Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Pacific Northwest Research Station | Resource Bulletin PNW-RB-273 | June 2025

Logging Utilization in California, 2018–2022

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Produced through a joint venture agreement with the University of Montana, Bureau of Business and Economic Research; California Department of Forestry and Fire Protection; and U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, (PNW agreements 18-JV-11261979-059 and 20-JV-11261979-110).

Piled logs from a fire salvage sale in California, 2022. Photo by Eric Simmons.

Abstract

Simmons, Eric A.; Koch, Lucas P.; Morgan, Todd A.; Berg, Erik C.; Christensen, Glenn A. 2025. Logging utilization in California, 2018–2022. Resour. Bull. PNW-RB-273. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 23 p. https://doi.org/10.2737/PNW-RB-273.

California forest land managers seek current information about tree utilization and the volume of merchantable bole wood residue produced by commercial timber harvesting. To address this need, University of Montana, Bureau of Business and Economic Research analysts investigated timber harvest utilization at active logging sites in California from 2018 through 2022. This research characterized current tree utilization, logging operations, and woody biomass left onsite after harvest. Study results were used to compute state-level utilization factors, which indicated that in California, for every 1,000 cubic feet of log volume delivered to the mill, harvest removed 1,052 cubic feet from growing stock (the portion of a tree that was live [green] at the time of harvest), which resulted in 57 cubic feet of growing-stock logging residue. An additional 5 cubic feet of nongrowing-stock material (portions of green trees below the 1-foot stump or above the 4-inch-diameter outside-bark top) was also delivered to the mill. A separate and novel salvage tree investigation quantified residue factors of dead trees harvested after fire. For every 1,000 cubic feet of salvage tree volume delivered to the mill, harvesting removed 1,066 cubic feet of timber from the merchantable bole (as defined by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program), with 72 cubic feet of logging residue coming from this portion of the tree. Study results can inform land managers of residues available for bioenergy uses, provide data for woody biomass life cycle analyses and carbon accounting, and improve estimates of removals from growing stock during commercial timber harvest.

KEYWORDS:

Forest inventory
Growing-stock removals
Logging residue
Removals factors
Timber harvest

Summary

Logging utilization studies, designed to quantify the volume of growing-stock removals and logging residue generated by commercial timber harvest of green (live) trees, have not been updated in California for nearly two decades. The last study was conducted in 2004 (Morgan and Spoelma 2008). This new study provides updated information based on current logging practices and associated logging residue volumes. Residue volumes can be directly associated with harvest volumes and U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis inventory parameters, such as removals from growing stock. We found that in California, for every 1,000 cubic feet of green tree volume delivered to the mill, 57 cubic feet of growing-stock logging residue was created. The previous logging utilization study in California did not include salvage (dead tree) sites. Examination of salvage harvesting can help inform carbon accounting by quantifying the volume of wood sequestered as carbon in products generated from the logging of dead trees, as well as the amount of residue left onsite. In addition, this two-part study allows comparisons of salvage tree utilization factors and utilization factors obtained from the green tree study. Results from the salvage tree study indicated that every 1,000 cubic feet of mill-delivered volume generated 72 cubic feet of logging residue from the merchantable bole, roughly 26 percent more bole residue than green-tree harvesting. The differences in logging residue factors highlight the need for studying salvage logging. Although harvesting practices for the green tree study and the salvage tree study were similar, the residue factors indicated that marginally more logging residue from the merchantable bole is left onsite (in the stand or at the landing) during salvage logging.

Contents

Introduction

California land managers seek updated information on state logging utilization for a suite of benefits. Knowing how much woody material is left in the forest after commercial logging operations can help managers understand fuel loads and predict potential feedstock for woody biomass energy facilities. Forest carbon accounting efforts in California, and other Pacific coast states, also require current information about logging residue and harvested wood product volumes (Christensen et al., in press). Since the last California utilization study in 2004 (Morgan and Spoelma 2008), characteristics of harvested trees and their utilization may have changed. Likewise, harvest methods may have shifted. The information developed from repeated logging utilization studies can enable quantification of these changes.

University of Montana, Bureau of Business and Economic Research analysts investigated timber harvest utilization at active logging sites in California from 2018 to 2022. The primary objective of this research was to update logging utilization factors from the 2004 study (Morgan and Spoelma 2008), characterize harvested tree attributes, and identify changes in commercial timber harvesting at the state level within California. In addition, due to increases in tree mortality from wildfire and drought prior to and during the study period, the analysts collected utilization data from salvage logging sites, where most of the trees were dead prior to harvest.

When conducted in a consistent manner, utilization studies can provide information about changes in timber harvest practices and resulting logging residue through time and across different geographic regions. A recent logging utilization study provided updated residue and harvest information for Alaska (Simmons et al. 2022). Older studies for nearby Oregon and Washington (e.g., Howard 1973, 1981a, 1981b) described and quantified slash or logging residue per 1,000 board feet (MBF) Scribner harvested; however, these studies did not directly associate the residue volume to harvest volumes and U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) inventory parameters (e.g., growing-stock[1] versus nongrowing-stock[2] sources; fig. 1). The California logging utilization 2018–2022 study, and others like it (Berg et al. 2018; Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014, 2022), make those direct connections among timber harvested for products, the associated logging residue, and the effects on forest inventory.

California Department of Forestry and Fire Protection analysts desired additional information on logging residue from salvage sites, so we visited additional sites and measured felled trees to assess salvage tree logging operations. The results of this assessment are included in a separate section of this report.

[1] Growing stock consists of all commercial species live trees that meet, or potentially meet, minimum merchantability standards. In general, these trees have at least one solid 8-foot section, are reasonably free of deformity on the merchantable bole, and are at least 26 percent merchantable by volume.

[2] Nongrowing-stock sources include wood from below the 1-foot stump height and from tops above the 4-inch diameter outside bark on "growing stock" trees, and from any portion of a (dead) tree that is not growing stock.

