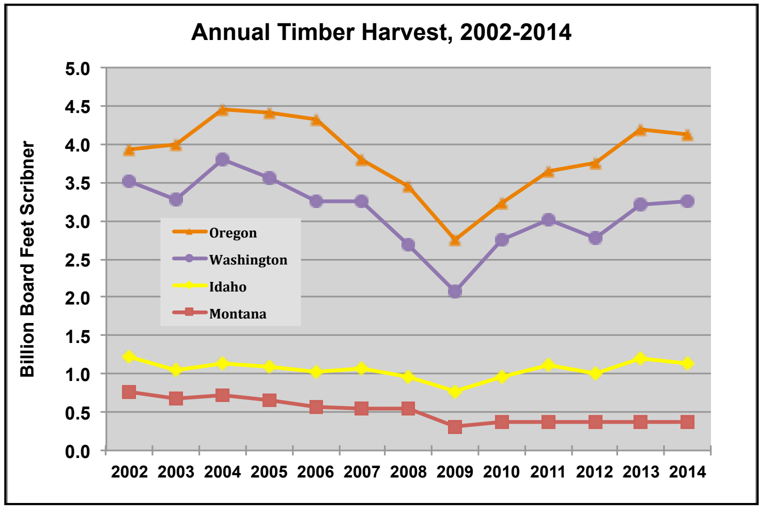

Figure TPO-1.1. Annual timber harvest volumes in Idaho, Montana, Oregon, and Washington; 2002-2014.

Idaho

Total harvest in Idaho in 2014 was 1,135 million board feet (MMBF) Scribner log scale, reflecting little change from 2004 (1,133 MMBF). The 2014 harvest was almost 47 percent higher than the 2009 low point (774 MMBF) during the Great Recession. Private industrial timberlands held stable around 47 percent (531 MMBF) of harvest from 2004 to 2014. Timber harvested from non-industrial private forest (NIPF) lands fell from 38 percent of the total harvest in 2004 to just 12 percent in 2014 (from 434 MMBF to 164 MMBF). Public lands contributed 53 percent of the harvest in 2014 compared to 66 percent in 2004. Harvest from state lands increased from 164 MMBF to 273 MMBF. National Forest harvest remained relatively stable at 13 percent in 2004 to 14 percent in 2014. The vast majority of Idaho timber has been harvested on highly productive forested sites north of the Salmon River (87 percent of total state harvest in 2014). Clearwater County provided 17 percent of Idaho's 2014 timber harvest, the highest of any Idaho county.

True firs were the largest component (35 percent) of Idaho's 2011 timber harvest, which was similar to 2006 (Simmons et al. 2014a). Douglas-fir, at 24 percent, was the second largest component of the 2011 harvest. As in 2006, western redcedar and ponderosa pine rounded out the top four most harvested species. These four species comprised 82 and 81 percent of the total harvest in 2006 and 2011 respectively.

In 2011, all of Idaho's species groups were used to produce lumber (Simmons et al. 2014a). Overall harvest by species for 2011 closely matched what was found in the 2006 mill census. As in 2006, true firs were the species most harvested for saw and veneer logs, comprising 36 percent of the saw and veneer log harvest, while Douglas-fir accounted for 26 percent. Western redcedar and ponderosa pine represented 10 and 11 percent of the saw and veneer log harvest in Idaho, respectively.

Changes in the harvest for products other than saw and veneer logs can be attributed to the influence of reduced demand for saw/veneer logs, house logs, and strong pulpwood markets. The 2011 harvest for other timber products (90 MMBF) including pulpwood, posts and poles, furniture log, and energy wood, was primarily made up of true firs (44 percent), western hemlock (26 percent), western redcedar (15 percent), and Douglas-fir (8 percent). Posts and small poles accounted for 3.6 percent (3.3 MMBF) for other products. The primary species harvested for posts and small non-utility pole products were lodgepole pine (79 percent) and ponderosa pine (14 percent). The western redcedar harvested for other timber products was used entirely to make utility poles. Harvest for cedar products was 30 MMBF in 2011, 30 percent higher than in 2006 (23 MMBF). Lodgepole pine and ponderosa pine comprised 59 percent of the timber used for house logs during 2011.

Montana

The timber harvest volume from lands in Montana was 365 million board feet (MMBF) Scribner in 2014, a decline of nearly 49 percent from the 2004 harvest of 713 MMBF. Between 2004 and 2014, harvest on all private ownerships (industrial, non-industrial and tribal) dropped off precipitously from a total private harvest of 520 MMBF to 190 MMBF. The poor lumber markets brought about by the Great Recession and inventory constraints on private lands of 2007 through 2009 resulted in total 2009 private land Montana harvest of only 146 MMBF. During the decade preceding 2004, private lands accounted for approximately 70 percent of Montana's timber harvest, and National Forests accounted for about 20 percent. The proportion of the National Forest harvest increased from 19 percent in 2004 to 33 percent in 2014, while the proportion from private lands dropped from 73 percent to 52 percent. Harvest volumes from other public ownerships (e.g. State and BLM lands) decreased slightly from 58 MMBF to 56 MMBF. All regions of Montana showed substantial declines in harvest between 2004 and 2014, with the largest proportionate changes occurring in eastern Montana. The four counties making up the Northwest region provided 54 percent of Montana's 2014 harvest, led by Flathead and Lincoln counties.

Douglas-fir was the leading species harvested in 2014 (41 percent), followed by lodgepole pine (21 percent), and ponderosa pine (16 percent). Lodgepole pine harvest dropped between 2009 (the peak year for lodgepole harvest for more than 30 years) and 2014 as salvage of bark beetle mortality declined. The decreased proportion of ponderosa pine can be attributed to decreasing harvest levels from non-industrial private lands in eastern Montana. Mill closures, high transportation costs and poor markets have all played a role in the reduction in harvest of this species.

Industrial timberlands provided more Douglas-fir (114 MMBF), ponderosa pine (40

MMBF), western larch (20 MMBF), and spruce (19 MMBF) than any other ownership. NIPF lands accounted for the majority of lodgepole pine (42 MMBF). In 2014, NIPF lands were the leading source of saw and veneer logs, and house logs (960 MMBF), while industrial lands were the leading source of other products (32 MMBF). During 2014, Douglas-fir was the most frequently harvested species for saw and veneer logs. Lodgepole pine accounted for the majority of house logs (1 MMBF) and other products (19 MMBF). Sawlogs accounted for the largest volume within each species.

Oregon

The majority (64.6 percent) of the timber harvested in Oregon in 2013 came from industrial timberlands; NIPF and Tribal timberlands provided 15.4 percent, National Forests 9.0 percent, State lands 6.6 percent, and BLM and other public sources provided the remaining 4.3 percent (Simmons et al., 2016). Nearly 16 percent (662 MMBF) of Oregon's 2013 timber harvest was exported to countries in the Pacific Rim.

Harvest in 2014 followed a similar trend. The majority (63.6 percent) of the timber harvested in Oregon in 2014 came from industrial timberlands mostly located west of the Cascade crest. NIPF and Tribal timberlands provided 14.9 percent, National Forests 9.4 percent, state lands 5.6 percent, and BLM and other public sources provided the remaining 6.5 percent. The 2014 NIPF and Tribal timber harvest grew by 168 percent from 2004. This large increase reflects increased domestic homebuilding and increased log demand from the Pacific Rim countries, predominantly China. Timber harvest on National Forest and BLM lands also increased from 2008, with a growth of 58 percent and 16 percent respectively. Between 2004 and 2014, harvest on all private ownerships (industrial, non-industrial and tribal) dropped off precipitously from a total private harvest of 3,685 MMBF to 2,145 MMBF. The poor lumber markets brought about by the Great Recession resulted in total 2009 Oregon harvest of only 2,748 MMBF.

Oregon has traditionally been divided into two major wood-producing regions. The Western Region contains all counties lying west of the crest of the Cascade Range; the Eastern Region consists of all the remaining counties. Overall, the Western Region supplied almost 90 percent of Oregon's 2014 total timber harvest; the Eastern Region supplied the remaining 10 percent.

Softwoods accounted for 96.5 percent of Oregon's 2013 harvest; hardwoods made up the remaining 3.5 percent (Simmons et al., 2016). Douglas-fir was the leading species harvested, accounting for 69.5 percent of total harvest. Western hemlock followed with 11.2 percent, and the remaining other softwoods accounted for 15.7 percent. Red alder represented 1.9 percent of the total timber harvest, and other hardwoods represented 1.6 percent. Douglas-fir was the leading species harvested on each ownership followed by western hemlock and true firs, except on national forests where pines were the second-most harvested species group by volume.

Harvest proportions of most species have remained fairly consistent through time (Simmons et al. 2016). Douglas-fir has been the leading species harvested in Oregon, accounting for 60 to 70 percent of annual harvest volume. The most notable exception is pines, which have declined as a proportion of total harvest, corresponding to declines in federal lands harvest levels, particularly in eastern and central Oregon.

Washington

More than 3.6 billion board feet Scribner of timber were processed in Washington's mills or exported in 2014 (Washington DNR 2015a and b). Mills received logs from 32 of Washington's 39 counties with about half of the volume coming from Grays Harbor, Lewis, Clallam, Snohomish, Cowlitz, and Pacific counties. Oregon contributed 11 percent of the total volume received by facilities in Washington, of which 82 percent was exported through the Port of Longview. Another 4 percent came from other states and British Columbia. More than 1,140 MMBF was exported from Washington ports in 2014.

Unlike Oregon's 63.6 percent industry contribution, industrial timberlands supplied only 35.2 percent of Washington's total 3,257 MMBF 2014 harvest. Non-industrial private and tribal lands supplied more than 40 percent (1,310 MMBF) and state lands provided nearly 18 percent. National Forests supplied 5.1 percent. NIPF and Tribal timber harvest consistently provided more than 40 percent for each year from 2004 to 2014. Much of this volume was harvested on Washington tribal lands. Timber harvest on National Forest and BLM lands also experienced increases from 2008, with a growth of 58 percent and 16 percent respectively. Between 2004 and 2014, total harvest dropped precipitously from 3,790 MMBF to 3,257 MMBF. The poor lumber markets brought about by the Great Recession resulted in a steep decline to a total 2009 harvest of only 2,067 MMBF. DNR land contributions ramped-up to more than 28 percent in 2009 (compared to 19 percent in 2008).

The major species harvested in 2014 were Douglas-fir (60 percent) and hemlock (25 percent); Washington is the second largest producer of these softwood species. Other species include hardwoods, such as red alder, and eastern Washington pines. Additional information on Washington timber harvest by species is available from Washington DNR (2015a and b).

Conclusions/Discussion

Timber harvest volumes have generally declined over the past 20 years across all four NARA states (McIver et al., 2013; Simmons et al., 2014a; Simmons et al., 2015; Washington DNR, 2015a). Private lands timber harvest declined in response to low demand for logs at domestic mills during the U.S. housing bust and Great Recession. However, substantial recovery of private lands harvest has been observed since 2010 in western Oregon and Washington as a result of increased log exports to Asia. As domestic demand for housing and wood products increases, private and state-owned timber harvest is also expected to rise.

TASK 2: PRODUCTION AND USES OF MILL RESIDUES IN THE PACIFIC NORTHWEST

Task Objective

Enhance and update primary mill residue information for the four-state region.

Methodology

Updated mill residue data, as well as location, operating status, capacity and other attributes of mills, were assembled from the BBER's periodic censuses of timber-processing facilities conducted during the NARA project. These include mill studies in Idaho (Brandt et al., 2012, Simmons et al., 2014b), Montana (McIver et al., 2013, Hayes and Morgan, in preparation), and Oregon (Gale et al., 2012, Simmons et al., 2016). The WA-DNR provided updated mill residue data for the state of Washington (Washington DNR, 2015b), which BBER converted to TPO format.

Each timber-processing facility provided data on the quantities, types (coarse, fine, bark), and uses of their manufacturing residue. Residue data were aggregated to the county or multi-county group to prevent disclosure of individual firm information, and the aggregated data were converted to the national FIA-TPO format and units of measure (cubic feet and BDT) for standardized reporting. Mill location and residue information for all four states were provided to NARA colleagues, including Natalie Martinkus at WSU and the IDEX Team at WSU and the University of Idaho, as well as the national TPO database for public availability and further analysis, including GIS spatial analysis.

Results

The mill residue data developed by BBER were used throughout the NARA project by researchers and students, and are available to the public. Data for the following years within the NARA region are available on request from BBER and the national FIA-TPO site: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php :

- Idaho: 1995, 2001, 2006, and 2011
- Montana: 1993, 1998, 2004, 2009, and 2014
- Oregon: 1994, 2003, 2008, and 2013
- Washington: 1996, 2002, 2010, 2012, and 2014.

The BBER's mill residue information for the four NARA states (Table TPO-2.1) clearly indicates the vast majority of mill residue is currently utilized. More than 9 million BDT of wood residue and over 3 million BDT of bark residue are generated annually in the region. Over 99 percent of wood residue is used in each state. Idaho and Montana have the highest proportions of unused mill residue (0.72 and 0.29 percent, respectively), and Idaho has the most unused wood residue, at more than 8,000 BDT. Montana has the highest volume (2,359 BT) and proportion (1.29 percent) of unused bark residue. The 2014 Washington mill survey (Washington DNR 2015b) reported only 2 BDT of unused bark residue.

"Internal" energy production at the timber-processing facility where the residue is generated accounts for 10 to 15 percent of total mill (wood and bark) residue volume and 38 to 72 percent of residue use for energy in each state. The use of mill residue for internal energy production is highest in Montana. Montana sawmills derive a large portion (77 percent) of their on-site energy use from wood and bark, primarily for process heat and steam for drying lumber (Loeffler et al., 2016). Larger proportions of mill residue are sold as fuel to other (e.g., biomass energy, wood pellet, or pulp & paper) facilities in the other NARA states.

