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LOGGING UTILIZATION IN ARIZONA AND NEW MEXICO, 2012-2017: CURRENT AND PAST TRENDS

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Abstract

A study of commercial timber-harvesting sites in Arizona and New Mexico was conducted from 2012 to 2017 to estimate growing-stock removals, characterize current tree utilization and logging operations, and assist with estimating the amount of woody biomass left on-site after harvesting. Fifty-four sample logging sites were selected within major geographic regions proportional to regional five-year timber harvests. A two-stage sampling method was used to compute State-level utilization factors from 1,358 felled trees. Results indicated that in Arizona, for every 1,000 cubic feet (CF) delivered to the mill, harvesting created 24 CF feet of growing-stock logging residue, and 38 CF of non-growing-stock material was delivered to the mill. This compared to 65 CF of growing-stock logging residue created and 20 CF of non-growing-stock utilized per 1,000 CF of mill-delivered volume in New Mexico. Different harvesting prescriptions and mill infrastructure contributed to the utilization differences between the two States. The 2012-2017 New Mexico utilization factors revealed an increase in growing-stock logging residue compared to the1980s, a unique finding among western States. This outcome is likely attributable to declines in the State's milling infrastructure, particularly facilities with the ability to use smaller diameter material.

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

Cover: Top photo: Stacked timber; Left photo: Felled trees in forst setting; Right photo: Stacked timber on both sides of a logging road. Photos by Eric A. Simmons.

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INTRODUCTION

Forest and mill managers in the Southwest desire current information on the characteristics and effects of timber harvesting on forest inventory. They may wish to know how much woody material remains in the forest after commercial logging operations to understand fuel loads or to predict potential feedstock for woody biomass energy. Likewise, the characteristics of harvested trees (e.g., d.b.h. , total tree height, or species mix), harvesting methods (e.g., mechanical vs. hand-felling or merchandising at the stump vs. at the landing), and logging residue may be of interest for forest planning or business development purposes. The information developed from logging utilization studies can meet these needs.

Logging utilization studies identify material removed from forest inventory during commercial timber harvest activities and provide the data used to develop logging utilization factors. These factors quantify the amount of growing-stock volume (fig. 1) removed from inventory and distinguish it as either timber products (e.g., sawlogs, fuelwood) delivered to processing facilities or as logging residue, which is left in the forest

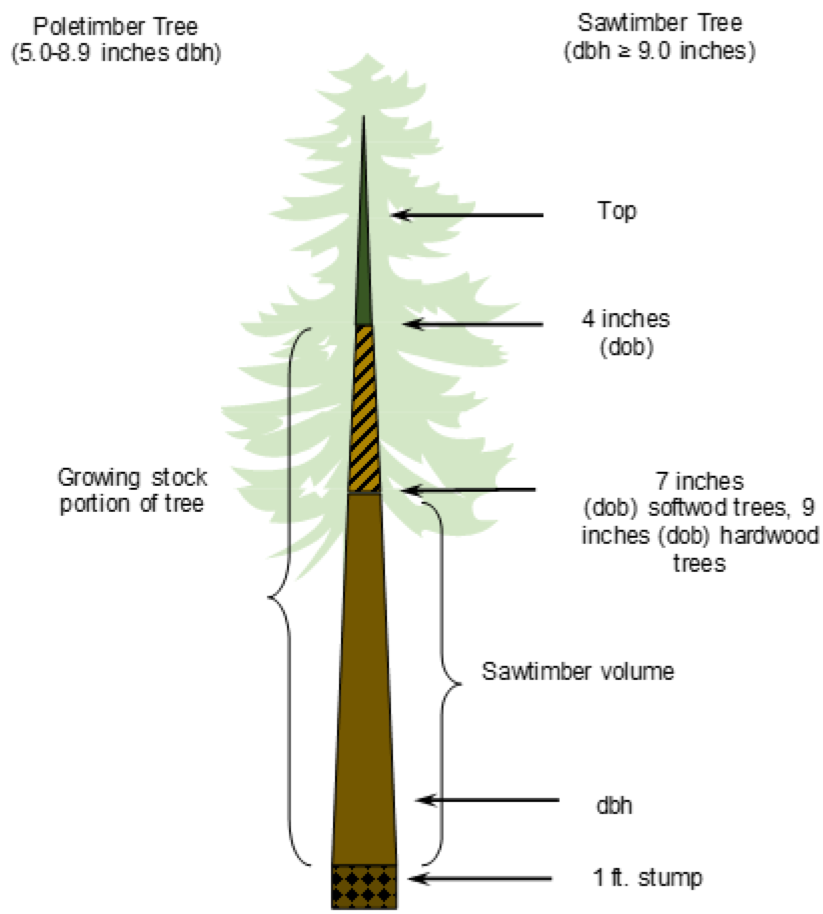


Figure 1—Growing stock sections of softwood trees.

or at the landing and is not used. Other factors quantify the volume of non-growing stock material utilized for products. These logging utilization factors are used in the calculation of logging residue volumes in the Timber Products Output (TPO) database (See “TPO Reporting Tool” at https://www.fia.fs.fed.us/tools-data/) maintained by the Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture, Forest Service. The factors can be applied to projected levels of timber harvest at various geographic scales to provide estimates of growing-stock removals from forest inventory. Logging utilization studies also characterize timber harvest activities and equipment and can provide estimates of the distributions of trees and volume harvested by species, size, and logging method.

When conducted in a consistent manner, these studies can provide a substantial amount of information about changes in timber harvesting practices and logging residue through time and differences between States or regions of the country. Recent logging utilization studies provided updated residue and harvesting information for Idaho (Simmons et al. 2014b), Oregon and Washington (Simmons et al. 2016), and Montana (Berg et al. 2018). However, the most recent studies for Arizona and New Mexico are 30 years old (McLain 1988, 1989). This study and others like it (Bentley and Johnson 2004; Berg et al. 2018; Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014b, 2016;) allow historic and between-State comparisons of timber harvested for products, the associated logging residue, and the impacts on growing-stock inventory.