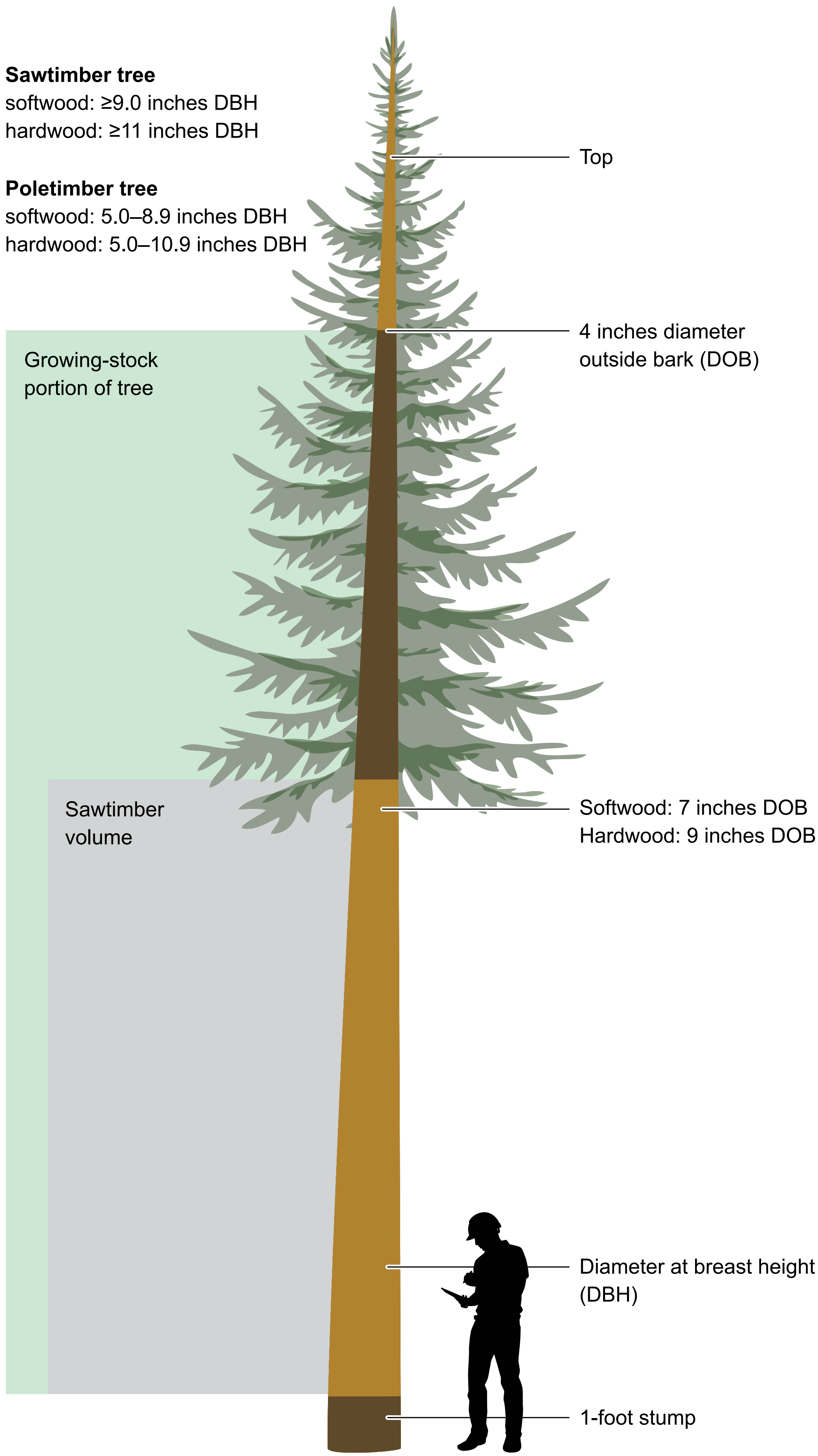

Figure 1—Sections of live softwood trees. Merchantable bole is the same section as growing stock, but not defined as growing stock in dead trees.

Methods

California Timberlands and Recent Timber Harvest Background

There are nearly 16.3 million acres of timberland[3] potentially available for timber harvest activities in California (table 1). Timber resources and harvest activities are concentrated in northern California, but harvest does occur across most of the state's forested resource areas (Marcille et al. 2020). Wood-product markets and forest policy issues, as well as wildfire and drought-related mortality have influenced annual timber harvest volumes and characteristics in the state.

Table 1—Distribution of timberland,[a] standing volume, and 5-year average harvest by ownership class in California

Ownership class	Area	Proportion of in-state timberland[a]	Standing volume	Proportion of in-state standing volume	Proportion of in-state harvest (2014–2018 average)
	1,000 ACRES	PERCENT	MMBF SCRIBNER	PERCENT	
National forest	8,721	54	193,048	58	19
Private	7,151	44	130,926	39	79
BLM and other public	232	1	3,925	1	0
State	159	1	6,193	2	2
All ownerships	16,262	100	334,092	100	100

Columns may not sum to total because of rounding. BLM = U.S. Department of the Interior, Bureau of Land Management; MMBF = 1 million board feet.

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

Sources: UM BBER (2023), USDA FS (2024).

Historically, more than 90 percent of California's annual timber harvest volume has been used for lumber (sawlogs) and veneer/plywood production (veneer logs) (Marcille et al. 2020). Other timber products (e.g., woody biomass and posts) are commonly merchandised with sawlogs.

Over the past 20 years, California's annual timber harvest reached a high of 1.8 billion board feet (BBF) Scribner in 2005 (fig. 2). With the collapse of U.S. housing markets and the subsequent decrease in demand for lumber, total timber harvest volumes declined beginning in 2008, falling to a low of less than 1 BBF Scribner in 2009 (UM BBER 2023). The 2020 timber harvest of 1.6 BBF Scribner was consistent with prerecession levels. Proportions of harvest among ownerships have varied somewhat year to year over the past 20 years, but the broader trends have been relatively stable. Most of California's timber has been harvested from private (industrial and nonindustrial) lands, ranging from 79 to 85 percent of the total state harvest. The proportion of total timber harvested from National Forest System lands has ranged from a low of 14 percent in 2006 to 21 percent in 2011 and 2014, with the 2020 national forest timber harvest constituting 17 percent of the state total. Timber harvests from

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

California state forests were less than 1 percent of the total state timber harvest prior to 2011 but have increased to about 1.5 percent of that total over the past 10 years from an average of 4.5 million board feet (MMBF) Scribner before 2011 to an average of 24 MMBF since 2011.