Wood residue from mills is most commonly sold for use as a raw material in pulp and paper or composite panel (e.g., MDF or particleboard) production. Nearly 80 percent (7.5 million BDT) of the wood residue in the region is currently used for pulp and composite panels. Washington has the lowest proportion (68 percent) of residue used for pulp and panels, while in Montana and Oregon it is over 90 percent.

Fuel is the major use for bark residue in the region, with almost 75 percent (2.4 million BDT) of bark used internally or sold for fuel. Washington is the only state in the region where other uses of bark exceed use for fuel. Stronger markets in Washington for landscaping material or "beauty bark" are believed to contribute to this difference.

Table TPO-2.1. Wood and bark residues from timber-processing facilities by use and state.

Residue & use	ID	MT	OR	WA	NARA region
			thousand dry tons		
Wood residue	**1,181.3**	**632.5**	**4,778.9**	**2,843.4**	**9,436.2**
Pulp & composite panels	1,061.0	586.2	3,954.2	1,924.0	7,525.4
Fuel	96.0	35.5	728.9	615.5	1,476.0
Miscellaneous	15.8	8.9	92.1	303.7	420.6
Not used	8.5	1.9	3.6	0.2	14.2
Bark residue	**466.5**	**182.4**	**1,783.4**	**869.6**	**3,301.9**
Pulp & composite panels			8.4	59.8	68.2
Fuel	359.1	135.3	1,546.4	391.0	2,431.8
Miscellaneous	106.1	44.8	226.4	418.8	796.0
Not used	1.4	2.4	2.2	0.0	5.9
Total	**1,647.9**	**815.0**	**6,562.2**	**3,713.0**	**12,738.0**

Mill residue is highly concentrated in counties with large timber-processing facilities (Figure TPO-2.1). About 20 counties across the four-state region account for almost 8 million BDT (60 percent) of total mill residue production. On the eastern side of the region, just five counties in northern Idaho account for 75 percent (1.2 million BDT) of the state total, and 9 percent of the regional total. In Montana, Flathead County accounts for 42 percent of statewide total residue, with four other counties accounting for another 40 percent. However, those five counties account for less than 0.7 million BDT, about 5 percent of the four-state regional total.

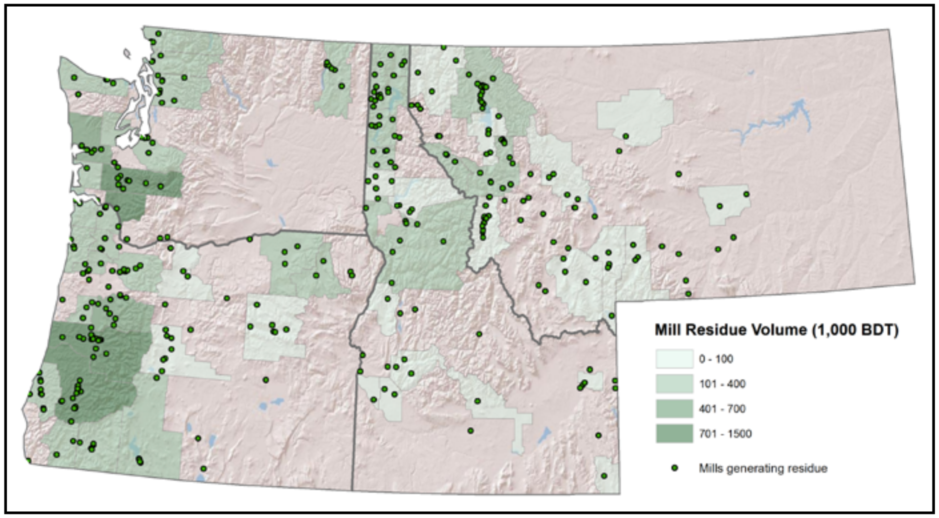

Figure TPO-2.1. Timber-processing facilities and mill residue production in the NARA region.

On the western side of the region, six counties in Oregon account for 3.9 million BDT of residue, which represents about 31 percent of the regional total and 60 percent of total mill residue in the state. And in Washington, four counties account for almost 2.2 million BDT of residue, 58 percent of the state total and 17 percent of the regional total. Clearly, the distribution of mill residue, like timber harvest and industry infrastructure is heavily skewed toward the counties in western Oregon and Washington. However, local concentrations of milling capacity and mill residue do exist in northern Idaho and western Montana.

Conclusions/Discussion

With such high levels of mill residue utilization and sales across the four-state region, mill residue seems unlikely to represent a significant source of feedstock for biojet production in the near term. Demand for mill residue such as chips is particularly high in western Oregon and western Washington. However, reductions in the domestic pulp and paper industry are occurring and could lead to local opportunities for new users of mill residue to enter the market. These new users would need to carefully examine the local mill residue market, investigate alternative feedstock sources, and scale themselves appropriately.

The mill residue information provided by BBER for the NARA project and through the FIA's TPO database is the most current and consistent available. By leveraging BBER's work on the NARA project and ongoing agreements with the FIA program, new data will continue to be developed and made available to the public. BBER can readily provide additional information about Idaho, Montana, and Oregon mill residue. Additional Washington mill residue information is available from WA-DNR. Firm level data are confidential and cannot be released.

TASK 3: CHARACTERIZING LOGGING RESIDUE VOLUMES AND BIOMASS IN THE PACIFIC NORTHWEST

Task Objective

Enhance and update logging residue information for the four-state region

Introduction

The Forest Service's Forest Inventory and Analysis (FIA) Program provides information on the condition and changes in the timber resource throughout the United States. This information derives from three interrelated sources: (1) multi-resource inventory based on re-measurement of a network of permanent plots (e.g., Donnegan et al., 2008, Menlove et al., 2012); (2) timber product output (TPO) mill surveys, which census timber-processing facilities to quantify the volume of timber harvested and delivered to mills (e.g., Gale et al., 2012; McIver et al., 2015; Simmons et al., 2014a); and (3) logging utilization studies, which characterize timber harvest operations and determine what proportion of felled timber is left in the forest as logging residue vs. delivered to mills (e.g., Morgan et al., 2005; Morgan and Spoelma, 2008; Simmons et al. 2014b).

The components of forest inventory change (i.e., growth, mortality, and removals) are captured by the FIA plot network. Removals consist of volume harvested for products, logging residue, and "other removals" due to changes in land use. Only through the TPO mill surveys and logging utilization studies can removals for various timber products (e.g., sawlogs, veneer logs, or pulpwood) delivered to mills be quantified and distinguished from removals that are left in the forest or at the landing as logging residue (i.e., material that is cut or killed during commercial harvest but not utilized).

This study, and others like it (Bentley and Harper, 2007, Morgan et al., 2005, Morgan and Spoelma, 2008, Simmons et al., 2014b), make those direct connections among timber harvested for products, the associated logging residue, and the impacts on growing-stock volume. There are several other studies (e.g., Howard, 1978, 1981) that quantify slash or logging residue, however they do not directly associate the residue volume to harvest volumes and FIA inventory parameters (e.g., growing-stock vs non-growing stock volume).

Logging utilization studies provide estimates of logging residue volumes without the need for detailed inventories or tree lists. Study results include calculation of the growing-stock[1] (Figure TPO-3.1) residue ratio, defined as the growing-stock logging residue volume divided by mill-delivered volume. This ratio can be used to quickly estimate growing-stock residue volumes simply by applying timber harvest volumes at stand, landscape, or state-levels (Morgan and Spoelma, 2008). Non-growing stock (i.e., tree top and branch) residue can then be estimated with allometric equations (Woodall et al., 2011) to provide a more complete accounting of total logging residue.

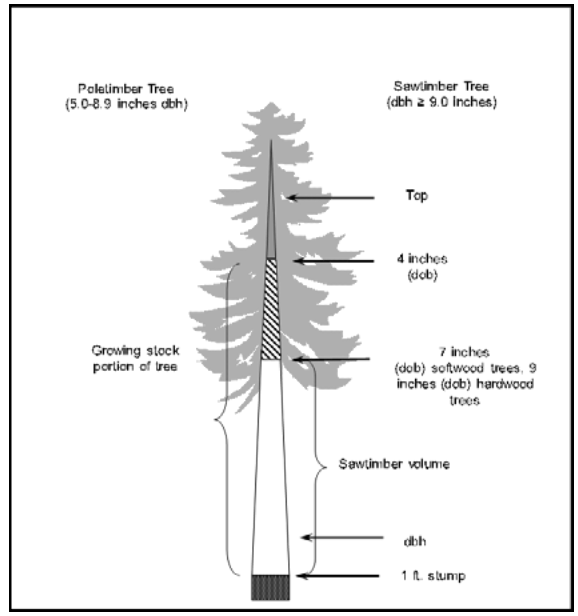

Figure TPO-3.1. Sections of trees and location of growing stock.

The residue ratio is used in the calculation of logging residue volumes published in the TPO database (USDA FS, 2015) maintained by the FIA Program. This internet-housed database utility, often referred to as "RPA-TPO", is used to periodically assess nationwide changes in timber products and logging residue as components of removals from inventory. Recent logging utilization studies in Idaho (Simmons et al., 2014b) and Montana (Morgan et al., 2005) have provided updated residue information for the inland northwest. However, similar studies that link logging residue to TPO and FIA removals have not been conducted in Oregon or Washington, and the most recent investigations in these states were published nearly 35 years ago (Howard, 1981).

Land managers seek information on how logging residue biomass and volume relate to tree and stand-level variables to improve their fuels and bioenergy management prescriptions (Morgan et al., 2009). Logging utilization studies could provide the data needed to improve prescriptions and enable managers to make informed site-specific fuels management and biomass utilization decisions. Spurred by bioenergy needs, European investigators have developed models relating logging

[1] Live trees ≥ 5.0 inches diameter breast height [dbh]; 4.5 feet above ground on the uphill side, measured from a 1-foot stump height to a 4-inch diameter top outside bark [dob].

residue biomass to individual tree and stand attributes (Bouriaud et al., 2013). European scientists have offered land managers tradeoff scenarios of utilization standards, such as minimum small end utilized diameter, versus residue production (Räisänen and Nurmi, 2011). Similar forecasting tools could greatly benefit U.S. land managers.

Because the Pacific Northwest's timber composition, harvest technology, and timber harvest ownership patterns have changed substantially since the 1980s (Gale et al., 2012, Simmons et al., 2014a, Simmons et al., 2016) comprehensive information that reflects the characteristics and effects of contemporary timber harvesting on residue production is needed to predict how post-harvest residues vary. To answer these needs the authors investigated logging residue production in Idaho, Montana, Oregon, and Washington.

The specific objectives of the NARA logging utilization research were:
1) Compute logging utilization factors, including the growing-stock logging residue ratio, for the four-state region;

2) Characterize timber harvest by tree species and dbh;

3) Characterize timber harvest operations by felling, yarding, and merchandising methods; and

4) Produce models that relate the residue ratio to individual tree and stand-level variables meaningful to land managers.

The BBER conducted several investigations to meet these objectives. State-level utilization factors, including the residue ratio, and timber harvest and logging systems were characterized using data collected during 2008 and 2011-2014 for Idaho (Simmons et al., 2014b), 2011-2015 for Oregon and Washington (Simmons et al., 2016), and 2011 to 2016 for Montana. Montana findings will be reported in the near future. Modeling to predict the residue ratio as a function of site and individual tree attributes (Berg et al., 2016) included felled tree measurements from all four states. These investigations shared the same methods (i.e., sampling protocol and data collection procedures). Data analysis, results, and discussion are reported separately.

Methodology

The target population was active logging sites in Idaho, Montana, Oregon and Washington where green (live) trees were being commercially harvested for conversion into wood products including lumber and veneer/plywood. 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, more than 70 percent of each of the four state's annual timber harvest volume had been used for lumber and veneer/plywood production (Simmons et al., 2016; Washington DNR, 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 majority of annual harvest volume as well as volume for other products.

The authors sought a sample of felled trees within logging sites that would provide data to estimate logging utilization factors expressed as the ratios of means at the 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 (McLain, 1996; Morgan and Spoelma, 2008; Simmons et al., 2014). As Morgan and Spoelma, (2008) pointed out, 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 (Lohr, 2009). Berg et al., (2015) analyzed the potential bias in design-based sampling without the use of a sampling frame and found that computed residue ratios exhibited less than 0.5 percent bias. BBER researchers computed state-level utilization factors using design-based procedures.

Model-based sampling offered an alternative method of estimating population parameters without a sampling frame through regression modeling (Sterba, 2009). Model-based approaches provided the opportunity to relate predicted residue ratios to logging-site and individual felled tree variables of interest to land managers, thereby meeting objective 4 of the NARA logging utilization research. Model-based approaches were used to relate the residue ratio to site and tree-level variables in multi-level models.

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 five-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 (Bureau of Business and Economic Research, 2016) provided the geographic location (i.e., county and state) and ownerships of potential sample logging sites (Figure TPO-3.2). 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.

The stage 2 sampling units consisted of felled trees at each selected logging site. In order to qualify as a potential measurement tree, it had to be growing stock (live prior to harvest, dbh ≥ 5 inches, and meet minimum merchantability standards) and the entire stem, including the stump and top, had to be measureable (Morgan and Spoelma, 2008; Woudenberg et al., 2010).