To update regional timber harvesting and logging residue information, a study of logging sites across Arizona and New Mexico was conducted from 2012 through 2017. This study was designed to quantify the creation of logging residue from commercial, green (live) tree timber harvesting at the State level, and characterize harvested trees and harvesting activities within each State. The specific objectives were to:

1. characterize each State’s timber harvest by tree species and d.b.h.;
2. characterize each State’s timber harvest operations by felling, yarding, and merchandising methods;
3. compute current logging utilization factors for each State to express:
    a. volumes of growing-stock logging residue generated per 1,000 CF of mill-delivered volume,
    b. proportions of mill-delivered volume coming from growing-stock vs. non-growing stock portions of harvested trees, and
    c. total removals (i.e., timber product and logging residue) from growing stock.

Recent Arizona and New Mexico Timber Harvests

There are nearly 7.3 million acres of non-reserved timberland potentially available for timber harvest activities in Arizona and New Mexico (table 1; Miles 2017). However, neither the timber resource nor harvesting activities are evenly distributed across the States. Wood product markets and forest policy issues have influenced the geographic and ownership sources of harvested timber as well as annual harvest volumes.

Table 1—Arizona and New Mexico timberland[a] by ownership class (Source: Miles 2017).

Ownership class	Arizona		New Mexico	
	Thousand acres	*Percentage*	*Thousand acres*	*Percentage*
National Forest	2,160	71.7	2,662	62.2
Undifferentiated private[b]	812	27.0	1,449	33.9
State	7	0.2	129	3.0
Bureau of Land Management	6	0.2	38	0.9
Other public	27	0.9	0	0.0
All owners	**3,012**	**100**	**4,279**	**100**

[a]Timberland is forest land that is producing or capable of producing more than 20 cubic feet of wood per acre per year at culmination of mean annual increment and not withdrawn from harvest by statute or administrative regulation (Helms 1998).

[b]Undifferentiated private includes industrial private, non-industrial private, Tribal, NGOs and unincorporated local partnership/association/clubs.

The combined annual timber harvest volumes in Arizona and New Mexico have ranged from nearly 550 million board feet (MMBF) Scribner in the mid-1980s to current levels of around 100 MMBF (Sorenson et al. 2016; fig. 2). Since the majority of timberlands in both States are national forest lands, harvests have been predominantly from these public lands. Steep declines in total timber harvest volumes and milling capacity in the Southwest were associated with the reduction of Federal harvest programs beginning in the early 1990s (Keegan et al. 2006; Morgan et al. 2006) and were exacerbated by the Great Recession, housing bust, and poor wood product markets from 2007 through 2011 (Keegan et al. 2012; Sorenson et al. 2016).

Forest management strategies are similar between Arizona and New Mexico, but milling and logging infrastructures vary. Northern Arizona's National Forest System stewardship and restoration projects, most notably the White Mountain Stewardship Project (WMSP) and Four Forest Restoration Initiative (4FRI) Collaborative Forest Landscape Restoration Projects (CFLRPs), use treatments that combine the removal of larger trees and thinning small-diameter trees with whole-tree utilization. This

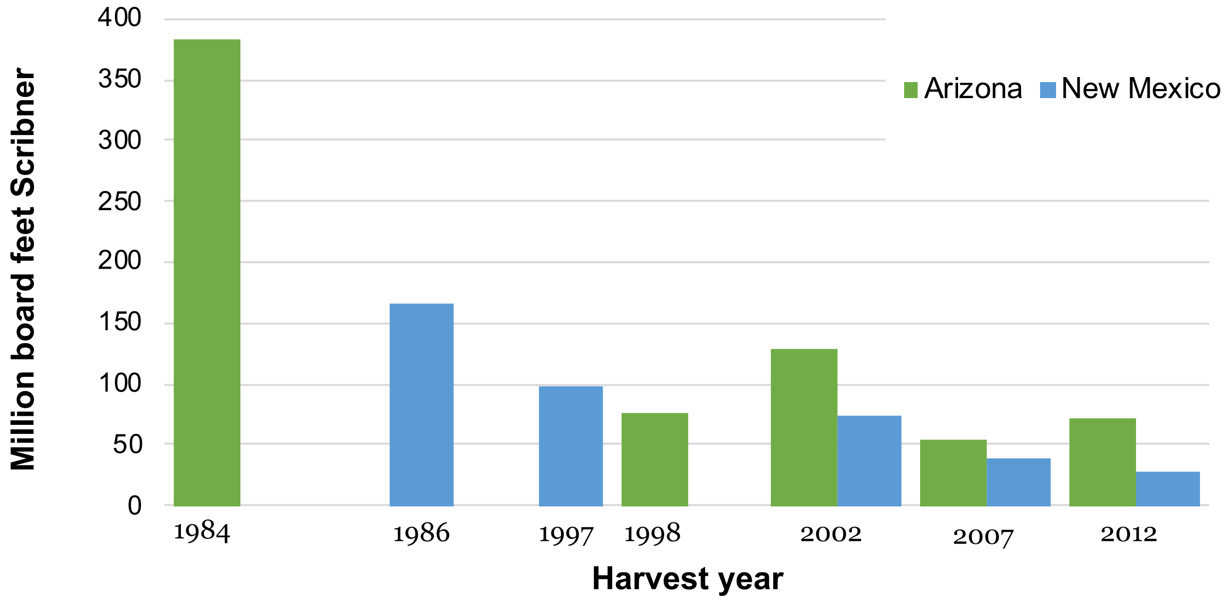


Figure 2—Arizona and New Mexico timber harvest, selected years (Setzer and Wilson 1970; McLain 1989; Keegan et al. 2001b; Morgan et al. 2006; Sorenson et al. 2016).

effort is designed to restore ecosystem health, improve wildlife habitat, and reduce the risk of uncharacteristic wildland fires (4FRI 2017). Although projects like the Zuni Mountains Stewardship and Southwest Jemez Mountains CFLRP have similar objectives and on-the-ground treatments, there is very little whole-tree utilization capability for commercial wood products in New Mexico. Arizona's timber-processing capacity of approximately 139 MMBF Scribner (Sorenson et al. 2016) includes a few high volume sawmills with the capability of utilizing smaller diameter logs, whereas most of New Mexico's 61 MMBF Scribner of timber-processing capacity is concentrated in mills that rely on larger diameter logs. New Mexico's wood products industry is undertaking improvements to increase the utilization of smaller diameter trees, however many efforts were still in planning or development stages at the time of this study. In contrast, logging infrastructure in Arizona is capable of grinding or chipping whole trees at the logging site, and there are large-capacity facilities that use the raw material for biomass energy, heating, and soil amendment products.