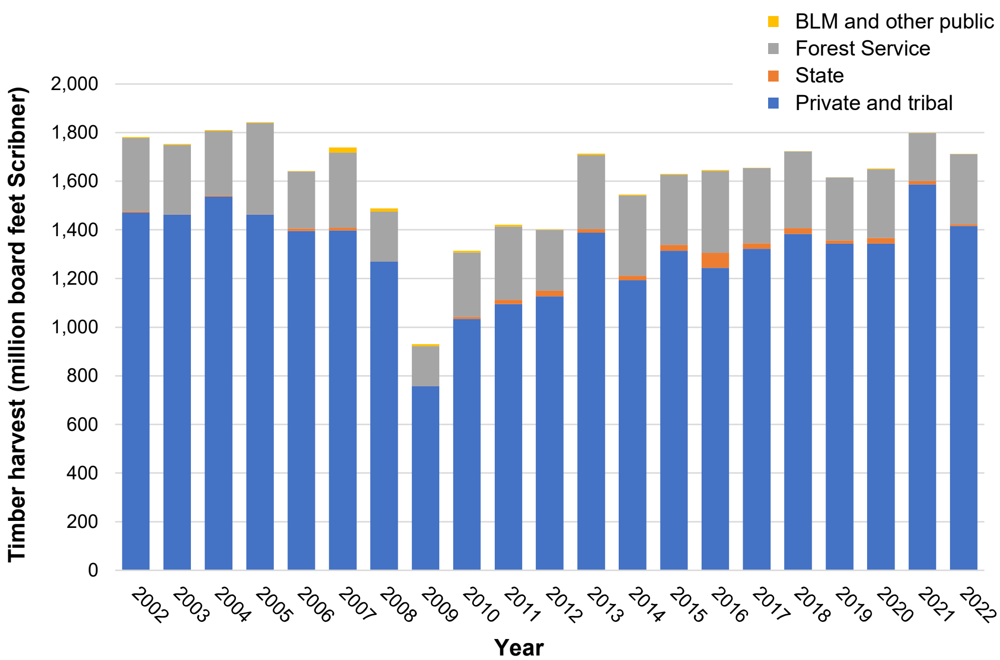

Figure 2—Volume of harvested timber in California, 2002–2022. BLM = U.S. Department of the Interior, Bureau of Land Management. Source: UM BBER (2023).

Study Design

The methods for this study followed those used by Morgan and Spoelma (2008) and Simmons et al. (2022). The target population was active logging sites in California, so we identified sites where timber was being harvested for commercial products.

We sought to sample felled trees within active logging sites (the primary sampling unit) that would provide data to estimate logging utilization factors expressed as the ratios of means at the California state level (Zarnoch et al. 2004). Ideally, the sampling protocol would yield ratios and attendant standard errors computed in the same manner as other logging utilization investigations to ensure comparability of results. Most state-level logging utilization investigations have reported factors and standard errors using design-based methods without selecting sample sites at random from a list of all active logging sites, i.e., the sampling frame (McClain 1992, Morgan and Spoelma 2008, Simmons et al. 2014). As indicated by Morgan and Spoelma (2008), 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 from those sites. Although not having a sampling frame to draw sites at random could bias design-based sampling parameter estimates and compromise any ability to make population inferences (Lohr 2009), a simulation analysis of utilization data from Pacific Northwest states demonstrated that design-based methods did not bias sample results (Berg et al. 2015). For our study in California during 2018–2022, as in other Western U.S. investigations, it was not possible to obtain a list of all active sites. Thus, sample sites were not selected at random, and ratios of means and standard errors were computed using design-based methods instead.

We used a stratified two-stage sampling scheme to select logging sites and trees for measurement within each site (Levy and Lemeshow 1999). Sample sites were allocated proportional to the 5-year average timber harvest volume in each multi-county resource area (fig. 3); these proportions served as sampling weights. Logging sites with active harvesting of trees for commercial products served as stage 1 sampling units. Annual timber-harvest summaries (UM BBER 2023) provided the county and ownership class of potential sample logging sites. Timberland managers, owners, and mills were contacted periodically throughout the study period to identify when and where logging activities would be occurring and to request access to conduct measurements. We visited loggings sites and measured trees between August 2018 and November 2022.

Stage 2 sampling units consisted of felled trees within each selected logging site. To qualify for measurement (for the live-tree portion of the study), a tree had to qualify as growing stock, and the entire stem, including the stump and top, had to be measurable (Morgan and

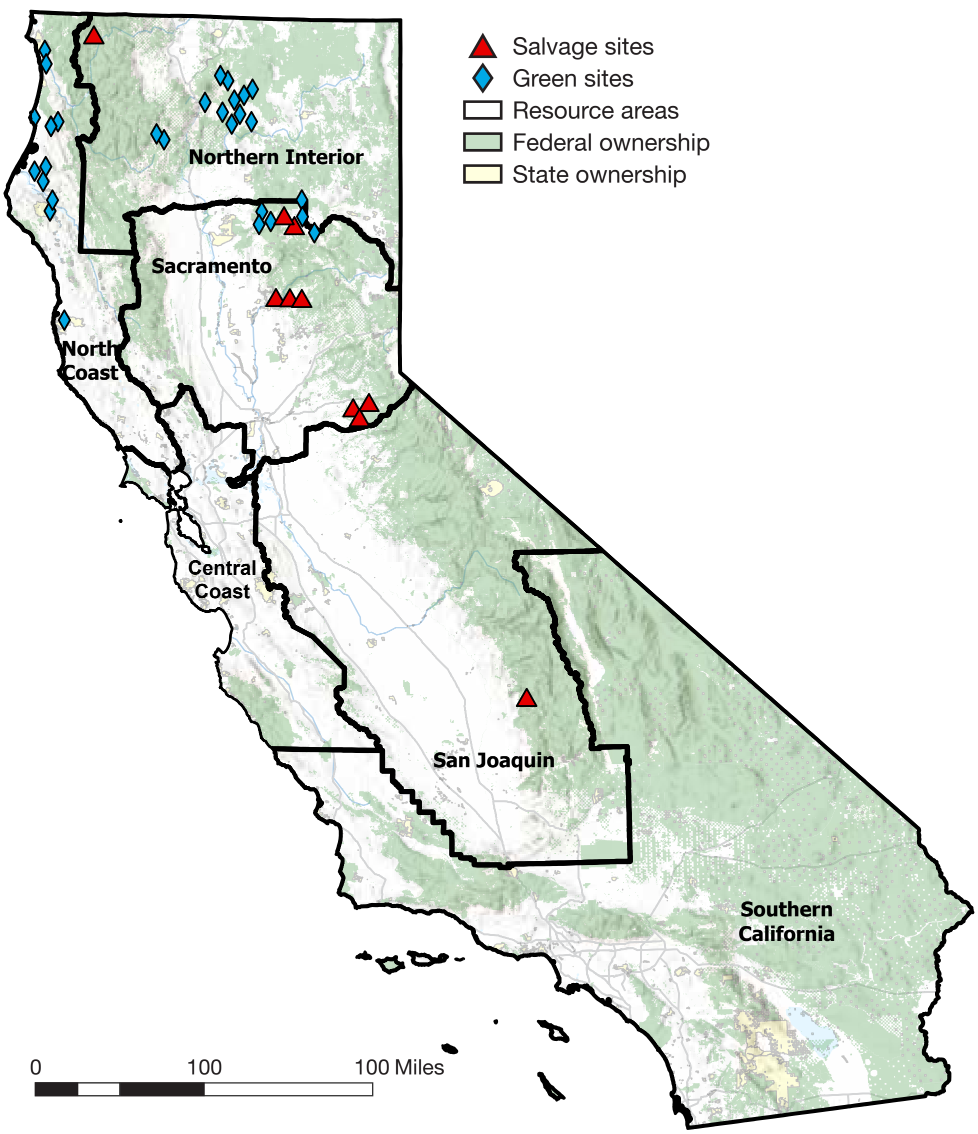

Figure 3—Green-tree and salvage logging site locations in California by resource area.