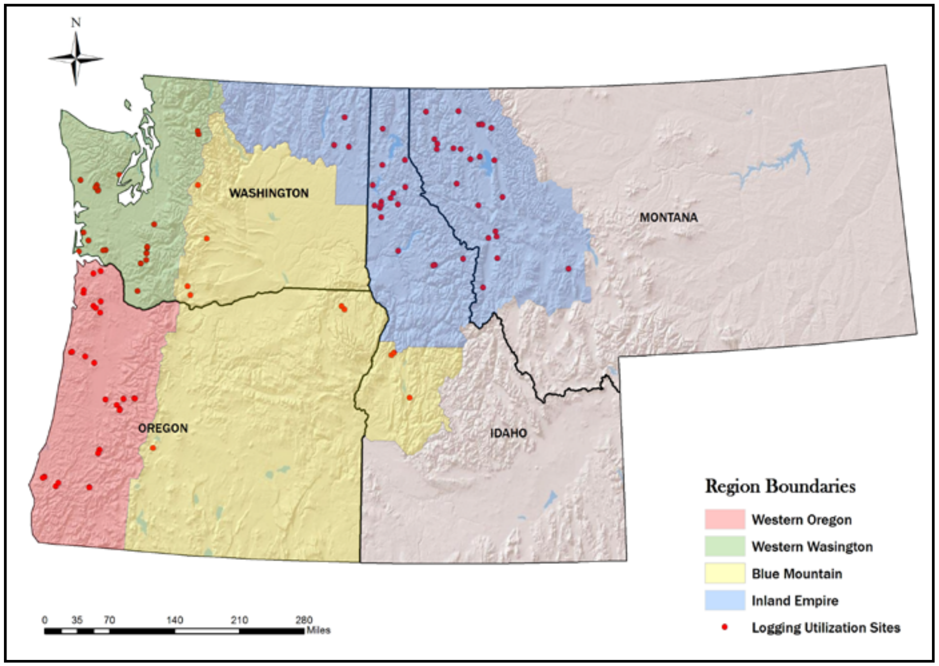

Figure TPO-3.2. Locations of logging utilization sample sites.

Sample sizes for stage 1 and 2 sample units were guided by standard errors achieved on 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., 2014b). 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

Data needed to compute utilization factors was obtained from measurements of felled live trees in active logging sites. Twenty to 33 trees were sampled in each of 112 sites for a total of more than 2,900 sample trees (19 Idaho sites were sampled in 2008 with FIA funding for a total of 131 sites) (Figure TPO-3.2,Table TPO-3.1).

Table TPO-3.1. Number of logging utilization sites measured by state.

State	Sites	Notes
Idaho	20 (+19)	Additional 19 sites measured during 2008, for 39 total in ID.
Montana	28	Additional Montana sites will be measured during August 2016.
Oregon	34	
Washington	30	
Total	**112 (131)**	

Logging contractors or foresters at each selected site were contacted three to five 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 were then able to discriminate between utilized versus non-utilized (residue) felled tree sections. Volumes of utilized and unutilized tree sections were then summed to compute the growing stock residue ratio for individual trees and logging sites. 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 one foot above ground level (uphill side of the tree), at dbh, the end of the first 16 foot log, at the 7.0-inch dob, at the 4.0-inch dob point (end of growing stock) (Figure TPO-3.3), 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 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.

Figure TPO-3.3. Eric Simmons, BBER Research Associate, measuring Douglas-fir log in Tillamook County, Oregon. (Photo courtesy David Wells, Oregon Department of Forestry).

Data Analysis – state-level to meet objectives 1-3.

Following the methods of Morgan and Spoelma, (2008), and Simmons et al., (2014b), 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, 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). Characteristics of the felled trees, harvest operations, and utilization factors were then summarized and compared with historic Idaho, Montana, Oregon, and Washington logging utilization studies and with recent studies from other western states.

Data Analysis- relating residue ratios to site and individual tree variables to meet objective 4.

Researchers developed two multilevel mixed models using the normal distribution. Models related individual tree residue ratios (not the ratio of means) to covariates of interest to land managers. One model related individual tree residue ratios to tree-level attributes designed to inform land managers how residues vary by tree characteristics such as dbh and utilization standards. The second related individual tree residue ratios to readily obtainable logging site-level attributes to enable land managers to easily predict residues on any specific site. Goodness of model fit was gauged by information theoretic metrics based on Aikaike's Information Criteria (AIC) and the proportion of variance explained by the model.

Results and Discussion

Characteristics of logging sites and operations to meet objectives 1-3

Harvesting methods included hand or mechanical felling and merchandising, as well as sites with a mix of the two (Table TPO-3.2). 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 west of the Cascades (Figure TPO-3.4) and gravity-feed or "shotgun" carriages east of the Cascades. Ground-based skidding included the use of shovels[2], rubber-tired skidders, and rarely with dozers 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 (Figure TPO-3.5).

[2] 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 TPO-3.2. Number of sampled logging sites by ownership and logging system.

IDAHO (n=39 sites)

Ownership	Felling: Hand**	Felling: Mechanical	Felling: Mixed	Yarding: Ground	Yarding: Cable	Skidding: Tree Length	Skidding: Log length	Merch Location: In Unit	Merch Location: At Landing	Merch Method: Hand**	Merch Method: Mechanical
	Number of sites										
Federal	1	1	–	1	1	1	1	1	1	–	2
State	3	3	2	7	1	5	3	1	7	2	6
NIPF*	1	2	–	3	–	3	–	1	2	–	3
Industrial Private	6	18	2	24	2	24	2	1	25	3	23
Total	11	24	4	35	4	33	6	4	35	5	34

MONTANA (n=28 sites)

Ownership	Felling: Hand**	Felling: Mechanical	Felling: Mixed	Yarding: Ground	Yarding: Cable	Skidding: Tree Length	Skidding: Log length	Merch Location: In Unit	Merch Location: At Landing	Merch Method: Hand**	Merch Method: Mechanical
	Number of sites										
Federal	3	3	–	3	3	6	–	–	6	–	6
State	3	2	1	6	–	4	2	2	4	1	5
NIPF*	2	3	–	5	–	3	2	3	2	2	3
Industrial Private	3	8	–	9	2	11	–	–	11	–	11
Total	11	16	1	23	5	24	4	5	23	3	25

OREGON (n=34 sites)

Ownership	Felling: Hand**	Felling: Mechanical	Felling: Mixed	Yarding: Ground	Yarding: Cable	Skidding: Tree Length	Skidding: Log length	Merch Location: In Unit	Merch Location: At Landing	Merch Method: Hand**	Merch Method: Mechanical
	Number of sites										
Federal	1	1	–	1	1	2	–	–	2	1	1
State	6	–	–	–	6	6	–	–	6	–	6
NIPF*	1	–	1	2	–	2	–	–	2	–	2
Industrial Private	10	11	3	13	11	24	–	–	24	–	24
Total	18	12	4	16	18	34	–	–	34	1	33

WASHINGTON (n=30 sites)

Ownership	Felling: Hand**	Felling: Mechanical	Felling: Mixed	Yarding: Ground	Yarding: Cable	Skidding: Tree Length	Skidding: Log Length	Merch Location: In Unit	Merch Location: At Landing	Merch Method: Hand**	Merch Method: Mechanical
	Number of sites										
Federal	2	1	–	1	2	1	2	1	2	–	3
State	2	2	1	3	2	5	–	–	5	1	4
NIPF*	1	6	4	8	3	11	–	–	11	–	11
Industrial Private	–	7	4	10	1	11	–	–	11	–	11
Total	5	16	9	22	8	28	2	1	29	1	29

*NIPF = non-industrial private

**Hand = with chainsaws.

Figure TPO-3.4. Skyline yarder with radio-controlled carriage (Photo by Eric Simmons, BBER).

Timber was felled by hand on 28 percent of the Idaho sites, 39 percent of the Montana, 53 percent of the Oregon, and 17 percent of Washington sites. Across the four states, timber was felled mechanically on 52 percent of all sites (68 of 131 total sites). Cable yarding was used on 53 percent of the sites in Oregon and 27 percent of the sites in Washington. Cable yarding was used on just 12 percent of Idaho sites; trees were typically mechanically felled and bunched for grapple skidder yarding in both Idaho and Montana. In all states, tree-length skidding predominated. Ground-based skidding with shovels (i.e., shovel logging) was common on industrial Oregon and Washington west-side private lands. The processing or merchandising of trees at landings by hand was employed on less than 10 percent of the sites in this study.

Figure TPO-3.5. Danglehead processor, western Montana (Photo by Eric Simmons, BBER).

Characteristics of Felled Trees

Trees sampled in Idaho ranged 5.0 to 29.3 inches dbh, 5.4 to 29.0 inches in Montana, 5.0 to 31.3 inches in Oregon, and 5.0 to 37.2 inches in Washington (Figure TPO-3.6, Table TPO-3.3). 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 in Oregon and inconsistent with studies in other western states where smaller trees tended to produce proportionally more residue (Morgan and Spoelma, 2008, Simmons et al., 2014b).

Table TPO-3.3. Distribution of sampled trees, mill-delivered volume, and growing stock logging residue volume in cubic feet (CF) by dbh class.

Idaho (n=959 trees)							
dbh class (inches)	Number of trees	Percent of sample trees	Cumulative percent	Percent of mill-delivered volume (CF)	Cumulative percent	Percent of growing-stock logging residue (CF)	Cumulative percent
6	55	5.7	5.7	0.6	0.6	1.9	1.9
8	152	15.8	21.6	3.8	4.4	5.7	7.6
10	182	19.0	40.6	8.6	13.0	8.8	16.3
12	169	17.6	58.2	12.4	25.4	10.3	26.6
14	120	12.5	70.7	13.0	38.4	12.4	39.0
16	92	9.6	80.3	14.1	52.5	14.3	53.3
18	72	7.5	87.8	13.3	65.7	13.6	66.9
20	52	5.4	93.2	12.6	78.3	12.6	79.5
22	23	2.4	95.6	6.5	84.8	6.6	86.1
24	27	2.8	98.4	9.0	93.8	6.4	92.4
26	10	1.0	99.5	4.1	97.9	5.1	97.5
28+	5	0.5	100	2.1	100	2.5	100

Montana (n=712 trees)							
dbh class (inches)	Number of trees	Percent of sample trees	Cumulative percent	Percent of mill-delivered volume (CF)	Cumulative percent	Percent of growing-stock logging residue (CF)	Cumulative percent
6	47	6.6	6.6	1.2	1.2	3.0	3.0
8	182	25.6	32.2	8.5	9.7	13.7	16.7
10	144	20.2	52.4	11.9	21.6	14.3	31.0
12	109	15.3	67.7	12.7	34.3	14.7	45.6
14	85	11.9	79.6	14.4	48.7	17.3	63.0
16	57	8.0	87.6	13.6	62.2	14.8	77.7
18	35	4.9	92.6	10.9	73.1	8.9	86.7
20	31	4.4	96.9	14.0	87.1	7.3	94.0
22	14	2.0	98.9	7.0	94.2	3.7	97.7
24+	8	1.1	100	5.8	100	2.3	100

Oregon (n=835 trees)							
dbh class (inches)	Number of trees	Percent of sample trees	Cumulative percent	Percent of mill-delivered volume (CF)	Cumulative percent	Percent of growing-stock logging residue (CF)	Cumulative percent
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+	5	0.6	100	2.5	100	4.5	100

Washington (n=726 trees)							
dbh class (inches)	Number of trees	Percent of sample trees	Cumulative percent	Percent of mill-delivered volume (CF)	Cumulative percent	Percent of growing-stock logging residue (CF)	Cumulative percent
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+	9	1.2	100	6.1	100	8.5	100

Percentages may not sum to 100 due to rounding.

In Idaho, about 50 percent of the harvested trees had a dbh ≤ 12 inches and accounted for 18 percent of mill-delivered volume, 19 percent of growing-stock removals, and 20 percent of the growing-stock logging residue. Roughly one-half of the mill-delivered volume, growing-stock removals, and growing-stock logging residue in Idaho came from trees with dbh < 16 inches.

Preliminary results in Montana suggest 50 percent of the sampled trees had a dbh < 10 inches, accounted for about 15 percent of mill-delivered volume and growing-stock removals, and almost 24 percent of growing-stock logging residue. About one-half of the mill-delivered volume and growing-stock removals came from trees with dbh < 15.2 inches. However, about half of growing-stock logging residue came from trees with dbh ≤ 13.5 inches. These findings suggest that smaller trees account for substantially more of the timber harvest and logging residue in Montana than the other NARA states. Additional research is ongoing to better understand these findings and their causes.

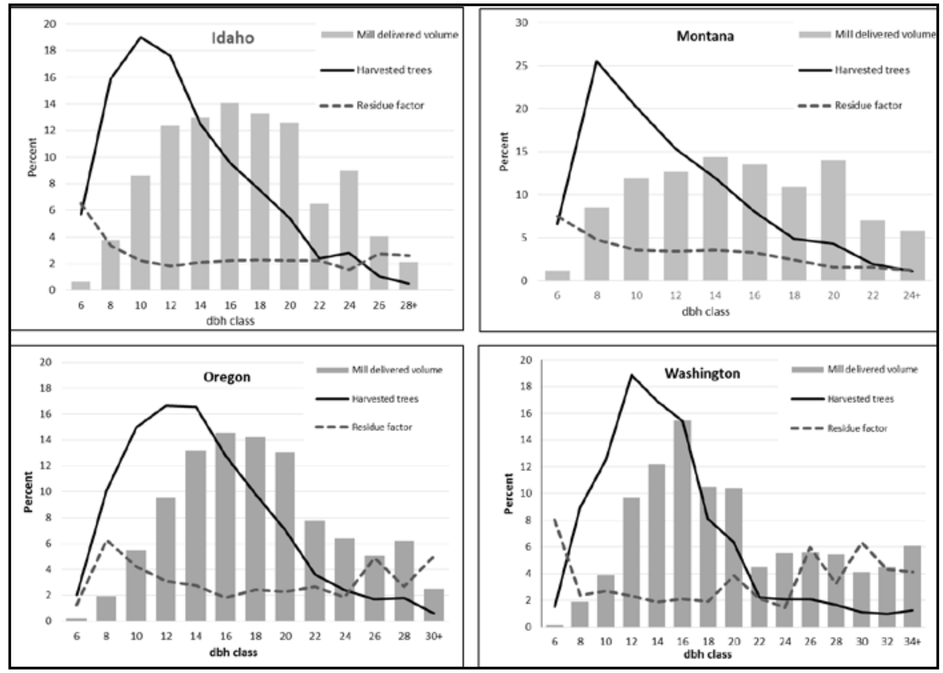

Figure TPO-3.6. Distribution of sampled trees, mill delivered volume, and growing-stock logging residue factor (CF of residue per 100 CF of mill delivered volume) for Idaho, Montana, Oregon, Washington.