METHODS

Sample Design

The target population for this study was active logging sites in Arizona and New Mexico where green (live) trees were being commercially harvested for conversion into wood products, primarily lumber. 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, the majority (65 to 95 percent) of annual timber harvests in both States have been used for lumber and other sawn products such as timbers and pallet stock (Hayes et al. 2012; Keegan et al. 2001a, b; Morgan et al. 2006; Sorenson et al. 2016). Other timber products (e.g., logs for posts, poles, vigas and latillas) are commonly merchandised with sawlogs. Thus, we identified sites where green sawlogs were the primary products to be harvested. These sites would account for the vast majority of annual harvest volume and allow us to capture some volume harvested for other products.

We sought a sample of felled trees within logging sites (the primary sampling unit) that would provide data to estimate logging utilization factors at the State level expressed as the ratios of means (Zarnoch et al. 2004). 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 (McClain 1988, 1989; Simmons et al. 2014b, 2016). As Morgan and Spoelma (2008) described, it is not possible to know in advance the full population of logging sites in a State for a given year and simply draw a sample of those sites to measure. But without a sampling frame from which to draw samples at random, using design-based sampling could bias parameter estimates and compromise any ability to make population inferences (Lohr 2009). Berg et al. (2015) analyzed the potential bias in design-based sampling without the use of a sampling frame and found that the computed design-based residue ratios exhibited less than 0.5 percent bias. In the current study, as in other investigations, the authors could not obtain a list of all active sites; sample sites were not selected at random.

A two-stage sampling protocol was used to select logging sites and trees within the sites for measurement (Levy and Lemeshow 1999). The number of logging sites in an area (e.g., county or multi-county region) was assumed to be proportional to harvest volume. Sample sites were thus selected proportional to 5-year timber harvest volumes. Logging sites with active harvesting of green trees for commercial products served as the stage 1 sampling units. Annual timber-harvest summaries (USDA Forest Service 2011-2015) provided the geographic location (i.e., county or National Forest) and ownerships of potential sample logging sites (fig. 3). Timberland owners and sawmills were contacted periodically throughout the study period to identify when and where logging activities would be occurring and to request access to logging sites to conduct measurements.

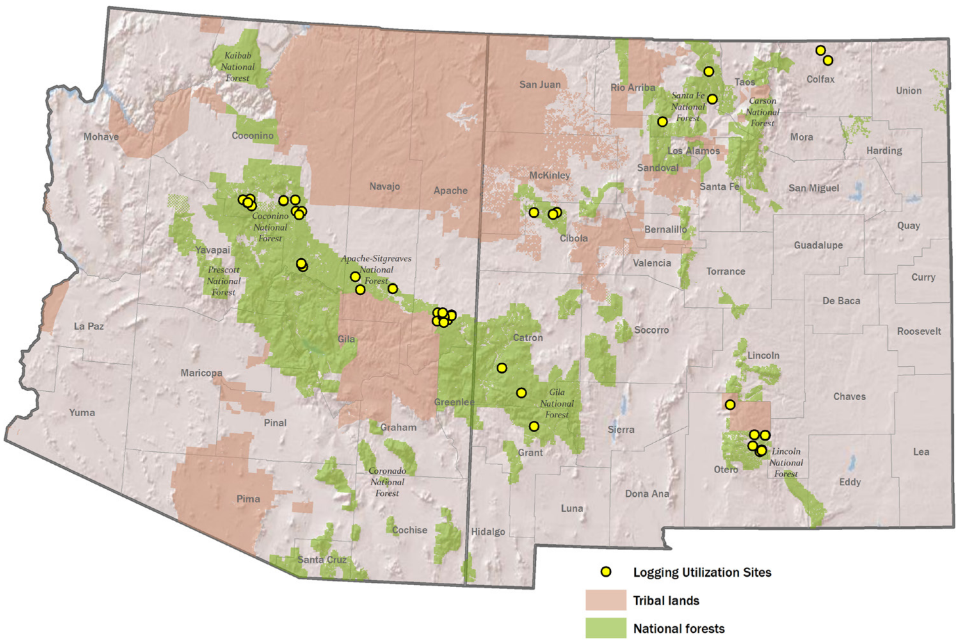


Figure 3. Sampled logging sites in Arizona and New Mexico, 2012-2017.

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

Sample sizes for stage 1 and 2 sample units were guided by standard errors obtained in previous utilization studies. Zarnoch et al. (2004) found that standard errors for utilization ratios dropped substantially by increasing the number of measured logging sites from 10 to 20. Previous logging utilization studies in Montana, California, Idaho, Oregon and Washington garnered low standard errors by measuring 25 to 35 trees on each of 30 to 35 logging sites per State (Morgan et al. 2005; Morgan and

Spoelma 2008; Simmons et al. 2014b, 2016). Logging utilization studies conducted by the Forest Service's Southern Research Station (Bentley and Johnson 2004; Zarnoch et al. 2004) suggested that a sample of 30 to 50 logging sites with 20 to 35 felled trees measured at each logging site would be sufficient to determine State-level utilization factors. Based on these guidelines, we decided to sample 20 to 30 felled trees located within each of 20 to 30 active logging sites throughout Arizona and New Mexico.

Data Collection

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 and diameters delivered to the receiving mill(s). Field crews recorded this information along with the date, county, land ownership class, felling method, yarding/skidding method, log merchandising location and method, logging contractor name, equipment in use, and names of the 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, d.b.h., and primary product (e.g., sawlog, veneer log, etc.) information were recorded. Diameter and section length measurements were taken at several points:

(1) the cut stump,
(2) at one foot above ground level (uphill side of the tree),
(3) at d.b.h.,
(4) at the end of the first 16-foot log,
(5) at the 7.0-inch diameter outside bark (d.o.b.),
(6) at the 4.0-inch d.o.b. point (end of growing stock), and
(7) 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 d.o.b. 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). The timber product type for each utilized section was also recorded.