Spoelma 2008, Woudenberg et al. 2010). For the salvage sites, the individual trees did not have to be alive at the time of harvest to be selected, but the entire stem had to be available for measurement.

Sample sizes for stage 1 and 2 sample units were guided by standard errors achieved in previous utilization studies. Zarnoch et al. (2004) found that standard errors for utilization ratios dropped substantially by increasing the number of measured logging sites from 10 to 20. Previous logging utilization studies in Alaska, California, Idaho, and Montana garnered low standard errors by measuring 25 to 35 trees on each of 27 to 35 logging sites (Morgan et al. 2005; Morgan and Spoelma 2008; Simmons et al. 2014, 2022). Further, 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.

Data Collection

Logging contractors or foresters at each selected site were contacted 1 to 2 weeks 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 mills. Bureau of Business and Economic Research 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), as well as information about logging residue disposal (e.g., to be burned or not, left at the landing, or returned to the stand).

A minimum of 15 felled trees were measured at each of 30 live-tree and 10 dead-tree logging sites from 2018 to 2022, with 25 trees per site being the most common. The 30 live-tree sites were spread across northern California, whereas the dead-tree sites tended to be in the Sacramento and Northern Interior Resource Areas where salvage logging activity was concentrated (fig. 3). A total of 691 felled live trees comprising 6,424 individual tree sections were measured, along with 221 felled dead trees comprising 2,327 sections.

Data Analysis

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 each site as a whole. Logging residue factors, standard errors, and 95-percent confidence intervals were computed at the state level based on the stratified two-stage sampling design using the ratios of means estimator (Zarnoch et al. 2004) obtained from SAS PROC SURVEYMEANS (SAS Institute Inc. 2023). Characteristics of the felled trees, harvest operations, and utilization factors were then summarized and compared with the previous California logging utilization study (Morgan and Spoelma 2008) and recent studies from other Western states.

Green Tree Results and Discussion

Characteristics of Logging Sites and Operations

The majority of our sample sites were in northern California as most of the commercial logging occurs in that part of the state. Most of the site selection was dependent on identifying logging operations where green trees were being harvested. However, during the 2021 and 2022 field seasons, salvage logging operations in recently burned areas constrained the availability of green-tree sites in the state. The limited availability of logging sites in the San Joaquin Resource Area and low proportions of the total harvest in Southern California Resource Area (fig. 3) resulted in no sites being measured there (table 2) despite substantial areas with tree mortality from the 2012–2016 drought and bark beetle outbreak. Likewise, the number of sites sampled on public timberlands (i.e., national forest, state, and other public) was lower than desired for these ownership classes (table 3) because of limited availability of active harvest sites.

Harvest methods included hand or mechanical felling and merchandising (table 4). Mechanical felling machines were typically equipped with hot saws and accumulating heads that enabled them to both fell and bunch trees for yarding. Hand felling and merchandising were done with chainsaws. Yarding was accomplished with cable or ground-based

Table 2—Distribution of 5-year average timber harvest and sampled green-tree logging sites by California resource area

Resource area	5-year average state timber harvest, 2014–2018	Sampled green-tree logging sites, 2018–2022	Sampled green-tree logging sites, 2018–2022
	MBF SCRIBNER	PERCENT	NUMBER
North Coast	27	40	12
Northern Interior	35	40	12
Sacramento	27	20	6
San Joaquin	11	0	0
Southern California	0	0	0
Total	**100**	**100**	**30**

MBF = 1,000 board feet. Source: UM BBER (2023).

Table 3—Distribution of 5-year average timber harvest and sampled green-tree logging sites by ownership class in California

Ownership class	Proportion of 5-year average state timber harvest, 2014–2018	Proportion of sampled green-tree logging sites, 2018–2022	Sampled green-tree logging sites, 2018–2022
	PERCENT		
Private	79	90	27
BLM and other public	—	—	—
Forest Service	19	7	2
State	2	3	1
Total	**100**	**100**	**30**

BLM = U.S. Department of the Interior, Bureau of Land Management, — = Less than 1 percent. Source: UM BBER (2023).

Table 4—Sampled green-tree logging sites in California by logging method and ownership class, 2018–2022

Ownership class	Felling			Yarding		Skidding		Merchandising location		Merchandising method		Total sites
	Hand[a]	Mechanical	Mixed	Tree length	Log length	Ground	Cable	In unit	At Landing	Hand[a]	Mechanical	
	NUMBER OF SITES											
Federal	—	2	—	2	—	2	—	1	1	—	2	2
Private	10	17	—	21	6	23	4	3	24	4	23	27
State	1	—	—	—	1	—	1	1	—	1	—	1
Total	**11**	**19**	**0**	**23**	**7**	**25**	**5**	**5**	**25**	**5**	**25**	**30**

[a] Hand felling and merchandising method refers to chainsaw use.
— = 0
Source: UM BBER (2023).

systems, depending on topography or harvest prescription. Ground-based skidding was accomplished with rubber-tired skidders and bulldozers equipped with either a grapple or a winch with chokers. Trees were skidded both tree-length and log-length. Processing heads attached to excavators was the most common method used for merchandising trees at landings.

Timber was mechanically felled on 63 percent of sites in this study, compared to only 19 percent of sites in 2004 (Morgan and Spoelma 2008). Log-length yarding occurred on 23 percent of sites in this study, while log-length yarding occurred on 67 percent of sites in 2004. Timber was most frequently mechanically felled and bunched in piles and skidded with dozers or rubber-tired skidders. Cable yarding, indicative of logging on steeper slopes, was used on about 17 percent of sites in this study and 21 percent in 2004. Timber was processed or merchandised at landings with mechanical systems on 83 percent of sites in this study, whereas 2004 study results indicated that timber was merchandised with chainsaws in the logging unit on 76 percent of sites. These findings suggest substantial shifts in California's timber harvest methods since 2004, with increased use of mechanical felling, merchandising and tree-length skidding/yarding, but relatively consistent proportions of steep-slope (cable yarded) operations.

Characteristics of Felled Trees

Sampled trees ranged from 7.0 to 61.0 inches diameter at breast height[4] (DBH). For this report, diameter class is referenced by the midpoint value of the 2-inch range of a diameter class (e.g., 8.0 inches DBH refers to trees in the 7.0 to 8.9 inches diameter class). The average end of utilization was 6.8 inches diameter outside bark (DOB) in 2018, whereas in 2004, the average end of utilization was 7.2 inches DOB. More than 80 percent of trees measured in the current study were less than or equal to 20.0 inches DBH, accounting for 50 percent of utilized volume, and 53 percent of growing-stock logging residue (table 5). In 2004, nearly 75 percent of the sampled trees were less than or equal to 20.0 inches DBH, which accounted for 36 percent of the utilized volume and 46 percent of growing-stock logging residue (Morgan and Spoelma 2008). Pole-timber trees (trees that are 5.0–8.9 inches DBH)

[4] Diameter at breast height is the tree's diameter outside the bark, measured at 4.5 feet aboveground on the uphill side (Helms 1998).