Douglas-fir, western hemlock, hardwoods, primarily red alder, and true firs were the four most sampled and harvested tree species in Oregon (Figure TPO-3.7). 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 Washington DNR (2015b). The mill-delivered volume of pines 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 and south of the Salmon River in Idaho, where pine species are more commonly harvested (Simmons et al., 2016, Washington DNR, 2015). 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. Grand fir was the species most frequently harvested in Idaho. Douglas-fir was also the most frequently sampled species in Montana, where pines (lodgepole and ponderosa) also accounted for more than a quarter of mill-delivered volume in this study.

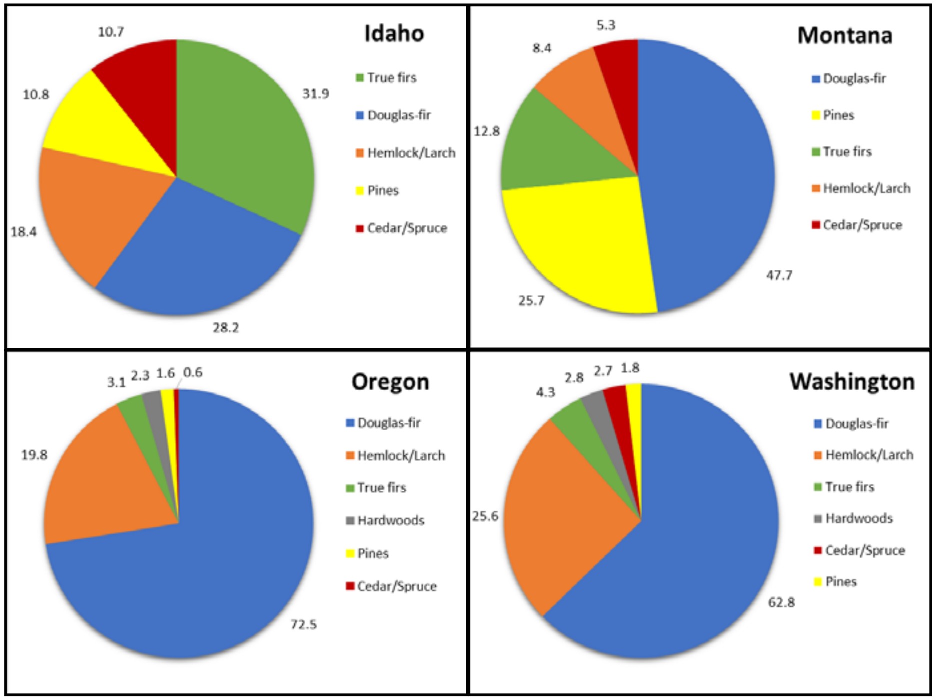

Figure TPO-3.7. Sampled felled tree percent of mill delivered volume by species.

Statewide Logging Utilization Factors

Logging utilization removals factors are state-wide ratios of removals volumes versus mill delivered volumes (Morgan and Spoelma, 2008, Simmons et al., 2014b). Removals factors calculated in this study indicated that commercial timber harvesting in Oregon created 28 CF of growing stock logging residue per 1,000 CF delivered to mills (Table TPO-3.4). 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) went to the mill. Washington removals factors were very similar to those found in Oregon. For each 1,000 CF delivered to the mill, 29 CF of growing-stock material was left on site as logging residue. And, an additional 9 CF of non-growing stock material was delivered to the mill. Montana and Idaho removals factors were similar to those of Oregon and Washington. Preliminary estimates for Montana show the state-wide growing-stock residue factor was 30 CF per mill-delivered MCF, and 20 CF of non-growing stock material was delivered to the mill, suggesting somewhat greater utilization of non-growing stock material in Montana. Idaho results indicated that harvesting efforts created 22 CF feet of growing-stock logging residue per mill-delivered MCF, and that 13 CF of non-growing-stock 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 changes in small-end utilized diameters (e.g. 4.0 inches dob versus 6.0 inches dob)

Table TPO-3.4. Logging utilization removals factors.

Removals factors	Lower bound (95% CI)	Estimate (ratio of means)	Upper bound (95% CI)	Standard Error	Cubic feet per mill-deliverd mcf
Idaho					
Non-growing stock product delivered to mills *(utilized non-growing stock ÷ total utilized)*	0.0090	0.0131	0.0171	0.0020	13
Growing-stock product delivered to mills *(utilized growing stock ÷ total utilized)*	0.9829	0.9869	0.9910	0.0020	987
Growing-stock logging residue *(unutilized growing stock ÷ total utilized)*	0.0153	0.0220	0.0288	0.0033	22
Removals from growing stock *((utilized + unutilized growing stock) ÷ total utilized)*	0.9998	1.0090	1.0182	0.0045	1,009
Montana					
Non-growing stock product delivered to mills *(utilized non-growing stock ÷ total utilized)*	0.0138	0.0203	0.0268	0.0032	20
Growing-stock product delivered to mills *(utilized growing stock ÷ total utilized)*	0.9732	0.9797	0.9862	0.0032	980
Growing-stock logging residue *(unutilized growing stock ÷ total utilized)*	0.0191	0.0298	0.0406	0.0052	30
Removals from growing stock *((utilized + unutilized growing stock) ÷ total utilized)*	0.9962	1.0095	1.0228	0.0065	1,009
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	1,020

yielded small differences in residue volume, residue ratios increased exponentially as small-end utilized diameters increased.

Objective 4- relationship of the residue ratio to variables of interest to land managers (developed with data from 2501 sample trees measured in 101 logging sites in Idaho, Montana, Oregon, and Washington).

Individual felled tree-attribute model

Both site-level and individual tree residue ratios followed an exponential decay pattern and were strongly skewed to the right (Figure TPO-3.8). The best nonlinear multilevel model (trees nested within logging sites) was parameterized with covariates dbh and minimum outside bark small-end diameter of the utilized bole (SEDMIN) using PROC NLMIXED (SAS 2013) (Table TPO-3.5).

Model: Predicted residue ratio = B_0*(SEDMIN)B_1 + EXP(- B_2 * dbh)**

Although this model was ranked number 1 for explanatory strength (Table TPO-3.6), the proportion of model variance explained was only 0.17, which suggested the model had low explanatory power. However, all multilevel models suffer the same problem: clustering comes with a statistical price- goodness of fit drops compared to single-level models (Raudenbush and Bryk, 2002).

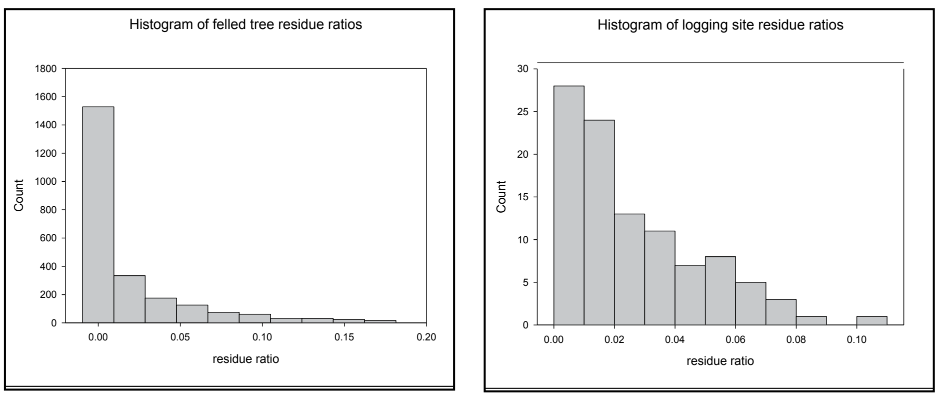

Figure TPO-3.8. Histograms of felled-tree and logging site growing stock residue ratios.

Small-end utilized diameter (SEDMIN) was the most influential of all single variable models as judged by its model rank of 2. (Table TPO-3.6). SEDMIN values were the actual small end diameters measured during field sampling, not the nominal values given on the cutting card. The residue ratio increased at an increasing rate with larger values of SEDMIN in the SEDMIN, DBH model. The opposite was true of dbh. The residue ratio declined exponentially with progressively larger values of dbh

Table TPO-3.5. Tree attribute model.

Parameter	Estimate	Standard Error	t Value	$p > \|t\|$	95% Confidence Limits	
Intercept (B_0)	0.0015	0.0004	04.06	<.0001	0.0008	0.0022
B_1	1.8846	0.1012	18.63	<.0001	1.6839	2.0853
B_2	0.3878	0.0102	37.92	<.0001	0.3675	0.4081
S2U	0.0008	0.0001	05.66	<.0001	0.0006	0.0011
S2E	0.0040	0.0001	34.53	<.0001	0.0038	0.0043

Model: Predicted residue ratio = B_0*(SEDMIN)**B_1 + EXP(- B_2 * DBH)

n = 2501 felled trees, nested within 101 logging sites.

Covariates (Table 3): SEDMIN, the minimum utilized small end outside bark diameter in inches; DBH, diameter breast height in inches.

Proportion of variance explained by the full versus the null model = (null model S2E – full model S2E) / (null model S2E) = 0.17; S2U is the variance of the random effects; S2E is the conditional variance of the response.

Table TPO-3.6. Information theoretic metrics for tree and site-attribute models and individually-modeled covariates.

Models	AIC	DELTA AIC	Akaike Weights	Evidence Ratios	Rank
TREE-ATTRIBUTE					
SEDMIN, DBH	-6497.00	0.00	1	1	1
SEDMIN	-6308.00	189.00	9.1027E-42	1.09857E+41	2
ALDER	-6173.00	324.00	4.4085E-71	2.26833E+70	3
DBH	-6145.00	352.00	3.6658E-77	2.7279E+76	4
WRC	-6077.00	420.00	6.2829E-92	1.59163E+91	5
STUMPHT	-6046.00	451.00	1.1657E-98	8.57839E+97	6
NULL (INTERCEPT ONLY)	-6044.00	453.00	4.288E-99	2.33185E+98	7
SITE-ATTRIBUTE					
PULPALLSOURCES	-6055.34	0.00	0.99663146	1	1
PULPALLSOURCES, FELLING	-6043.93	11.40	0.00332943	299.3399847	2
NULL (INTERCEPT ONLY)	-6034.94	20.40	3.7095E-05	26867.02561	3
OWNERSHIP	6028.64	26.70	1.5896E-06	626970.6448	4
FELLING	-6026.01	29.33	4.2708E-07	2333582.037	5

AIC = Akaike's Information Criterion, smaller AIC values indicate superior fit; DELTA AIC = difference in AIC values between the subject model and the model with lowest AIC; Akaike weights = relative likelihoods of the candidate models; evidence ratios = ratios of the best model's Akaike weight versus the candidate model's Akaike weight, smaller numbers indicate superior models. Rank- based on evidence ratios, e.g. 1 = best overall model.

to approximately 15 inches. The relationship was then linear with essentially no change in the predicted residue ratio when dbh exceeded 15 inches (Figure TPO-3.9). The residue ratio (individual tree residue volume divided by its utilized volume) was highly sensitive to changes in utilized volume but changes in residue volumes yielded only minor differences in predicted ratios for most sampled trees.

Stump height and tree species variables were evaluated but provided little explanatory value and so were not included in the final SEDMIN, DBH model (Tables TPO-3.5 and TPO-3.6).

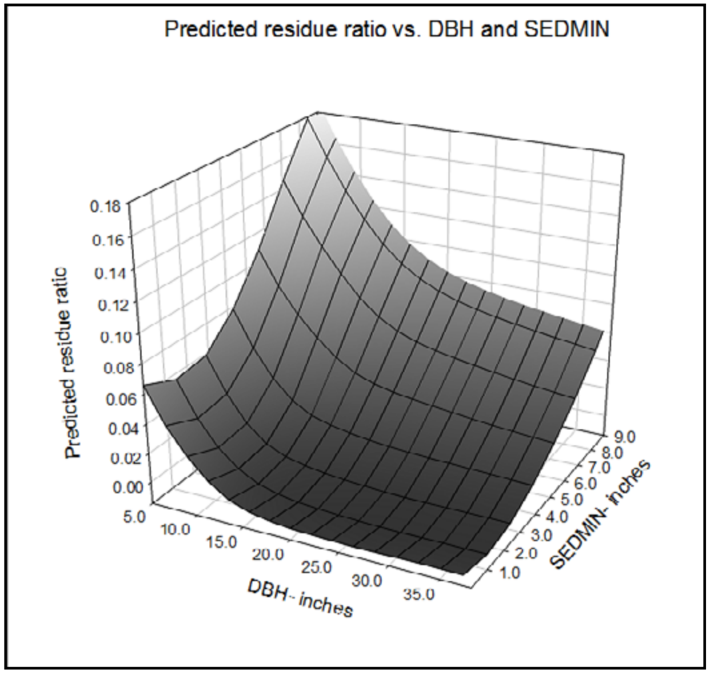

Figure TPO-3.9. The relationship of the predicted residue ratio with dbh and small end utilized diameter (SEDMIN).