A minimum of 20 felled, live trees were measured at each of 54 logging sites – 30 in Arizona, and 24 in New Mexico – from 2012 to 2017. These 54 active logging sites were spread across both States. A total of 1,358 felled trees—750 in Arizona, and 608 in New Mexico—were measured.

Data Analysis

Following the methods of Morgan and Spoelma (2008), and Simmons et al. (2014b, 2016), cubic volumes for more than 11,600 individual tree sections were calculated using Smalian's formula (Avery and Burkhart 1994). Section volumes were summed for each tree by category (e.g., utilized vs. unutilized stump, bole, and upper stem sections of the trees), and utilization factors were calculated for each tree and site. Logging residue factors, standard errors, and 95 percent confidence intervals (CIs) were computed at the State level for Arizona and New Mexico based on the two-stage sampling design, using the ratios of means estimator (Zarnoch et al. 2004) obtained from SAS PROC SURVEYMEANS (SAS 2013). Residue factors were also calculated for individual species, species groups, and for each tree d.b.h. class. Characteristics of the felled trees, harvest operations, and utilization factors were then summarized and compared with historic Arizona and New Mexico logging utilization studies and with recent studies from other western States.

RESULTS AND DISCUSSION

Characteristics of Logging Sites and Operations

Since the largest share of commercial logging in both States occurs on lands within the National Forest ownership class (Sorenson et al. 2016), the sample sites were selected proportional to geographic regions associated with national forests (table 2). Limited harvesting activity and availability of logging sites in the Santa Fe National Forest (in New Mexico) and National Forests south of the Mogollon Rim (in Arizona) resulted in somewhat fewer sites being measured relative to recent harvest volumes in those regions.

Table 2—Percent of five-year average harvest and logging utilization sample sites by National Forest.

Arizona			New Mexico		
Region	Percent of harvest[a]	Percent of sample	Region	Percent of harvest[a]	Percent of sample
Apache/Sitgreaves	56	50	Lincoln	33	42
Coconino	19	23	Cibola	26	25
Kaibab	17	27	Sante Fe	17	4
Prescott	5	0	Gila	14	13
Tonto	3	0	Carson	10	17
Coronado	0	0			
Total	**100**	**100**	**Total**	**100**	**100**

[a] USFS Cut and Sold, various years.

Harvesting methods included hand and mechanical felling and merchandising (table 3). Mechanical felling methods included the use of a "hot saw" or equipment with accumulating heads such as a feller-buncher. Hand felling and merchandising was done with chainsaws. Only ground-based (no cable or sky-line) skidding/yarding systems were observed in both States. Trees and or logs were mostly yarded with rubber-tired skidders and rarely with dozers equipped with either a grapple or a winch with chokers. The trees, both log- and tree-length, were skidded. Mechanical merchandising methods included the use of stroke (slide-boom) de-limbers and dangle-head processors.

In Arizona, trees were mechanically felled on all but two of the sites; in New Mexico, timber was hand-felled with chainsaws on 42 percent of the sites. Cable yarding was not employed in either State since moderate slopes and soils were conducive to the use of ground-based yarding systems. In both States, timber was skidded tree-length on most sites, but New Mexico had a higher proportion (33 percent) of sites skidded log-length. The processing or merchandising of trees at landings with mechanical systems was employed on the majority of sites in both States. New Mexico, however, had substantially more sites (33 percent) where trees were merchandised in the unit and over 40 percent of sites with merchandising done by hand. The more frequent use of chainsaws for felling and merchandising in New Mexico reflected the smaller and less mechanized forest industry in a State with relatively low timber harvest levels and limited timber-processing capacity. It also suggested less capability among New Mexico facilities for using smaller-diameter material, which is often more expensive to process and requires very efficient processing of large volumes.

Table 3—Number of Arizona and New Mexico logging sites sampled by harvesting attribute, 2012-2017.

	Felling method			**Yarding**	**Skidding**		**Merchandising location**		**Merchandising method**	
Ownership	Hand*	Mechanical	Combination	Ground based	Tree length	Log length	In unit	At landing	Mechanical	Hand*
	Number of Sites									
Arizona USFS	2	28	—	30	29	1	1	29	28	2
New Mexico USFS/NIPF	10	13	1	24	16	8	8	16	14	10

*Hand felling and merchandising done with chainsaws.

Characteristics of Felled Trees

In Arizona, the sample of felled trees ranged from 5.0 to 26.7 inches d.b.h.; the New Mexico trees ranged from 6.4 to 27.1 inches d.b.h. The median diameter tree by mill-delivered volume was 14.2 inches d.b.h. for Arizona and 14.8 inches d.b.h. for New Mexico. Half of the trees measured in Arizona were ≤ 12.4 inches d.b.h., but they accounted for about 25 percent of the utilized volume and 31 percent of growing-stock logging residue. Half of the harvested trees in New Mexico were also ≤ 12.4 inches d.b.h., and accounted for about 24 percent of the mill-delivered volume and 44 percent of growing-stock logging residue volume. In New Mexico, the higher proportion of growing-stock logging residue from trees ≤ 12.4 inches d.b.h. resulted from only sawlogs being merchandised there. Arizona, on the other hand, had numerous sites with whole-tree utilization, including use for biomass energy.

In Arizona, trees < 15 inches d.b.h. accounted for roughly 59 percent of mill-delivered volume and 60 percent of growing-stock logging residue (table 4). In New Mexico, trees < 15 inches d.b.h. accounted for about 52 percent of mill-delivered volume, but 74 percent of growing-stock logging residue. This indicates more residue from, and less utilization of, smaller trees in New Mexico as compared to Arizona.

As in Idaho (Simmons 2014b), timber harvests in Arizona and New Mexico have shifted dramatically from larger diameter trees to smaller trees during the past three decades. In the late 1980s, trees ≥ 24 inches d.b.h. provided between 40 and 60 percent of the mill-delivered volume (McLain 1988, 1989). In this 2012-2017 study, trees in the same diameter class provided less than 5 percent of the mill-delivered volume (fig. 4). The sawmill industry's increased use of smaller trees and declining use of large trees throughout the western United States has been documented (Keegan et al. 2010). In the Southwest, this trend is likely due to perceived reductions in the inventory of larger-diameter trees, restoration or fuel reduction prescriptions that focus on removing smaller trees, and harvest diameter limits (e.g., no trees > 16 inches d.b.h. allowed to be cut) on some public lands. In other regions (e.g., western Oregon and Washington), the industry has largely shifted to shorter rotation (e.g., 30 to 40 year), plantation-grown trees.