Table 5—Distribution of sampled green trees in California, mill-delivered volumes, and growing-stock logging residue volumes by diameter class

Diameter class	Sampled green trees	Proportion of sampled trees	Cumulative sampled trees	Mill-delivered volume	Cumulative mill-delivered volume	Growing-stock logging residue volume	Cumulative growing-stock logging residue volume
INCHES DBH	NUMBER	PERCENT					
8	23	3.3	3.3	0.4	0.4	2.2	2.2
10	66	9.6	12.9	1.9	2.3	5.5	7.7
12	106	15.3	28.2	5.2	7.5	8.3	16.0
14	107	15.5	43.7	8.0	15.6	8.5	24.6
16	103	14.9	58.6	10.6	26.1	9.5	34.1
18	93	13.5	72.1	12.8	38.9	10.3	44.4
20	58	8.4	80.5	10.2	49.1	8.5	52.8
22	44	6.4	86.8	9.5	58.6	9.5	62.4
24	29	4.2	91.0	7.8	66.4	6.2	68.6
26	14	2.0	93.1	4.7	71.1	3.5	72.0
28	18	2.6	95.7	7.7	78.9	7.1	79.1
30	8	1.2	96.8	4.3	83.2	2.1	81.3
32	7	1.0	97.8	3.9	87.1	6.4	87.7
34	7	1.0	98.8	4.7	91.7	4.9	92.6
36	3	0.4	99.3	1.9	93.6	0.4	93.0
≥38	5	0.7	100	6.4	100	7.0	100

Diameter class represents the midpoint of the 2-inch diameter class, i.e., 8.0 inches refers to trees with diameter of 7.0 to 8.9 inches diameter at breast height (DBH). Columns may not sum to total due to rounding. Volumes refer to cubic-foot volumes. Source: Helms (1998).

accounted for 0.4 percent of the mill-delivered volume and generated 2.2 percent of the current growing-stock logging residue volume. Morgan and Spoelma (2008) found that 3.5 percent of total logging residue came from pole-timber trees and that they accounted for the same percentage of mill-delivered volume as in the 2018 study (0. 4 percent).

White fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), and redwood (*Sequoia sempervirens*) were three of the most frequently sampled tree species in the 2018 study (table 6). In 2004, the most frequently sampled tree species were true firs (*Abies* spp.), Douglas-fir and ponderosa pine (*Pinus ponderosa*) (Morgan and Spoelma 2008). White fir, Douglas-fir, and ponderosa pine accounted for the majority (73 percent) of the harvested volume in California during 2016 (Marcille et al. 2020) (table 6), and these three species accounted for 68 percent of the mill-delivered volume from California sites in this study. We suggest that the difference in the proportion of white fir in California's 2016 timber harvest and sampled volumes in this study was due to four sites being in one geographic area where salvage or sanitation treatments were prescribed to mitigate a fir engraver (*Scolytus ventralis*) infestation. Some of these sites were in areas where ponderosa pine would typically be the preferred species to harvest, which may account for some of the imbalance between reported timber harvest and this study's sampled volume for ponderosa pine.

Statewide Logging Utilization Factors

Logging utilization factors are statewide ratios of used or unused bole volumes to mill-delivered volumes (Morgan and Spoelma 2008, Simmons et al. 2016). As was the case for the Pacific Northwest states (Berg et al. 2015), using a design-based sampling protocol was shown to not bias California green-tree factor estimates. In this study, for each 1,000 cubic feet of green tree volume delivered to the mill, the California growing-stock removals factors were found to be as follows: commercial timber harvesting removed 1,052 cubic feet of growing-stock volume, where 995 cubic feet of growing-stock was utilized, and 57 cubic feet of growing-stock was left in the forest or at the landing as logging residue (table 7). In addition, 5 cubic feet of nongrowing-stock material from stumps cut below 1 foot in height and tops (portions of trees between the 4 inch diameter outside bark (DOB) and the end of the tree) went to the mill. Most of this utilized nongrowing-stock volume came from stump material. Two percent of growing-stock logging residue came from portions of the bole that broke during felling.

Table 6—Distribution of sampled green trees in California, their total and mill-delivered volumes and residues, and 2016 state timber harvest volume by species

Species	Sampled trees	California state timber harvest volume, 2016	Sampled tree mill-delivered volume	Proportion of total logging residue volume	Residue proportion of sampled tree mill-delivered volume
	NUMBER	PERCENT			
White fir	229	26.9	36.8	36.0	5.9
Douglas-fir	170	23.6	27.2	25.0	5.6
Redwood	127	13.9	17.5	24.8	8.6
California red fir	55	0.3	5.8	5.6	5.9
Ponderosa pine	35	22.8	4.1	3.8	5.6
Western hemlock	29	0.2	2.6	1.7	3.9
Incense cedar	20	3.4	2.1	0.4	1.2
Other soft/hardwoods	26	8.8	3.8	2.7	4.3
All species	**691**	**100**	**100**	**100**	**5.7**

Columns may not sum to total because of rounding. Timber harvest volumes refer to 1,000-board feet volumes; mill-delivered volumes refer to cubic-foot volumes of sampled trees. 2016 California timber harvest source: Marcille et al. (2020).

Table 7—Green-tree removals factors for logging utilization in California

Removals factor	Lower bound (95-percent confidence interval)	Estimate (ratio of means)	Upper bound (95-percent confidence interval)	Standard error	Cubic feet per MCF mill delivered
Nongrowing-stock product delivered to mills (utilized nongrowing stock ÷ total utilized)	0.0028	0.0053	0.0078	0.0012	5
Growing-stock product delivered to mills (utilized growing stock ÷ total utilized)	0.9922	0.9947	0.9972	0.0012	995
Growing-stock logging residue (unutilized growing stock ÷ total utilized)	0.0469	0.0573	0.0676	0.0050	57
Removals from growing stock (utilized + unutilized growing stock ÷ total utilized)	1.0405	1.0520	1.0635	0.0056	1052

MCF = 1,000 cubic-feet. Source: SAS Institute Inc. (2023).