Residue ratios varied little by species. Notable exceptions were red alder and western redcedar. Alder was strongly related to the residue ratio with model rank of 3 (Table TPO-3.6). Higher residue ratios of the 57 measured alder trees likely reflected their smaller dbh, substantial top branching, and sinuous bole form compared to other species. Western redcedar was moderately related to the residue ratio (model rank of 5, Table TPO-3.6). Because sampled redcedars and alders were located in only a fraction of the sampled logging sites (13 sites for alder and 24 sites for redcedar) and many sites east of the Cascade crest cannot support the survivorship and growth of these two species, covariates for these species would have limited informative value to many land managers and so were not included in the final tree-attribute model.

Site-attribute model

The residue ratio was predicted using site-attribute covariates in a multilevel linear mixed model parameterized with SAS PROC HPMIXED (SAS 2013) (Table TPO-3.7). Trees were nested within sites, which were nested within regions (Figure TPO-3.2, please see figure legend for region titles).

Model: Predicted residue ratio= B_0 + B_1*PULPALLSOURCES + B_2*FELLING

Despite its simplicity, the above model explained 30 percent of the variation in the predicted residue ratio (Table TPO-3.7). PULPALLSOURCES is a logging site-level dichotomous covariate for whether or not the logger removed any live tree pulp products from the logging site. Pulp logs, generally 10 to 20 feet in length, were bucked from felled tree tops with pulp product SEDMIN ranging 0.1 to 4.0 inches. Entire green trees were seldom merchandised into pulp products. The residue ratio was strongly related to whether or not pulp was removed (PULPALLSOURCES) with model rank of 1.

Table TPO-3.7. Logging site attribute model.

Covariate and (parameter)	Covariate level	Parameter Estimate	Standard Error	t Value	$p > \|t\|$
Intercept (B_0)		0.0550	0.0067	8.26	<.0001
PULPALLSOURCES (B_1)	n	0.0000	.	.	.
PULPALLSOURCES (B_1)	y	-0.0380	0.0070	-5.44	<.0001
FELLING (B_2)	0	0.0143	0.0073	1.94	0.0525
FELLING (B_2)	1	0.0000	.	.	.
FELLING (B_2)	2	0.0109	0.0097	1.13	0.2604

Model: Predicted residue ratio= B_0 + B_1*PULPALLSOURCES + B_2*FELLING

n = 2501 felled trees, nested within 101 logging sites, sites were nested within 4 sub-regions.

Covariates (Table 3): PULPALLSOURCES, taking pulp from the logging site, yes (y) or no (n); FELLING, by hand (chainsaw) = 0, mechanized = 1, combination hand and mechanized within same logging site = 2.

Proportion of variance explained by full versus null model = (null model variance – full model variance) / (null model variance) = 0.30.

Tree felling methods were weakly related to the residue ratio with covariate FELLING (Table TPO-3.7), which represented three categorical values: hand, mechanical, or a combination of hand and mechanical in the same logging site. Hand-felled timber suffered the most breakage and resulted in higher residue ratio values. But breakage sometimes spiked in combination sites. For example, extensive breakage was observed in three western Washington sites with combined mechanical and hand felling. Mechanically felled trees in these units were carefully laid undamaged into bunched piles ready for skidding. Loggers then hand-felled larger-diameter trees onto the piles- resulting in substantial breakage and a residue ratio more than double the mean residue ratio for western Washington.

Figure TPO-3.10 summarizes the tradeoffs in predicted residue ratios by varied values of the PULPALLSOURCES, FELLING model. The smallest predicted residue ratio was found to be the combination of taking pulp plus mechanized felling, 0.01692, and the largest, 0.06921, was not taking pulp in hand-felled units; nearly a four-fold difference in the residue ratio between these two variable combinations.

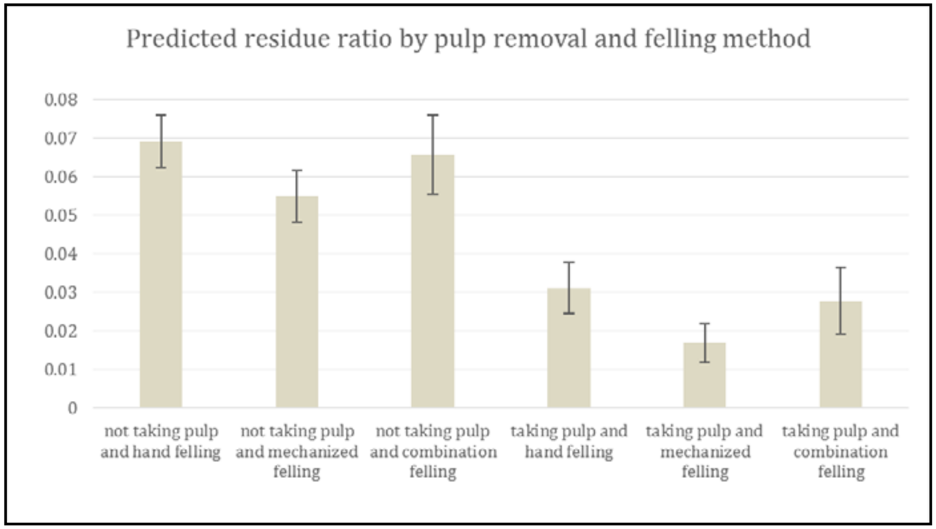

Figure TPO-3.10. Predicted residue ratio (individual tree cubic foot residue volume/mill delivered cubic foot volume) by pulp removal: yes or no, and felling method: hand, mechanized, and combination of hand and mechanized; with standard error bars.

Individual tree and site-attribute models were moderately successful in predicting the variability in the residue ratio. Lack of predictive capability was largely a function of high standard errors commonly experienced with multilevel models, variability in tree-level residue ratios within and among logging sites, and having a strongly skewed residue ratio distribution with many observations equal to zero (Anderson, 2010). However, the authors repeatedly tested models with varied values of the covariates and suggest the models could serve land managers as realistic forecasting tools.

Discussion- modeled residue ratios to meet objective 4

Results concurred with other contemporary logging utilization studies: the residue ratio was less than 4 percent of mill delivered volume. For example, Simmons et al. (2014b) found that Idaho state residue ratio of means declined from 0.123 in 1965 to 0.024 in 2011 in response to progressively more efficient logging and milling technologies, removal of greater percentages of bole wood, and a shift from logging old growth to young growth timber. Morgan et al. (2005) reported a similar rate of decline in Montana: a state-wide residue ratio of 0.163 in 1965 and 0.092 in 2002. Without comparable past logging utilization studies for Oregon or Washington, direct comparisons of this study's results to previous research in western Washington or western Oregon were not possible. But results from the current study are comparable among the four-state region and other western states.

This study's key findings of the growing stock residue ratio's relation to dbh and SEDMIN dovetailed with those of other investigations. For example, Räisänen and Nurmi (2011) developed prediction equations and lookup tables relating a residue ratio (similar to this study's residue ratio) to SEDMIN. They found that total logging residue (including tops and limbs) biomass per ha for Scots pine increased at an increasing rate with SEDMIN. They also found that residue ratios declined exponentially with increasing dbh.

Simmons et al. (2013) summarized the impacts of felling methods on Idaho, California, and Montana state-level residue ratios. Hand-felling was found to produce twice the growing-stock residue compared to mechanized felling in Idaho (0.0400 versus 0.0200). Residue ratios for California and Montana averaged 0.0600 on hand-felled logging sites compared to 0.0500 on mechanized felling sites. Current study results aligned with those of California and Montana. The residue ratio was predicted to increase by 0.0143 in hand-felled sites compared to mechanized felling sites (Table TPO-3.7).

The predicted residue ratio was substantially lower on industry lands than on other ownerships largely because industrial sites more frequently had pulpwood products removed from logging sites and almost exclusively employed mechanical felling.

Conclusions

Summary Findings- all four objectives

1. The residue ratios of means by state were: Idaho- 0.0220 (i.e. 22 cubic feet of growing-stock logging residue generated per 1,000 cubic feet of mill-delivered volume); Montana- 0.0298; Oregon- 0.0278; Washington- 0.0294 (Table TPO-3.4).

2. Douglas-fir was the most frequently sampled tree species across the four-state area; comprising more than 72 percent of the sampled trees in Oregon, 51 percent in Washington, and nearly 48 percent in Montana, but only 28 percent in Idaho (Figure TPO-3.7). True firs (mostly grand fir) were the most frequently sampled species in Idaho (32 percent), largely because

more than 90 percent of sampled Idaho sites were located in mesic lands north of the Salmon River.

3. Sample tree distributions were strongly skewed to the right; the 12 inch dbh class was most frequently sampled in both Oregon and Washington (Table TPO-3.3); the 10 inch class was most often sampled in Idaho, and the 8 inch class in Montana.

4. Timber was felled mechanically on 58 percent of the Idaho, 57 percent of the Montana, 35 percent of the Oregon, and 53 percent of the Washington logging sites. The low percentage of mechanically felled sites in Oregon was largely due to the high proportion of cable yarded sites (53 percent) that required hand-felling (Table TPO-3.2).

5. The majority of sampled logging sites and timber harvest were located on industrial, non-industrial private (NIPF), and state timberlands. Only 6 percent of all Oregon and 10 percent of Washington sampled sites were located on federal lands (Table TPO-3.2). These trends mirror the proportion of timber harvest volumes contributed by federal lands.

6. Individual tree residue ratios were found to be positively and strongly related to small-end utilized top diameter. Residue ratios declined sharply as dbh increased. This same exponential decay pattern of residue ratio versus dbh was observed in logging site residue factors (Figure TPO-3.6).

7. Predicted residue ratios were lowest when pulp was a product removed from the site and much higher when timber was hand-felled and not mechanically felled (Figure TPO-3.10). Felling-related breakage accounted for more than 90 percent of logging residue in all four states.

Conclusions- all four objectives

Growing-stock logging residue ratios have continued to decline with time. For example, Simmons et al. (2014) found that Idaho residue ratios declined from 0.123in 1965 to 0.024 in 2011. Morgan et al. (2005) reported that Montana ratios declined from 0.163 in 1965 to 0.092 in 2002. Preliminary results from the Montana NARA logging utilization sites indicate a current residue ratio of 0.0298, showing further reduction in the growing-stock logging residue factor.

Residue ratios varied little among states, ranging 0.0240 to 0.0294.The likely cause for ratio conformity among states is highly consistent current utilization standards and logging systems across the region, as the timber-using industry has dramatically downsized, moved away from harvesting old-growth timber, and shifted more to mechanized harvesting. Trees were often mechanically felled with stump heights less than one foot and small end utilized diameter of 4.0 to 6.0 inches throughout the four states.

This study's residue ratio models could be used to estimate regional or state-level logging residues. Individual tree predictive models provide the groundwork for tradeoff scenarios of how dbh and small-end utilized top diameter change the growing-stock residue ratio in the Pacific Northwest. Land managers can quickly gauge the impacts of taking pulp and felling method on the residue ratio by referring to Figure TPO-3.8, which summarizes residue ratio estimates for combinations of these two variables. But land managers need to know how these outcomes impact total residue, including boles, tops, and branches. Web-based residue prediction tools to guide fuels management plans, estimate biomass availability, and complete life cycle analyses would be helpful and a logical next step. Creating these internet-based applications concurrently with fundamental research could be the focus of future logging utilization research efforts.

Logging residue ratios can be used in concert with tree crown biomass functions to produce estimates of total logging residue associated with commercial timber harvest (Figure TPO-3.11). The total annual residue quantities by state reveal the major influence that variations in timber harvest volume have on the quantity of logging residue produced.

(Figure TPO-3.11). The total annual residue quantities by state reveal the major influence that variations in timber harvest volume have on the quantity of logging residue produced.

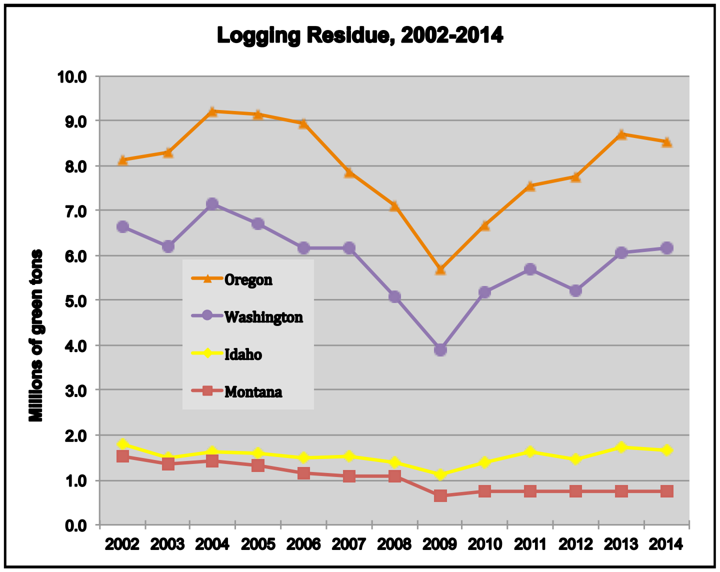

Figure TPO-3.11. Annual logging residue quantities in Idaho, Montana, Oregon, and Washington; including bole wood, tops and limbs, 2002-2014.

NARA OUTPUTS

NARA-Supported Outputs

These BBER outputs were directly supported (in part or in full) by USDA-NIFA funding of the NARA project.