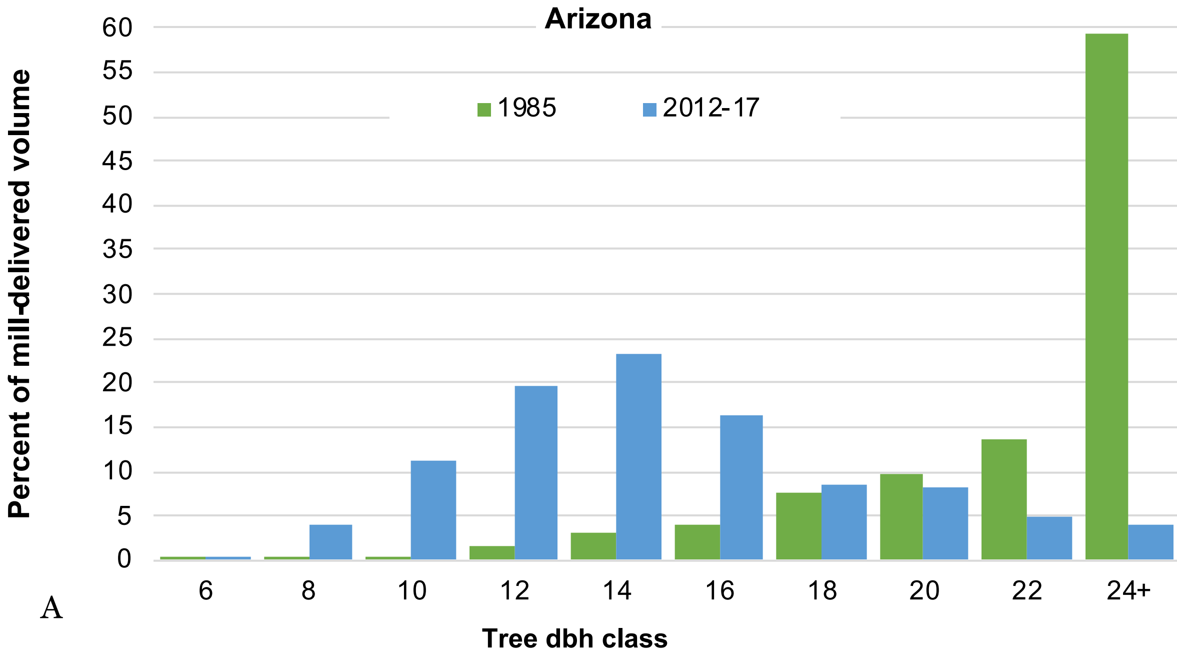
Table 4—Distribution of trees, mill-delivered volume, and growing-stock logging residue volume in cubic feet (CF) by dbh[a] class for Arizona and New Mexico logging sites, 2012-2017.

Arizona (750 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	19	2.5	2.5	0.3	0.3	2.1	2.1
8	113	15.1	17.6	4.1	4.5	9.1	11.2
10	156	20.8	38.4	11.3	15.8	12.3	23.4
12	171	22.8	61.2	19.8	35.6	17.1	40.6
14	142	18.9	80.1	23.2	58.8	19.2	59.7
16	77	10.3	90.4	16.3	75.1	12.0	71.7
18	31	4.1	94.5	8.4	83.4	5.4	77.1
20	23	3.1	97.6	8.0	91.5	7.2	84.3
22	10	1.3	98.9	4.7	96.2	4.7	89.0
24+	8	1.1	100	3.8	100	11.0	100

New Mexico (608 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	6	1.0	1.0	0.1	0.1	0.7	0.7
8	65	10.7	11.7	2.4	2.5	11.1	11.8
10	158	26.0	37.7	12.4	14.9	22.4	34.2
12	133	21.9	59.5	16.6	31.5	19.2	53.4
14	110	18.1	77.6	20.8	52.3	20.3	73.7
16	58	9.5	87.2	15.4	67.6	7.4	81.0
18	46	7.6	94.7	16.8	84.4	9.7	90.7
20	23	3.8	98.5	10.0	94.4	6.3	97.1
22	7	1.2	99.7	4.0	98.5	2.6	99.7
24+	2	0.3	100	1.5	100	0.3	100

[a] dbh = diameter at breast height

Note: Percentages may not sum to 100 due to rounding.



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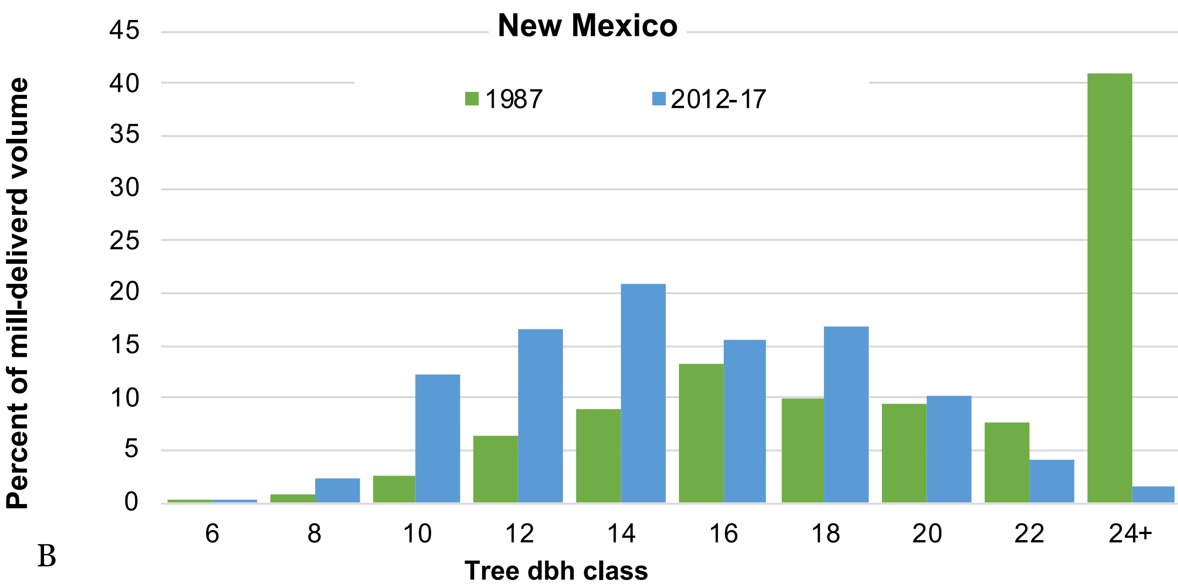

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Figure 4a-b—Distribution of trees by dbh and percent of total growing stock delivered to (a) Arizona and (b) New Mexico mills 1985, 2012-17 (McLain 1988; McLain 1989).