The growing-stock logging residue ratio for this study is very similar to what Morgan and Spoelma (2008) found in 2004 (table 8). However, Morgan and Spoelma (2008) found that 10 cubic feet of nongrowing-stock material was delivered to the mill in the 2004 study. Results for California in 2018 indicate only 5 cubic feet of the same material was delivered to the mill, a 50-percent decrease in utilized nongrowing-stock volume. This decrease was directly related to the differences in height of the cut stumps measured between the two studies. California's mean stump height in this study was 0.83 feet, compared with a 0.74-feet mean stump height in 2004. Increases in stump height between the two studies differ from findings in other studies; where felling methods have shifted from chainsaws to mechanical systems (Simmons et al. 2014, 2016), stump heights decreased. Increased use of mechanical felling versus chainsaws has resulted in more of the stump (i.e., nongrowing-stock volume) being utilized. The observation of taller stumps in the current study could be attributed to types of harvesting heads used, concerns that saws would create sparks that start fires, or as a way of preserving equipment integrity.

Table 8—California growing-stock removals factors for each cubic foot of green material delivered to mills, 2004 and 2018–2022

Removals factor	2004	2018–2022
Nongrowing-stock product delivered to mills	0.0101	0.0053
Growing-stock product delivered to mills	0.9899	0.9947
Growing-stock logging residue	0.0615	0.0573
Removals from growing stock	1.0594	1.0520

Source: Morgan et al. (2008).

Logging utilization studies in the Western states have been conducted on a periodic basis. Each analysis is specific to a state and uses the same methodology over the course of a 4- or 5-year study period. Studies in other Northwest states were conducted in Oregon and Washington 2011–2015, Alaska 2016–2019, and the 2018–2022 California study. Logging residue factors for each state were developed from data collected during each of the study periods (fig. 4). The logging residue ratio for California compared with sampled Northwest states indicated that Oregon and Washington logging operations generated 50-percent less logging residue volume for every 1,000 cubic feet of tree volume delivered to the mill (Simmons et al. 2016). However, logging operations in California generated 39-percent less logging residue volume from growing-stock residues than in Alaska. Both Oregon and Washington have active pulpwood markets that are likely contributing to smaller small-end inside-bark diameter end of utilization in those states compared to California. Although California has a biomass energy sector capable of utilizing smaller small-end inside-bark diameter logs (Marcille et al. 2020), most facilities are currently using other sources for their raw materials (Scott et al., in press). Previous studies have established that residue factors increase exponentially as the smaller small-end inside-bark diameter logs at the end of utilization increases (Simmons et al. 2014, 2016).

Residue ratios varied somewhat among California resource areas, with the North Interior Resource Area having the lowest growing-stock residue ratio at 41 cubic feet and the Sacramento Resource Area having the highest ratio at 74 cubic feet for every 1,000 cubic feet delivered to the mill. White fir trees sampled in the Sacramento Resource Area had

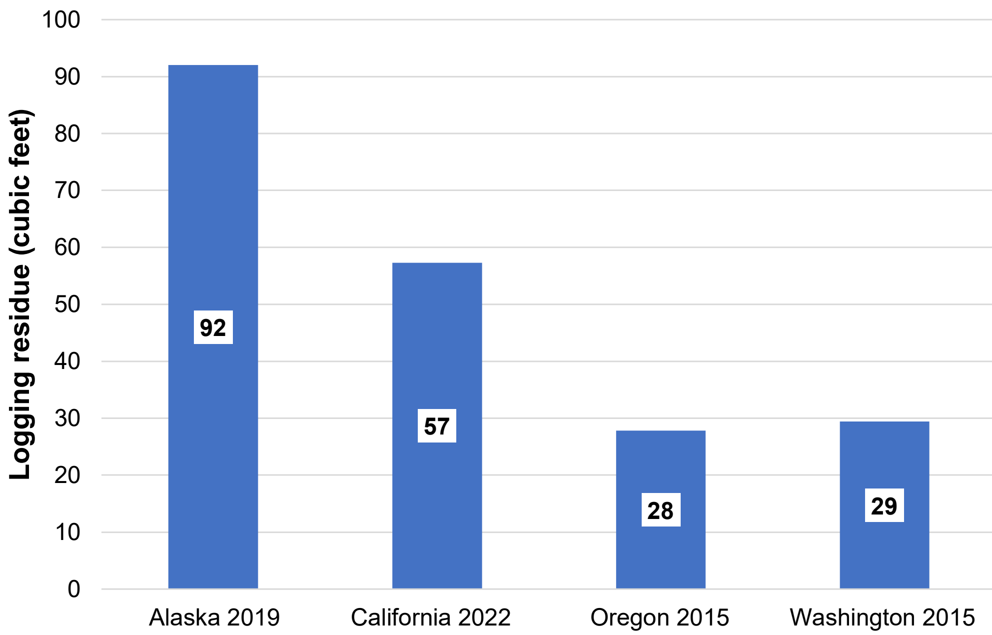

Figure 4—Growing-stock ratios for California and Pacific Northwest states, select years: cubic feet of growing-stock logging residue for every 1,000 cubic feet of mill-delivered volume to California and Pacific Northwest states.

proportionally higher residue ratios than other species, driving the total ratio of means higher for that resource area. These findings differ from those of the four-state study by Berg et al. (2015) and suggest that 2018–2022 California residue ratios were influenced by the diversity in tree form caused by regional site quality or logging practices. Additionally, the California residue ratio was not related to felling systems, which was an important variable that shaped residue ratios for the four-state study.

For both the 2004 and the 2018 logging utilization studies, and consistent with findings from other states, smaller diameter trees produced proportionally more logging residue for every cubic foot of volume delivered to the mill, as compared to larger trees (fig. 5) (Morgan and Spoelma 2008). Much of the rapid decline in the smaller diameter class residue proportional to mill-delivered volume was an artifact of cubic volume computation: the residue ratio denominator, mill-delivered volume, is small in trees less than or equal to 8.0-inch DBH but increases rapidly from 8.0 to 12.0 inches DBH, resulting in exponential reductions in the residue ratio. In the 2004 and 2018 studies, the growing-stock residue proportional to mill-delivered volume declined steadily from the 8.0- to 14.0-inch diameter classes and remained relatively stable through the 30.0-inch diameter class. For the current study, trees in the 32.0-inch diameter class had dramatically more residue proportional to mill-delivered volume than other diameter classes. This finding is a product of two factors: (1) limited observations across a limited number of sites, and (2) logging damage for these trees accounted for 58 percent of the residue volume, while logging damage for the study overall accounted for 35 percent of the logging residue volumes.

Trees sampled in the largest diameter classes during the 2004 and 2018 studies exhibited some increases in the proportion of growing-stock residue to mill-delivered volume, a finding that was similar to study results for Idaho, Oregon, and Washington (Simmons et al. 2014, 2016). More breakage in the upper stem was observed on several sites where larger trees were felled.