Several pages on the BBER website were developed (and continue to be updated) to help share information from the BBER team's NARA work and from related forest industry research in the four-state NARA region. These pages contain links to numerous BBER posters, presentations, and publications sharing information on our biomass, logging utilization, and forest industry research done with NARA:

- NARA page: www.bber.umt.edu/FIR/L_NARA.asp
- Harvest by County Tool: a five-state (ID, MT, OR, WA, and CA) annual (starting with 2002) timber harvest by county and ownership database that can be accessed at: www.bber.umt.edu/FIR/H_Harvest.asp .
- Logging Utilization page: www.bber.umt.edu/FIR/L_Util.asp

BBER updated the national TPO database, maintained by the USDA Forest Service's FIA Program, with county level timber harvest, logging residue, and mill residue data for Idaho (2011), Montana (2014), Oregon (2013) and Washington (2012 and 2014), developed by BBER for NARA and FIA. The TPO database is accessible at: http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php .

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Related Outputs

These BBER outputs were not directly supported by USDA-NIFA funding of the NARA project but contain related content.

Several pages on the BBER website host forest industry research information from the four-state NARA region. These pages contain links to numerous BBER posters, presentations, and publications sharing information on our biomass, logging utilization, timber harvest, and forest industry research done with the Forest Service's FIA program, other sponsors, and cooperators such as WA-DNR:

- Idaho page: www.bber.umt.edu/FIR/S_ID.asp
- Montana page: www.bber.umt.edu/FIR/S_MT.asp
- Oregon page: www.bber.umt.edu/FIR/S_OR.asp
- Washington page: www.bber.umt.edu/FIR/S_WA.asp

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NARA OUTCOMES

Through BBER's publications, presentations, and website Pacific Northwest land managers, biomass energy developers, policy makers, and students are gaining increased understanding of timber harvest levels and post-harvest logging residue volumes and distribution throughout the region. This enables them to more accurately forecast woody biomass feedstock availability, plan for coarse woody debris retention, and plan post-timber-harvest fuels treatments.

In particular, land managers have gained understanding of how logging residue biomass production changes by tree and logging site attributes such as dbh, species, utilization standards, logging systems, and products that have been removed from the forest. The TPO data that BBER has developed and makes available through the FIA program is an essential input to the econometric model developed and used by Greg Latta and Darius Adams, and is widely used by academics, agencies, and commercial parties seeking consistent, detailed information on harvest and logging residue biomass quantities, availability, and costs.

Fellow researchers, agencies, investors, industrial partners, policy makers, and the general public have learned about the overall lack of readily available, affordable mill residue in the Pacific Northwest. This information has helped NARA scientists and others focus on logging residues as the primary source for biojet feedstock. Barring any major changes in mill residue utilization, this knowledge should enable future investigations to quickly rule-out mill residue as a readily available biomass energy feedstock.

FUTURE DEVELOPMENT

- The BBER's timber harvest and logging utilization research provides land managers with estimates of total logging residues based on commercial harvest levels. Clearly, estimates of *available* logging residues are needed. The BBER welcomes opportunities to leverage logging utilization research results with other NARA investigations to produce easy to use residue prediction tools.

- BBER's logging utilization research data set could facilitate estimates of specific bole wood section and crown biomass contributions. For example, we could predict the quantity of top wood residues above varied small end utilized diameters, e.g. 4 inches dob versus 6 inches dob, to support life cycle or feedstock supply curve analyses. Further, BBER's data sets could discriminate among section locations that contribute to residues, e.g. long-butts versus top wood.

- Further logging utilization study results could support sensitivity analyses of the influence of changing pulp markets and other variables on residue production.

- To keep producing information and benefits beyond NARA's five-year project life, BBER, with ongoing support from FIA, will be producing a report on logging. utilization in Montana, using data collected as part of the NARA project. This report will formally report additional findings and incorporate Montana logging site data collected during the 2016 field season.

- Likewise, with ongoing support from the FIA program, BBER will continue updating the five-state annual harvest-by-county tool developed under NARA, enhancing it with advanced search features and a logging residue calculator. BBER will also continue to provide TPO data for the region, using the logging residue factors, timber harvest, and mill information developed through NARA.

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APPENDIX

BBER's Montana 2014 mill census draft review tables, not yet published online or in hardcopy, are included here as an appendix.

BUREAU OF BUSINESS AND ECONOMIC RESEARCH
UNIVERSITY OF MONTANA

Montana's Forest Products Industry and Timber Harvest, 2014

Draft Data Tables for Review

The University of Montana's Bureau of Business and Economic Research (BBER), in conjunction with the Interior West Forest Inventory and Analysis (IW-FIA) Program of the US Forest Service, conducted a census of Montana's timber processors operating during calendar year 2014. Through a written questionnaire, phone, or in-person interview, timber-processing and residue-utilizing facilities provided information about their 2014 operations, including:

- Plant location, production, capacity, and employment
- Volume of raw material received, by county and ownership
- Species of timber received and live/dead proportions
- Finished product volumes, types, sales value, and market locations
- Volume, utilization, and marketing of manufacturing residue

Because this study is based on a census, rather than statistical sample of firms, there is no statistical error associated with the estimates presented. Possibilities of reporting and measurement error exist, but are minimized by checking each facility's data for internal consistency and cross checking summarized data against other public and private information. We also like to share our draft data tables with those knowledgeable about the state's industry to get a high-level review.

Some firms choose not to participate or do not provide complete data. Data for facilities that did not respond were estimated using previous years' surveys, data from similar facilities, and other information. For the 2014 census, 71 of the 102 active, in-state facilities responded. Responding firms represented 99 percent of the state-wide harvest and 95 percent of the timber processed in Montana. The resulting facility-level information was then compiled and summarized as presented here.

We appreciate your time reviewing these preliminary tables and checking them against what you know about the industry in general and specifically during 2014. Because they are preliminary, we ask that you not share them. A final version of the data tables will be made available to the public after they have been reviewed. In addition, a series of brief reports will be prepared that will include these tables along with some historical information and current industry trends. Past reports for Montana can be found at: www.bber.umt.edu/fir/S_MT.asp

Please provide your comments and any questions to the lead analyst on this report. Thank you for reviewing this information.

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BBER

Table 1--Montana nonreserved timberland by ownership class (source: Interior West Forest Inventory and Analysis, 2014, BBER est.).

Ownership class	Thousand acres	Percentage of nonreserved timberland
National Forest	12,097	61.2
Non-industrial private	5,060	25.6
State	890	4.5
Industrial	867	4.4
Bureau of Land Management	844	4.3
Other public	22	0.1
All owners[a]	19,780	100

[a]Percentage detail may not sum to 100% due to rounding.

Table 2—Montana timber harvest by ownership class, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Ownership class	1981	1988	1993	1998	2004	2009	2014
	Thousand Board Feet, Scribner						
Private	**583,413**	**689,986**	**694,160**	**640,709**	**602,043**	**211,210**	**265,597**
Industrial	351,744	397,853	304,854	354,430	285,324	115,590	94,943
Non-industrial private	208,815	235,381	353,092	262,566	265,691	95,619	170,654
Tribal	22,854	56,752	36,214	23,713	51,028	a	a
Public	**451,664**	**546,308**	**307,069**	**228,699**	**182,915**	**162,329**	**145,998**
National Forest	412,867	496,803	282,324	190,870	116,965	93,580	83,148
Other public[b]	38,797	49,505	24,745	37,829	65,950	68,749	62,850
All owners	1,035,077	1,236,294	1,001,229	869,408	784,958	373,538	411,595
	Percentage of harvest						
Private	**56.4**	**55.8**	**69.3**	**73.7**	**77.0**	**56.5**	**64.5**
Industrial	34.0	32.2	30.4	40.8	36.0	30.9	23.1
Non-industrial private	20.2	19.0	35.3	30.2	34.0	25.6	41.5
Tribal	2.2	4.6	3.6	2.7	7.0	a	a
Public	**43.6**	**44.2**	**30.7**	**26.3**	**23.0**	**43.5**	**35.5**
National Forest	39.9	40.2	28.2	22.0	15.0	25.1	20.2
Other public[b]	3.7	4.0	2.5	4.3	8.0	18.4	15.3
All owners[c]	100	100	100	100	100	100	100

[a]Industrial and Tribal combined to prevent disclosure issues.
[b]Other public includes state and BLM.
[c]Percentage detail may not sum to 100% due to rounding.

Table 3--Proportion of Montana timber harvest (MBF, Scribner) by species, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Species	1981	1988	1993	1998	2004	2009	2014
	Percentage of harvest						
Douglas-fir	27	27	29	34	38	31	41
Lodgepole pine	25	28	26	25	18	35	21
Ponderosa pine	12	17	19	15	19	15	16
Spruces	8	7	6	8	7	8	8
Other species[a]	12	7	8	7	6	4	7
Western larch	16	14	12	10	12	7	7
All species[b]	100	100	100	100	100	100	100

[a]Other species include: true firs, western white pine, western redcedar, western hemlock, Rocky Mountain juniper, aspen and cottonwood, and other softwoods.
[b]Percentage detail may not sum to 100% due to rounding.

Table 4--Proportion of Montana timber harvest (MBF, Scribner) by product, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Product	1981	1988	1993	1998	2004	2009	2014
	Percentage of harvest						
Sawlogs	71	81	79	77	76	73	89
Veneer logs	22	17	17	18	16	c	c
Other timber products[a]	7	3	5	6	8	27	11
All products[b]	100	100	100	100	100	100	100

[a]Other timber products include logs used for pulpwood, posts and poles, house logs, cedar products, log furniture, and industrial fuelwood.
[b]Percentage detail may not sum to 100% due to rounding.
[c]Harvest of veneer logs included in sawlog category to prevent disclosure.

Table 5--Montana timber harvest (million board feet, Scribner) by county, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

	1981		1988		1993		1998		2004		2009		2014	
County	MMBF, Scribner	Percent of Total	MMBF, Scribner	Percent of Total	MMBF, Scribner	Percent of Total	MMBF, Scribner	Percent of Total	MMBF, Scribner	Percent of Total	MMBF, Scribner	Percent of Total	MMBF, Scribner	Percent of Total
Northwest Montana	**633**	**61.1**	**725**	**58.6**	**519**	**51.8**	**415**	**47.7**	**383**	**48.7**	**171**	**45.9**	**222**	**54.0**
Flathead	245	23.6	255	20.6	150	15.0	148	17.0	156	19.8	79	21.2	91	22.2
Lake	28	2.7	53	4.3	53	5.3	38	4.4	33	4.2	23	6.2	31	7.5
Lincoln	267	25.8	324	26.2	208	20.8	153	17.6	119	15.1	43	11.6	60	14.6
Sanders	93	9.0	93	7.5	107	10.7	76	8.7	75	9.6	26	6.9	40	9.7
Western Montana	**229**	**22.3**	**246**	**20.0**	**229**	**22.9**	**203**	**23.3**	**189**	**24.0**	**79**	**21.2**	**70**	**17.1**
Granite	23	2.3	29	2.4	21	2.1	31	3.6	25	3.2	6	1.6	7	1.7
Mineral	45	4.4	40	3.3	32	3.2	20	2.3	41	5.2	13	3.4	16	4.0
Missoula	120	11.6	141	11.4	136	13.6	129	14.8	109	13.9	56	15.0	43	10.5
Ravalli	41	4.0	36	2.9	40	4.0	23	2.6	13	1.7	4	1.2	4	0.9
Southwest Montana	**68**	**6.5**	**88**	**7.0**	**72**	**7.0**	**32**	**3.7**	**37**	**4.8**	**32**	**8.5**	**28**	**6.7**
Beaverhead	10	1.0	16	1.3	5	0.5	2	0.2	6	0.8	11	2.9	5	1.2
Deer Lodge	8	0.7	6	0.5	11	1.1	8	0.9	4	0.5	7	1.9	2	0.4
Gallatin	36	3.5	29	2.3	30	2.9	4	0.5	8	1.0	2	0.5	8	1.8
Madison	3	0.3	18	1.4	9	0.9	11	1.3	5	0.7	3	0.8	9	2.3
Park	8	0.8	16	1.3	11	1.1	6	0.7	8	1.1	6	1.5	4	0.9
Silver Bow	3	0.2	3	0.2	5	0.5	1	0.1	5	0.7	3	0.8	1	0.1
West-Central Montana	**80**	**7.6**	**105**	**8.6**	**80**	**8.0**	**136**	**15.8**	**92**	**11.7**	**70**	**18.7**	**73**	**17.7**
Broadwater	7	0.7	2	0.2	4	0.4	4	0.5	2	0.3	8	2.2	1	0.1
Cascade	1	0.1	5	0.4	1	0.1	10	1.2	3	0.4	1	0.2	2	0.5
Jefferson	8	0.7	8	0.7	3	0.3	6	0.7	12	1.5	6	1.7	5	1.1
Judith Basin	1	0.1	-	0.0	3	0.3	5	0.6	0	0.1	0	0.0	-	-
Lewis & Clark	26	2.5	17	1.4	13	1.3	30	3.5	21	2.7	24	6.4	31	7.5
Meagher	17	1.6	15	1.2	12	1.2	27	3.1	6	0.8	3	0.7	11	2.7
Powell	20	1.9	56	4.6	43	4.3	50	5.7	46	5.9	27	7.3	14	3.4
Wheatland	-	0.0	1	0.1	1	0.1	4	0.5	-	0.0	1	0.2	2	0.6
Other counties													7	1.7
Eastern Montana	**26**	**2.4**	**73**	**6.0**	**102**	**10.3**	**73**	**8.4**	**84**	**10.8**	**20**	**5.4**	**18**	**4.5**
Big Horn	3	0.3	12	1.0	13	1.3	12	1.4	16	2.0	3	0.7	1	0.2
Fergus	9	0.9	11	0.9	24	2.4	9	1.0	15	2.0	3	0.9	3	0.8
Musselshell	2	0.1	4	0.3	13	1.3	6	0.7	1	0.2	1	0.2	2	0.4
Powder River	1	0.1	15	1.2	11	1.1	8	0.9	18	2.3	-	0.0	1	0.2
Rosebud	6	0.6	12	1.0	8	0.8	11	1.3	6	0.8	-	0.0	1	0.1
Other counties	4	0.4	19	1.6	34	3.4	26	3.1	28	3.5	14	3.6	11	2.7
Unspecified	**-**	**0.0**	**-**	**0.0**	**-**	**0.0**	**10**	**1.1**	**-**	**0.0**	**1**	**0.4**	**-**	**-**
All counties[a]	1,035	100	1,236	100	1,001	100	869	100	785	100	373	100	412	100

[a]Percentage detail may not sum to 100% due to rounding.