Ponderosa pine (*Pinus ponderosa* var. scopulorum Engelm.) was the most sampled and harvested tree species in both States, followed by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). In Arizona, ponderosa pine comprised over 80 percent of the logging utilization sample and 2012 harvest volume from the Sorenson et al. (2016) mill study (table 5). Douglas-fir and other species were somewhat underrepresented in the Arizona logging utilization sample, compared to the 2012 harvest volume. In New Mexico, the mix of species in both the logging utilization sample and the 2012 harvest volume were more similar, with both capturing over 50 percent of ponderosa pine and 19 percent or more of Douglas-fir and other softwoods including spruce (*Picea* spp), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), and Southwestern white pine (*Pinus strobiformis* Engelm).

Table 5—Number of sampled trees, percent of sampled tree mill-delivered volume, percent of 2012 statewide timber harvest volume, percent of growing-stock logging residue volume, and growing-stock residue as a percent of mill-delivered cubic foot (CF) volume by species and State, 2012-2017.

Species	Percent of sampled trees	Percent of sampled tree mill-delivered CF volume	Percent of 2012 timber harvest volume (MBF, Scribner)[a]	Percent of growing-stock logging residue CF volume	Residue as a percent of mill-delivered CF volume
Arizona					
Ponderosa pine	96.1	97.0	83.6	91.6	2.3
Douglas-fir	3.9	3.0	8.1	8.4	6.8
Other species	0.0	0.0	8.3	0.0	
Total	100	100	100	100	2.4
New Mexico					
Ponderosa pine	59.9	56.7	54.0	59.7	6.9
Douglas-fir	22.0	22.5	19.0	23.2	6.8
Other species	18.1	20.8	27.0	17.1	5.4
Total	100	100	100	100	6.5

[a] Sorenson et al. 2016.

Statewide Logging Utilization Factors

Logging utilization factors are Statewide ratios of removals volumes versus mill-delivered volumes (Morgan and Spoelma 2008, Simmons et al. 2014b, 2016). The logging utilization factors calculated in this 2012-2017 study for Arizona indicated that for each 1,000 CF delivered to mills:

- 38 CF of non-growing stock material (stumps cut below 1-foot in height and tops utilized beyond the 4-inch d.o.b.) was utilized,
- 962 CF of growing-stock material was utilized,
- 24 CF of growing-stock material was left in the forest or at the landing as logging residue, and
- commercial timber harvesting removed a total of 986 CF of growing-stock volume (table 6).

Table 6—Arizona and New Mexico logging utilization factors, 2012-2017.

Arizona factor	**Lower bound (95% CI)**	**Estimate (ratio of means)**	**Upper bound (95% CI)**	**Standard error**	**Cubic feet (CF) per 1,000 CF mill-delivered**
Non-growing stock product delivered to mills *(utilized non-growing stock ÷ total utilized)*	0.0302	0.0385	0.0467	0.0040	38
Growing-stock product delivered to mills *(utilized growing stock ÷ total utilized)*	0.9533	0.9615	0.9698	0.0040	962
Growing-stock logging residue *(unutilized growing stock ÷ total utilized)*	0.0135	0.0244	0.0353	0.0053	24
Removals from growing stock *((utilized + unutilized growing stock) ÷ total utilized)*	0.9702	0.9860	1.0018	0.0077	986
New Mexico factor	**Lower bound (95% CI)**	**Estimate (ratio of means)**	**Upper bound (95% CI)**	**Standard Error**	**Cubic feet (CF) per 1,000 CF mill-delivered**
Non-growing stock product delivered to mills *(utilized non-growing stock ÷ total utilized)*	0.0142	0.0201	0.0259	0.0028	20
Growing-stock product delivered to mills *(utilized growing stock ÷ total utilized)*	0.9741	0.9799	0.9858	0.0028	980
Growing-stock logging residue *(unutilized growing stock ÷ total utilized)*	0.0495	0.0654	0.0814	0.0077	65
Removals from growing stock *((utilized + unutilized growing stock) ÷ total utilized)*	1.0296	1.0454	1.0612	0.0077	1045

New Mexico removals factors were considerably different from Arizona. For each 1,000 CF delivered to mills from New Mexico logging sites: 20 CF came from of non-growing stock material, 980 CF of growing stock was utilized, 65 CF of growing-stock was left on site as logging residue, and commercial harvest removed a total of 1,045 CF of growing-stock volume.

The lower growing-stock logging residue factor (24 CF) in Arizona compared to (65 CF) New Mexico and the somewhat higher non-growing stock delivered to mill factor (38 CF in Arizona vs. 20 CF in New Mexico) reflected the types and capabilities of processing facilities operating in each State, as well as timber harvesting prescriptions. In Arizona, about half of the sites were restoration or stewardship treatments requiring whole-tree removal. These trees were merchandised as sawlogs for sawmills with most of the remaining material processed into fuelwood for a biomass power plant in Snowflake. Sawmills in Arizona also indicated using sawlogs with smaller top diameters than sawmills in New Mexico. In New Mexico, there were no sites with a whole-tree removal requirement, and timber was merchandised almost exclusively for sawlogs. Without a local biomass facility, much more growing-stock material was left as logging residue and less non-growing stock material was utilized.