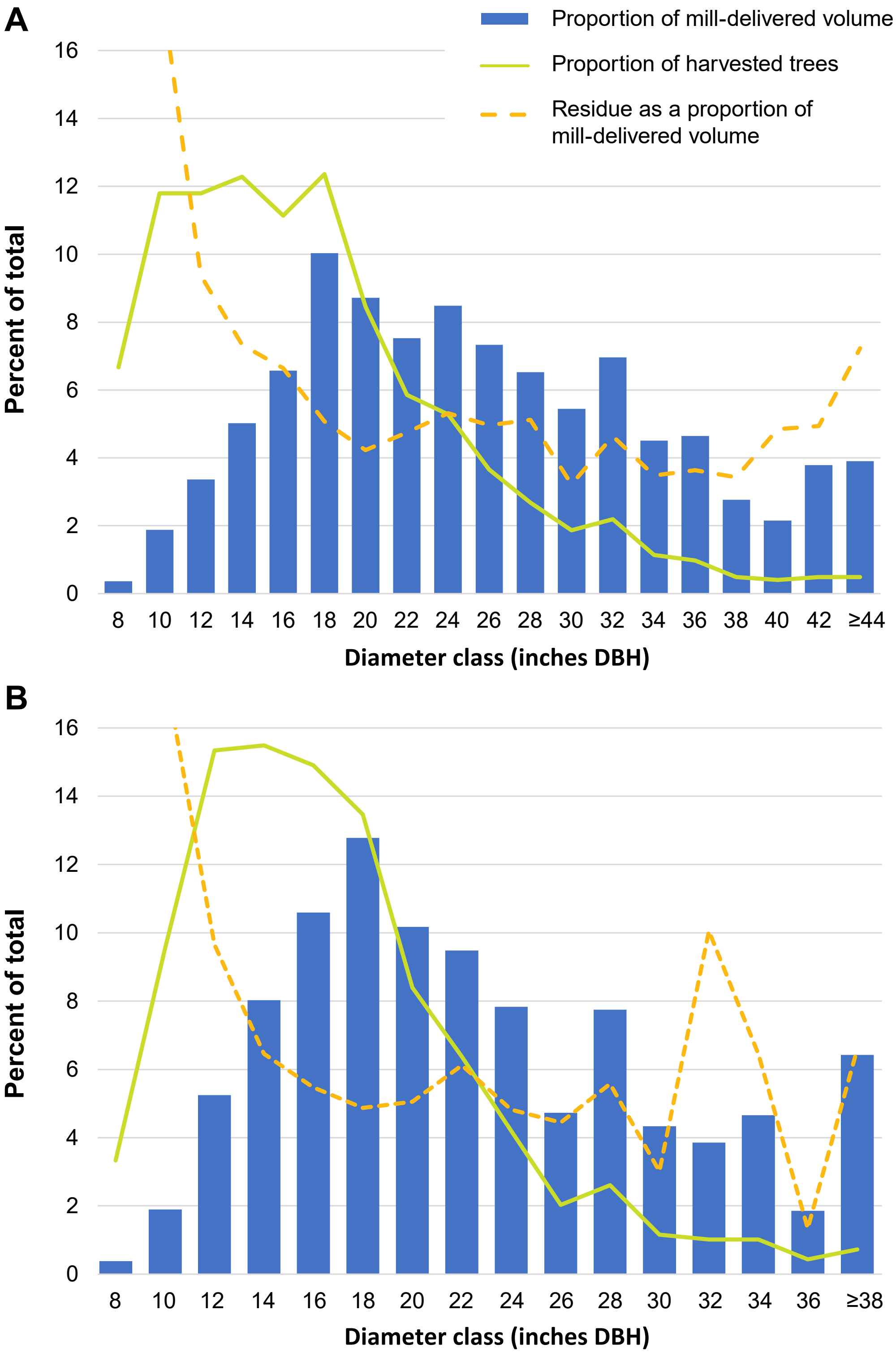

Figure 5—California mill-delivered volumes and green-tree harvests as percentages of totals and logging residue as a percentage of mill-delivered volume by diameter class, 2004 (A) and 2018 (B). Diameter class represents the midpoint of the 2-inch diameter class, i.e., 8.0 inches refers to trees with diameter of 7.0 to 8.9 inches diameter at breast height (DBH). Source: Morgan et al. (2004).

Generally speaking, statistically significant differences in residue ratios by species have not been common in logging utilization studies but were observed for western redcedar (*Thuja plicata*) in the Idaho study (Simmons et al. 2014). In this California study, redwood exhibited the highest residue factor (77 per 1,000 cubic feet delivered to the mill), although not substantially higher when compared to other species (fig. 6). Bureau of Business and Economic Research analysts found that redwood trees had somewhat taller stumps, averaging 1.25 feet compared to 0.83 feet for the sample as a whole. Taller stumps, greater than 1 foot, correspond to more growing-stock volume left onsite as logging residue, thus driving up the growing-stock residue factor for redwood.

Results of this study can also be used to characterize utilization of the entire bole of the harvested tree without regard to growing stock or sawtimber definitions (fig. 7). In California, 6.4 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 on the forest as logging residue, with 0.7 percent coming from above the 4-inch DOB top. A total of 93.1 percent of the bole was delivered to the mill, which included 0.5 percent from outside the merchantable bole, usually from below the 1-foot stump. This information can benefit forest managers who do not use the FIA distinctions of growing-stock and nongrowing-stock tree components.

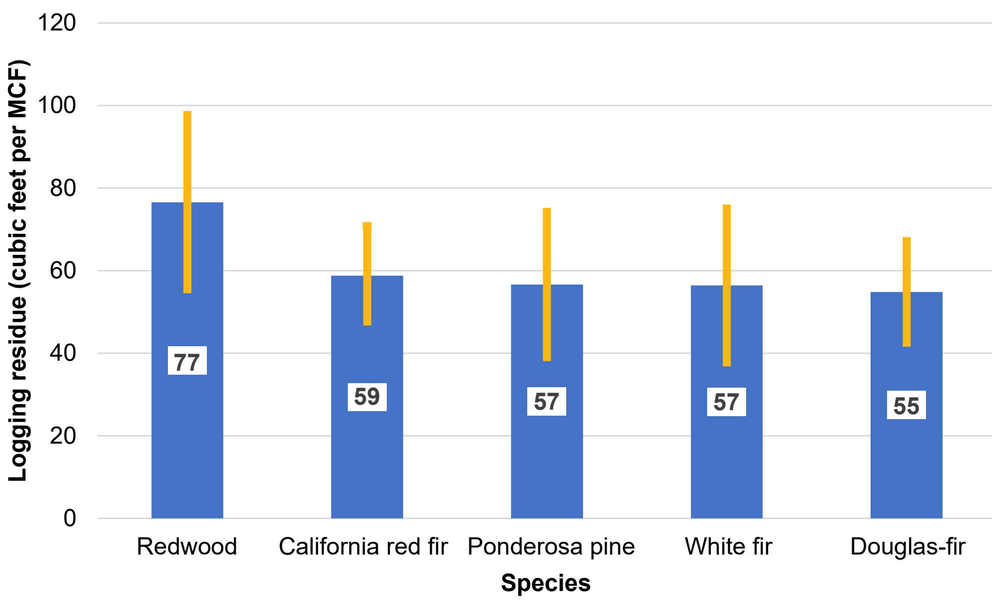

Figure 6—California growing-stock logging residue per 1,000 cubic feet (MFC) of mill-delivered volume by species (yellow vertical lines represent 95-percent confidence intervals). Source: SAS Institute Inc. (2023).