Table 6--Montana timber harvest by ownership class and species, 2014.

Ownership class	Douglas-fir	Lodgepole pine	Ponderosa pine	Spruces	Other species[a]	Western larch	All species
	Thousand board feet, Scribner						
Private	**113,602**	**55,453**	**39,890**	**18,771**	**18,111**	**19,771**	**265,597**
Industrial and Tribal[b]	41,240	13,714	13,560	5,937	7,884	12,608	94,943
Non-industrial private	72,362	41,739	26,330	12,834	10,227	7,163	170,654
Public	**56,266**	**32,794**	**24,627**	**12,111**	**11,636**	**8,564**	**145,998**
National Forest	29,157	19,754	16,482	6,435	7,626	3,695	83,149
Other public	27,109	13,040	8,145	5,676	4,010	4,869	62,849
All owners	169,868	88,247	64,517	30,882	29,747	28,335	411,595
	Percentage of harvest						
Private	**27.6**	**13.5**	**9.7**	**4.6**	**4.4**	**4.8**	**64.5**
Industrial and Tribal[b]	10.0	3.3	3.3	1.4	1.9	3.1	23.1
Non-industrial private	17.6	10.1	6.4	3.1	2.5	1.7	41.5
Public	**13.7**	**8.0**	**6.0**	**2.9**	**2.8**	**2.1**	**35.5**
National Forest	7.1	4.8	4.0	1.6	1.9	0.9	20.2
Other public	6.6	3.2	2.0	1.4	1.0	1.2	15.3
All owners[c]	41.3	21.4	15.7	7.5	7.2	6.9	100.0

[a]Other species include: true firs, western white pine, western redcedar, western hemlock, Rocky Mountain juniper, aspen and cottonwood, and other softwoods.
[b]Industrial and Tribal combined to prevent disclosure issues.
[c]Percentage detail may not sum to 100% due to rounding.

Table 7--Montana timber harvest by ownership class and product, 2014.

Ownership class	Saw and veneer logs	House logs	Other products[a]	All products
	Thousand board feet, Scribner			
Private	**243,826**	**962**	**20,809**	**265,597**
Industrial and Tribal[b]	90,460	354	4,129	94,943
Non-industrial private	153,366	608	16,680	170,654
Public	**121,008**	**770**	**24,220**	**145,998**
National Forest	65,008	453	17,687	83,148
Other public[c]	56,000	317	6,533	62,850
All owners	364,834	1,732	45,029	411,595
	Percentage of harvest			
Private	**59.2**	**0.2**	**5.1**	**64.5**
Industrial and Tribal[b]	22.0	0.1	1.0	23.1
Non-industrial private	37.3	0.1	4.1	41.5
Public	**29.4**	**0.2**	**5.9**	**35.5**
National Forest	15.8	0.1	4.3	20.2
Other public[c]	13.6	0.1	1.6	15.3
All owners[d]	88.6	0.4	10.9	100.0

[a]Other products include logs used for pulpwood, posts and poles, cedar products, log furniture, and industrial fuelwood.
[b]Industrial and Tribal combined to prevent disclosure issues.
[c]Other public includes state and BLM.
[d]Percentage detail may not sum to 100% due to rounding.

Table 8--Montana timber harvest by species and product, 2014.

Species	Saw and veneer logs	House logs	Other products[a]	All products[b]
	Thousand board feet, Scribner			
Douglas-fir	156,949	195	12,724	169,868
Lodgepole pine	68,028	1,123	19,096	88,247
Ponderosa pine	55,745	-	8,772	64,517
Spruces	30,442	209	231	30,882
Other species[c]	27,104	-	2,643	29,747
Western larch	26,566	205	1,563	28,334
All species	364,834	1,732	45,029	411,595
	Percentage of harvest			
Douglas-fir	38.1	0.0	3.1	41.3
Lodgepole pine	16.5	0.3	4.6	21.4
Ponderosa pine	13.5	0.0	2.1	15.7
Spruces	7.4	0.1	0.1	7.5
Other species[c]	6.6	0.0	0.6	7.2
Western larch	6.5	0.0	0.4	6.9
All species[b]	88.6	0.4	10.9	100.0

[a]Other products include logs used for pulpwood, posts and poles, cedar products, log furniture, and industrial fuelwood.
[b]Percentage detail may not sum to 100% due to rounding.
[c]Other species include: true firs, western white pine, western redcedar, western hemlock, Rocky Mountain juniper, cottonwood and aspen, and other softwoods.

Table 9--Timber flow into and out of Montana, 2014.

Timber products	Log flow into Montana	Log flow out of Montana	Net inflow (net outflow)
	- - - - - Thousand board feet, Scribner - - - - -		
Saw and veneer logs	36,228	14,729	21,499
House logs	2,730	-	2,730
Other products [a]	792	-	792
All products	39,750	14,729	25,021

[a]Other products include logs for pulpwood and posts and poles.

Table 10--Active Montana primary wood products facilities by county and product during 2014 and other years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others).

County	Lumber	Plywood	Pulp and board	Post and poles	Log homes	Log furniture	Other products[a]	All products
Northwest Montana	**10**	**2**	**1**	**2**	**5**	**2**	**8**	**30**
Flathead	5	2	1	-	4	2	5	19
Lake	2	-	-	1	-	-	-	3
Lincoln	1	-	-	1	1	-	2	5
Sanders	2	-	-	-	-	-	1	3
Western Montana	**7**	**-**	**1**	**4**	**11**	**2**	**7**	**32**
Granite	-	-	-	1	-	-	1	2
Mineral	1	-	-	1	-	-	2	4
Missoula	3	-	1	1	2	-	2	9
Ravalli	3	-	-	1	9	2	2	17
Southwest Montana	**3**	**-**	**-**	**3**	**7**	**1**	**3**	**17**
Beaverhead	1	-	-	1	-	1	-	3
Deerlodge	-	-	-	-	-	-	1	1
Gallatin	-	-	-	-	4	-	2	6
Madison	-	-	-	1	3	-	-	4
Park	1	-	-	1	-	-	-	2
Silver Bow	1	-	-	-	-	-	-	1
West-Central Montana	**6**	**-**	**-**	**2**	**-**	**-**	**3**	**11**
Broadwater	1	-	-	-	-	-	1	2
Cascade	1	-	-	-	-	-	-	1
Jefferson	1	-	-	1	-	-	-	2
Lewis & Clark	2	-	-	1	-	-	-	3
Powell	1	-	-	-	-	-	2	3
Eastern Montana	**6**	**-**	**-**	**1**	**2**	**1**	**2**	**12**
Carbon	-	-	-	-	1	-	-	1
Chouteau	-	-	-	-	-	1	-	1
Fergus	2	-	-	-	-	-	-	2
Musselshell	2	-	-	1	-	-	-	3
Stillwater	1	-	-	-	-	-	-	1
Yellowstone	1	-	-	-	1	-	2	4
2014 Total	**32**	**2**	**2**	**12**	**25**	**6**	**23**	**102**
2009 Total	41	2	3	14	33	14	20	127
2004 Total	57	3	3	22	88	29	13	215
1998 Total	73	4	3	29	75	25	11	220
1993 Total	86	4	3	31	59	4	10	197
1988 Total	87	4	3	37	35	2	15	183
1981 Total	142	4	3	35	27	0	17	228

[a]Other products include biomass energy, cedar shakes and shingles, decorative bark and mulch, roundwood pulp-chip conversion, and fuel pellets.

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Table 11--Proportion of timber received by Montana facilities (MBF, Scribner) by ownership class, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Ownership class	1981	1988	1993	1998	2004	2009	2014
	- - - - - - - - - Percentage of timber received - - - - - - - -						
Private	**56**	**55**	**67**	**73**	**74**	**55**	**60**
Industrial	34	34	31	43	39	31	20
Non-industrial private	20	18	33	27	31	24	40
Tribal	2	4	3	3	5	a	a
Public	**44**	**45**	**33**	**27**	**26**	**45**	**40**
National Forest	41	40	30	22	15	24	23
Other public[b]	4	5	2	5	11	21	17
All owners[c]	100	100	100	100	100	100	100

[a]Industrial and Tribal combined to prevent disclosure issues.
[b]Includes timber receipts from unspecified out-of-state sources.
[c]Percentage detail may not sum to 100% due to rounding.

Table 12--Timber received by Montana facilities by ownership class and product, 2014.

Ownership class	Saw and veneer logs	House logs	Other products[a]	All products
	- - - - - - - - - - - - - Thousand board feet, Scribner - - - - - - - -			
Private	**240,504**	**1,701**	**21,149**	**263,354**
Industrial and Tribal[b]	85,544	734	4,129	90,407
Non-industrial private	154,960	967	17,020	172,947
Public	**144,896**	**910**	**24,671**	**170,477**
National Forest	79,486	593	17,899	97,978
Other public	65,410	317	6,772	72,499
Canadian and unspecified[c]	**933**	**1,852**	**0**	2,785
All owners	386,333	4,463	45,820	436,616

[a]Other products include logs used for pulpwood, posts and poles, log furniture, and industrial fuelwood.
[b]Industrial and Tribal combined to prevent disclosure issues.
[c]Includes timber receipts from Canada and unspecified out-of-state owners.

Table 13--Proportion of timber receive by Montana facilities (MBF, Scribner) by product, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Species	1981	1988	1993	1998	2004	2009	2014
	Percentage of timber received						
Saw and veneer logs	92	97	95	94	89	72	88
Other timber products[a]	8	3	5	6	11	28	12
All products[b]	100	100	100	100	100	100	100

[a]Other timber products include logs used for posts and poles, house logs, pulpwood, log furniture, and industrial fuelwood.

[b]Percentage detail may not sum to 100% due to rounding.

Table 14--Timber received by Montana facilities by species and product, 2014.

Species	Saw and veneer logs	House logs	Other products[a]	All products[b]
	Thousand board feet, Scribner			
Douglas-fir	164,830	704	13,041	178,575
Lodgepole pine	71,419	2,427	19,293	93,139
Ponderosa pine	60,503	-	8,931	69,434
Spruces	33,067	878	231	34,176
Other species[c]	29,489	-	2,721	32,210
Western larch	27,026	453	1,603	29,082
All species	386,334	4,462	45,820	436,616
	Percentage of timber received			
Douglas-fir	37.8	0.2	3.0	40.9
Lodgepole pine	16.4	0.6	4.4	21.3
Ponderosa pine	13.9	-	2.0	15.9
Spruces	7.6	0.2	0.1	7.8
Other species[c]	6.8	-	0.6	7.4
Western larch	6.2	0.1	0.4	6.7
All species[b]	88.5	1.0	10.5	100.0

[a]Other products include logs used for pulpwood, posts and poles, log furniture, and industrial fuelwood.

[b]Percentage detail may not sum to 100% due to rounding.

[c]Other species include: true firs, western white pine, western redcedar, western hemlock, Rocky Mountain juniper, cottonwood and poplar, and other softwoods.

Table 15--Timber received by Montana facilities by ownership class and species, 2014.

Ownership class	Douglas-fir	Lodgepole pine	Ponderosa pine	Spruces	Other species[a]	Western larch	All species
	Thousand board feet, Scribner						
Private	**112,579**	**55,954**	**40,302**	**18,701**	**16,683**	**19,135**	**263,354**
Industrial and Tribal[b]	39,120	13,722	13,560	5,637	6,419	11,949	90,407
Non-industrial private	73,459	42,232	26,742	13,064	10,264	7,186	172,947
Public	**65,602**	**35,997**	**28,781**	**14,906**	**15,482**	**9,709**	**170,477**
National Forest	34,572	21,443	18,740	8,406	10,320	4,497	97,978
Other public	31,030	14,554	10,041	6,500	5,162	5,212	72,499
Canadian and unspecified[c]	**394**	**1,188**	**351**	**569**	**45**	**238**	**2,785**
All owners	178,575	93,139	69,434	34,176	32,210	29,082	436,616
	Percentage of timber received						
Private	**25.8**	**12.8**	**9.2**	**4.3**	**3.8**	**4.4**	**60.3**
Industrial and Tribal[b]	9.0	3.1	3.1	1.3	1.5	2.7	20.7
Non-industrial private	16.8	9.7	6.1	3.0	2.4	1.6	39.6
Public	**15.0**	**8.2**	**6.6**	**3.4**	**3.5**	**2.2**	**39.0**
National Forest	7.9	4.9	4.3	1.9	2.4	1.0	22.4
Other public	7.1	3.3	2.3	1.5	1.2	1.2	16.6
Canadian and unspecified[c]	**0.1**	**0.3**	**0.1**	**0.1**	**0.0**	**0.1**	**0.6**
All owners[d]	40.9	21.3	15.9	7.8	7.4	6.7	100.0

[a]Other species include: true firs, western white pine, western redcedar, western hemlock, rocky mountain juniper, cottonwood and aspen, and other softwood

[b]Industrial and Tribal combined to prevent disclosure issues.