Consistent with other studies (Morgan and Spoelma 2008, Simmons et al. 2014b, 2016), smaller trees in both Arizona and New Mexico tended to produce more growing-stock logging residue per 1,000 CF of mill-delivered volume than larger trees (fig. 5). Overall, the growing-stock residue factor was higher across all tree sizes (except the 24+ inch d.b.h. class) in New Mexico than in Arizona, and the residue factors for the smallest trees (in the 6 to 10 inch d.b.h. classes) were substantially higher in New Mexico than in Arizona. With only eight trees in the 24+ inch class in Arizona and two trees in New Mexico, the sample size was too small to determine a conclusive cause for higher residue factors of those largest trees.

The differences in utilization factors between the two States were related to each State's milling infrastructure. Less ability to process smaller material, whether at biomass facilities or sawmills capable of using logs with a smaller top diameter, translated into lower utilization of the upper portions of trees. Thus the State-to-State differences in residue factors for trees in the 6 to10-inch d.b.h. class largely reflected differences in felled-tree, small-end utilization diameters. The average diameter for end of utilization in Arizona was 2.6 inches d.o.b. compared to 6.1 inches d.o.b. in New Mexico. These findings were consistent with Berg et al. (2016), which found that growing-stock residue ratios increased exponentially as the diameter at the end of utilization increased.

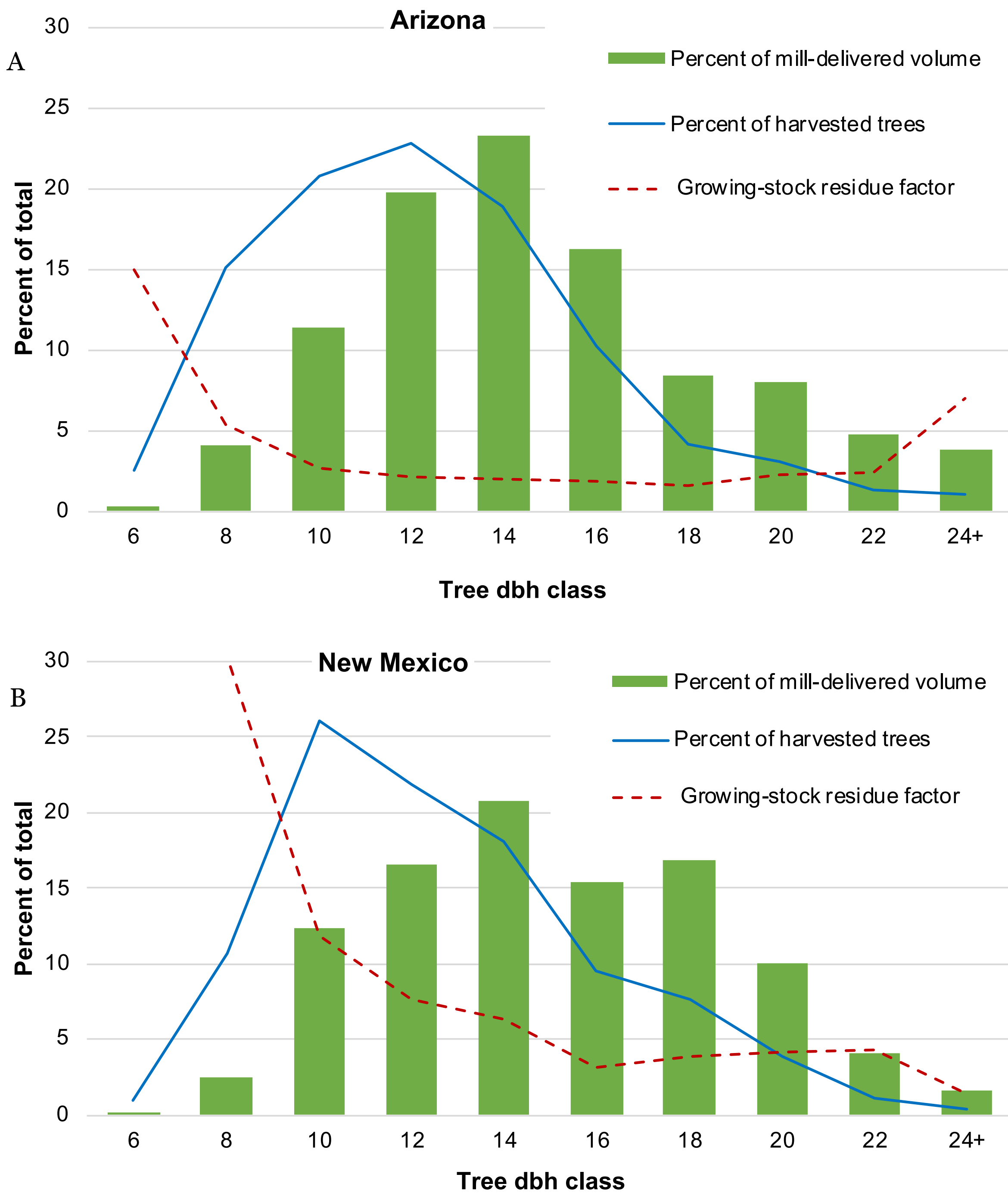
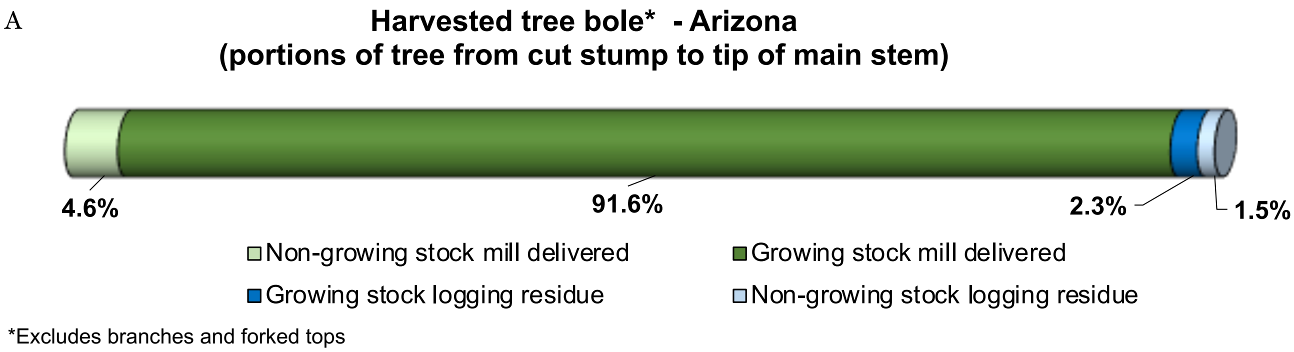


Figure 5a-b—Distribution of mill delivered volume, harvested trees, and residue per cubic foot (CF) of mill delivered volume by tree d.b.h. and State, 2012-2017.

In Arizona, 3.8 percent of the harvested bole volume (i.e., portions of the tree from the cut stump to the tip of the tree, excluding branches) remained in the woods as logging residue (fig. 6). In New Mexico, 8.6 percent of the harvested bole volume remained in the woods as logging residue. In Arizona, 4.6 percent of the volume delivered to the mill came from non-growing stock portions of trees, compared to just 1.8 percent in New Mexico. Most of the additional non-growing stock volume utilized in Arizona came from upper portions of trees – beyond the 6-inch d.o.b. average end of utilization for trees harvested in New Mexico.



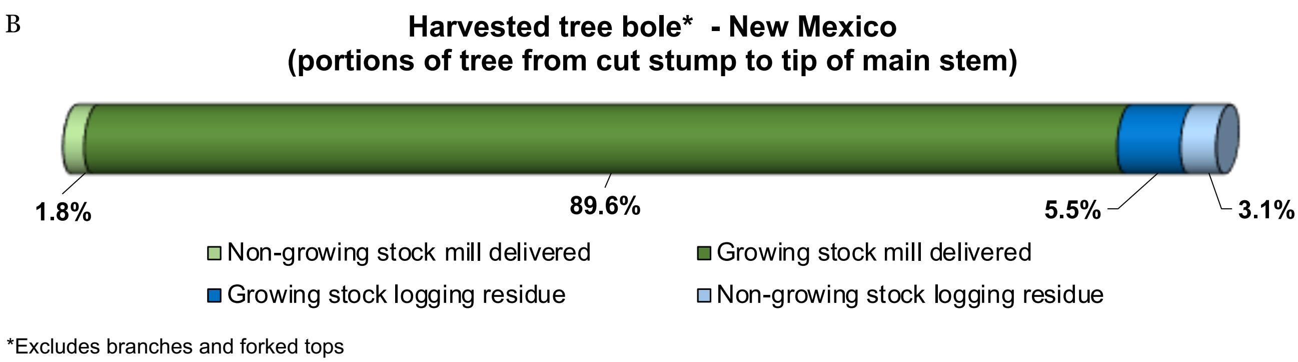


Figure 6a-b—Arizona and New Mexico harvested tree bole utilization, 2012-2017.

Logging Utilization Factors Through Time

Logging utilization studies in other western States have consistently found that the growing-stock residue factor has decreased and the non-growing stock delivered to mill factor has increased over time (Morgan et al. 2005; Simmons et al. 2014b; Berg et al. 2018), indicating higher overall utilization of harvested trees. These trends held for Arizona, where the 2012-2017 growing-stock residue factor was one-third of what it was in 1985 (McLain 1988) and less than one-fifth of what it was in 1968 (Setzer et al. 1970). In Arizona, the non-growing stock delivered to mill factor also increased from zero to 38 CF (table 7). New Mexico, however, did not have increased utilization as compared to the 1980s.

Table 7—Arizona and New Mexico logging utilization factors for each 1,000 cubic feet of green material delivered to mills, selected years.

Factor	1968[a]	1985[b]	2012-17
Arizona	------------ *cubic feet* -----------		
Non-growing stock product delivered to mills	–	0	38
Growing-stock product delivered to mills	1,000	1,000	962
Growing-stock logging residue	122	71	24
Removals from growing stock	1,122	1,071	986
Factor	**1968[a]**	**1987[c]**	**2012-17**
New Mexico	------------ *cubic feet* -----------		
Non-growing stock product delivered to mills	–	4	20
Growing-stock product delivered to mills	1,000	996	980
Growing-stock logging residue	122	43	65
Removals from growing stock	1,122	1,039	1,045

[a] Setzer et al. 1970; [b] McLain 1988; [c] McLain 1989.

In New Mexico, there was an increase in non-growing stock delivered to mills (from 4 CF to 20 CF per 1,000 CF) since the 1980s, but the 2012-2017 growing-stock residue factor was 50 percent higher than in 1987 (McLain 1989). This is the first instance of an increased growing-stock residue factor through time among western States. New Mexico, like Arizona and most of the western United States, had a reduction in timber-processing capacity and the number of facilities operating since the 1980s (Keegan et al. 2006; McIver et al. 2013; Simmons et al. 2014a; Sorenson et al. 2016). Despite this, logging utilization increased in other States, and the use of smaller-diameter material by sawmills generally increased (Keegan et al. 2010). The increase in New Mexico's growing-stock residue factor suggests that the ability to process smaller-diameter material in New Mexico declined with the closure of many sawmills. Additionally, the remaining facilities are in the process of transitioning to using smaller logs, but large capacity, biomass-utilizing facilities have not yet been developed.

CONCLUSIONS

Arizona and New Mexico logging utilization factors have varied substantially through time. Progressive reductions in New Mexico timber-processing capacity and attendant demand for timber, as well the different wood products infrastructures between the two States have created major differences in logging utilization factors. In particular, New Mexico's growing-stock residue factor was found to be 170 percent greater than Arizona's in this study. This largely resulted from the greater quantities of upper stem bole material that were left unutilized on New Mexico logging sites as compared to Arizona logging sites.

This logging utilization study and resulting factors can help forest managers in the Southwest understand the impacts of commercial timber harvesting on growing-stock inventories and woody residue volumes potentially available for bioenergy uses. Likewise, they can provide measures and insights into how the milling infrastructure in each State affects the utilization of timber. Variables—logging method, species, tree size (i.e., d.b.h.), and the presence/absence of an industry (e.g., pulp or biomass energy) that can use smaller diameter material—can have profound impacts on the production of logging residue.

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END NOTES

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

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

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

[4]Vigas are peeled logs used as exposed ceiling joists or beams in traditional Southwestern style building. Latillas are smaller-diameter peeled logs running perpendicular to or between vigas.

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