[c]Includes timber receipts from Canada and unspecified out-of-state owners.

[d]Percentage detail may not sum to 100% due to rounding.

Table 16--Montana lumber overrun and lumber recovery factor (LRF), selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Year	Timber processed	Lumber produced	Overrun	LRF[b]
	MMBF[a] Scribner	*MMBF[a] Lumber tally*		
2014	337	611	1.81	7.11
2009	237	449	1.89	7.35
2004	521	1,040	2.00	7.26
1998	725	1,287	1.78	7.17
1993	782	1,367	1.75	6.97
1988	985	1,558	1.58	6.79
1981	739	1,071	1.45	6.67

[a]MMBF = million board feet.

[b]LRF = board feet of lumber per cubic foot of log input.

Table 17--Number of Montana sawmills by annual lumber production, selected years (sources: Schweitzer and others 1975; Setzer and Wilson 1970; Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Year	Annual lumber production			Total mills
	Less than 10 MMBF[a]	*10 MMBF[a] to 50 MMBF*	*More than 50 MMBF[a]*	
2014	23	3	6	32
2009	30	6	5	41
2004	43	3	11	57
1998	54	8	11	73
1993	60	14	12	86
1988	58	16	13	87
1981	114	23	5	142
1976	68	24	6	98
1973	86	22	7	115
1966	111	37	b	148
1956	307	26	b	333

[a]MMBF = million board feet, lumber tally.
[b]Mills with production over 50 MMBF are included in the 10 MMBF to 50

Table 18--Proportion of Montana lumber production by sawmill size class, selected years (sources: Schweitzer and others 1975; Setzer and Wilson 1970; Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Year	Less than 10 MMBF[a]	More than 10 MMBF[a]	Total lumber production	Average production per mill
	Percentage of production		*Million board feet*	
2014	2	98	611	19.09
2009	2	98	449	10.96
2004	3	97	1,040	18.24
1998	2	98	1,287	17.63
1993	4	96	1,367	15.90
1988	4	96	1,558	17.91
1981	8	92	1,071	7.54
1976	4	96	1,176	12.00
1966	10	90	1,375	11.96
1962	13	87	1,259	8.51
1956	33	67	979	2.97

[a]MMBF = million board feet, lumber tally.

Table 19--Lumber production by Montana sawmills, 2014.

Lumber production size class	Number of mills	Percentage of production	Lumber production	Average production per mill
			Million board feet	
More than 50 MMBF[a]	6	75.0	459	77.00
10 to 50 MMBF	3	23.0	139	46.00
1 to 10 MMBF	7	1.0	9	1.29
Less than 1 MMBF	16	<1	4	0.25
Total	32	100	611	19.09

[a]MMBF = million board feet, lumber tally.

Table 20--Sawtimber processing capacity and utilization, selcted years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Plant Type	Processing capacity	Volume processed	Percentage of capacity utilized
	Million Board Feet, Scribner		
	2014		
Sawmills	546	337	62%
Other sawtimber users[a]	89	57	64%
Total	635	394	62%
	2009[b]		
Sawmills	554	237	43%
Other sawtimber users[a]	106	66	62%
Total	660	303	46%
	2004		
Sawmills	743	521	70%
Other sawtimber users[a]	191	135	71%
Total	934	656	70%
	1998		
Sawmills	844	725	86%
Other sawtimber users[a]	247	221	89%
Total	1,091	946	87%
	1993		
Sawmills	964	782	81%
Other sawtimber users[a]	287	234	82%
Total	1,251	1,016	81%
	1988		
Sawmills	1,237	985	80%
Other sawtimber users[a]	324	241	74%
Total	1,561	1,226	79%
	1981		
Sawmills	1,207	739	61%
Other sawtimber users[a]	276	241	87%
Total	1,483	980	66%

[a]Other sawtimber users include plywood and veneer plants, house log manufacturers, and utility pole plants.

[b]2009 figures revised from McIver et al. 2013.

Table 21--Montana sawmill residue factors, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Type of residue	1981	1988	1993	1998	2004	2009	2014
	BDU of residue per MBF lumber tally[a]						
Coarse	0.47	0.51	0.48	0.49	0.47	0.44	0.42
Sawdust	0.25	0.22	0.23	0.22	0.19	0.21	0.21
Bark	0.23	0.21	0.21	0.19	0.20	0.19	0.16
Planer Shavings	0.22	0.18	0.16	0.17	0.15	0.14	0.12
Total	1.17	1.12	1.08	1.07	1.01	0.98	0.91

[a]Bone-dry unit (BDU = 2,400 lb of oven-dry wood) of residue generated for every 1,000 board feet of lumber manufactured.

Table 22--Production and disposition of residues from Montana sawmills and plywood plants, 2014.

Residue type	Total utilized	Pulp and board	Energy	Mulch or animal bedding	Unspecified use	Unutilized	Total produced
	Bone dry units[a]						
Coarse	309,176	289,626	17,703	-	1,847	27	309,203
Fine	205,394	197,590	4,741	2,420	643	512	205,906
Sawdust	132,143	*125,332*	*4,601*	*1,811*	*399*	*332*	132,475
Planer shavings	73,251	*72,258*	*140*	*609*	*244*	*180*	73,431
Bark	126,857	-	92,698	34,159	-	1,276	128,133
All residues	641,427	487,216	115,142	36,579	2,490	1,815	643,242
	Percentage of residue use by type						
Coarse	100.0	93.7	5.7	-	0.6	0.0	100
Fine	99.8	96.0	2.3	1.2	0.3	0.2	100
Sawdust	*99.7*	94.6	3.5	1.4	0.3	0.3	100
Planer shavings	*99.8*	98.4	0.2	0.8	0.3	0.2	100
Bark	99.0	-	72.3	26.7	-	1.0	100
All residues	99.7	75.7	17.9	5.7	0.4	0.3	100

[a]Bone dry unit= 2,400 lb oven-dry wood.

Table 23--Production and disposition of residues from Montana's primary wood products sectors, 2014.

Sector	Total utilized	Pulp and board	Energy	Mulch or animal bedding	Unspecified use	Unutilized	Total produced
	Bone dry units[a]						
Lumber, plywood and other sawn products	641,427	487,216	115,142	36,579	2,490	1,815	643,242
House logs and log homes	4,326	-	3,343	323	660	506	4,832
Posts and poles	14,572	1,300	8,737	4,384	151	1,116	15,688
Other sectors[b]	15,295	-	15,103	190	2	72	15,367
All sectors	675,620	488,516	142,325	41,476	3,303	3,509	679,129
	Percentage of residue use production and use by sector						
Sawmill and plywood	99.7	75.7	17.9	5.7	0.4	0.3	100
House log and log home	89.5	-	69.2	6.7	13.7	10.5	100
Post and pole	92.9	8.3	55.7	27.9	1.0	7.1	100
Other sectors[b]	99.5	-	98.3	1.2	0.0	0.5	100
All sectors	99.5	71.9	21.0	6.1	0.5	0.5	100

[a]Bone dry unit= 2,400 lb oven-dry wood.

[b]Other sectors include firewood, pulp chipping and log furniture.

Table 24--Proportion of finished product sales of Montana's primary wood products sectors, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Sector	1981	1988	1993	1998	2004	2009	2014
	Percentage of sales value						
Lumber, plywood, and other sawn products	58	55	67	60	53	29	57
Pulp, board, and residue-related products	38	41	28	30	39	63	36
House logs and log homes	2	3	5	9	7	4	4
Other products[a]	2	1	1	1	1	4	3
All products[b]	100	100	100	100	100	100	100

[a]Other products include: posts and poles, log furniture, and energy products.
[b]Percentage detail may not sum to 100% due to rounding.

Table 25--Destination and sales value of Montana's primary wood products and mill residue, 2014.

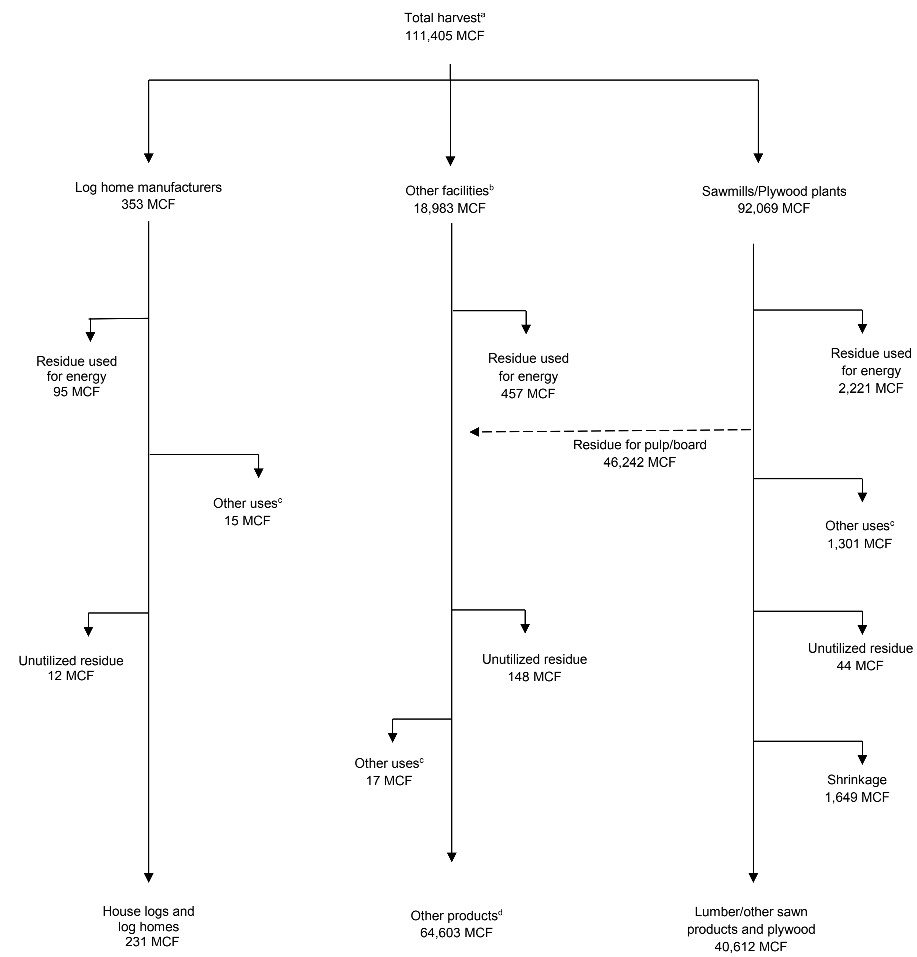
Product	North Central[a]	Far West[b]	South[c]	Montana	Rockies[d]	Northeast[e]	Other countries[f]	Total
	Thousand 2014 dollars							
Lumber, plywood, and other sawn products	115,369	19,982	74,726	53,829	52,357	17,818	7,508	341,589
House logs and log homes	2,862	4,379	2,371	6,714	3,527	1,410	1,106	22,369
Residue-related products[g]	69,239	71,608	15,911	10,598	25,271	1,826	25,382	219,835
Other finished products	340	5,055	445	12,845	1,434	582	77	20,778
All products and residues	187,810	101,024	93,453	83,986	82,589	21,636	34,073	604,571
	Percentage of sales							
Lumber, plywood, and other sawn products	19	3	12	9	9	3	1	57
House logs and log homes	<1	1	0	1	1	<1	<1	4
Residue-related products[g]	11	12	3	2	4	<1	4	36
Other finished products	<1	1	0	2	0	<1	<1	3
All products and residues[h]	31	17	15	14	14	4	6	100

[a]North Central includes Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.
[b]Far West includes Alaska, California, Hawaii, Oregon, and Washington
[c]South includes Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia.
[d]Rocky Mountains includes Arizona, Colorado, Idaho, Nevada, New Mexico, Utah, and Wyoming.
[e]Northeast includes Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, Pennsylvania, Rhode Island, and Vermont.
[f]Other countries include Canada, Pacific Rim countries, and other countries.
[g]Residue-related products include pulp chips, MDF and particleboard, fuel pellets, bark products, and mill residue.
[h]Percentage detail may not sum to 100% due to rounding.

Table 26--Proportion of Montana primary wood product sales by market region, selected years (sources: Keegan 1980; Keegan and others 1983, 1990, 1995, 2001; Spoelma and others 2008; McIver and others 2013).

Market area	1981	1988	1993	1998	2004[c]	2009[c]	2014[c]
	Percentage of sales						
North Central	34	40	37	28	28	27	31
Far West	22	17	15	19	17	18	17
South	10	10	11	16	15	13	15
Montana	7	5	10	12	12	12	14
Rocky Mountains	14	11	15	13	10	11	14
Northeast	6	7	6	9	12	8	4
Other countries[a]	3	9	6	4	6	10	6
Unknown	4	1	0	0	0	0	0
All areas[b]	100	100	100	101	100	100	100

[a]Other countries include Canada, Pacific Rim countries, and other countries.
[b]Percentage detail may not sum to 100% due to rounding.
[c]Includes mill residue sales; previous years do not include residue sales.



[a]Harvest volume does not include bark.
[b]Other facilities include post, pole, log furniture, cedar products, firewood and pulp and reconstituted board plants.
[c]Other uses include landscape, mulch, animal bedding, and miscellaneous uses.
[d]Other products include particleboard, medium-density fiberboard, pulp chips, posts, poles, and log furniture.