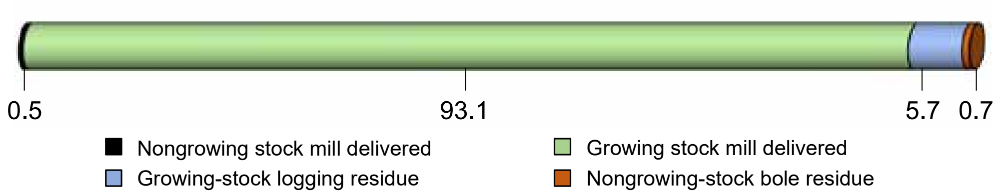

Figure 7—California utilization of entire green-tree bole from tree harvests. Note: excludes branches and forked tops.

Dead-Tree Study Results

Logging utilization studies to determine growing-stock removals factors target felled trees that were live at the time of harvest. The target population for this portion of the study, however, was active logging sites in California where dead trees were being harvested for conversion into wood products. Methods for the dead-tree study were the same as for the green-tree study, however, data was not stratified or weighted by resource area.

In California, across inventory cycles beginning in 2012, average annual mortality of growing-stock tree volume on timberland from all sources is 660 million cubic feet (MMCF) (USDA FS 2023). Insects, disease, fire, and weather-related events account for 84 percent of all mortality (556 MMCF), of which volume killed by fire accounts for 42 percent (232.7 MMCF). When trees are killed by environmental events, land managers have taken steps to utilize salvageable volumes to produce wood products. This was especially true in the wake of the 2020 and 2021 fire seasons, which left nearly 6.9 million acres of land in California burned with varying intensity and severity (Cal Fire 2023).

Like the green-tree portion of this study, Bureau of Business and Economic Research crews found that during the study time frame there was limited availability of active logging sites where dead trees were being harvested for commercial products. Eighty percent of the sampled sites were in the Sacramento Resource Area. No sites were sampled in the North Coast or the Southern California Resource Areas. Ninety percent of the sites sampled were under private ownership. The time between disturbance and harvest on sampled sites varied from 3 months to 6 years.

Results and Discussion

Four of the ten sites had a mix of both green and salvage logs. Hand and mechanical felling methods were observed on salvage logging operations, with two of the sites having a mix. Both ground-based and cable-systems skidding were used (on 80 and 20 percent of sites, respectively), along with hand and mechanical merchandising (40 and 60 percent of sites, respectively) (table 9). Tree-length yarding occurred on 60 percent of sampled salvage sites.

Table 9—Number of sampled salvage, dead-tree sites by logging methods and ownership class, 2018–2022

Ownership class	Felling			Yarding		Skidding		Merchandising location		Merchandising method		Total
	Hand[a]	Mechanical	Mixed	Tree length	Log length	Ground	Cable	In unit	At landing	Hand[a]	Mechanical	
	NUMBER OF SITES											
Public	2	—	—	1	1	2	—	1	1	2	—	2
Private	2	4	2	5	3	6	2	3	5	2	6	8
Total	**4**	**4**	**2**	**6**	**4**	**8**	**2**	**4**	**6**	**4**	**6**	**10**

— = no sites.

[a]Hand felling and merchandising method refers to chainsaw use.

Characteristics of Felled Dead Trees

Sampled salvage trees ranged from 7.5 to nearly 48.0 inches DBH. Compared to the green-tree end of utilization (6.8 inches DOB), the average end of utilization was larger, at 8.6 inches DOB. Dead trees that were less than or equal to 20.0 inches DBH accounted for 64 percent of trees measured (table 10). Within the same diameter class range, dead trees generated 22 percent of the utilized volume and 26 percent of merchantable bole[5] residue (table 5). By comparison, in the green tree study 80 percent of the trees measured were less than or equal to 20.0 inches DBH and generated 50 percent of the utilized volume and 53 percent of the merchantable bole logging residue.

Ponderosa pine, Douglas-fir, and white fir made up more than 70 percent of the dead-tree sample (table 11). Though a large proportion (21 percent) was sugar pine (*Pinus lambertiana*), that species only accounted for 7 percent of the California statewide harvest (Marcille et al. 2020). Among harvested dead trees, Douglas-fir accounted for fewer cubic feet of logging residue per 1,000 cubic feet of mill-delivered volume (table 11) than among live Douglas-fir. White fir had the highest residue ratio for every 1,000 cubic feet of mill-delivered volume at 2.8 cubic feet. Pole-timber (5.0 to 8.9 inches DBH) represented only 0.2 percent of mill-delivered volume.

[5] Portions of trees from the 1-foot stump to the 4-inch small-end, inside-bark diameter top.

Table 10—Distribution of dead trees in California, mill-delivered volume, and merchantable bole logging residue volume by diameter class

Diameter class	Trees	Proportion of tree sample	Cumulative sampled trees	Mill-delivered volume	Cumulative mill-delivered volume	Merchantable bole logging residue volume	Cumulative merchantable bole logging residue volume
INCHES DBH	NUMBER	PERCENT					
8	8	3.6	3.6	0.2	0.2	2.3	2.3
10	13	5.9	9.5	0.8	0.9	2.0	4.3
12	26	11.8	21.3	2.5	3.4	3.9	8.2
14	36	16.3	37.6	4.6	8.1	5.8	14.0
16	24	10.9	48.4	4.4	12.5	3.8	17.8
18	26	11.8	60.2	6.7	19.2	5.9	23.7
20	8	3.6	63.8	2.5	21.7	2.6	26.3
22	13	5.9	69.7	6.2	27.9	2.9	29.2
24	12	5.4	75.1	7.5	35.4	5.2	34.5
26	8	3.6	78.7	5.7	41.1	2.5	37.0
28	11	5.0	83.7	9.7	50.8	4.5	41.5
30	10	4.5	88.2	10.9	61.7	28.6	70.1
32	9	4.1	92.3	11.0	72.7	2.9	72.9
34	6	2.7	95.0	8.6	81.3	4.2	77.1
36	6	2.7	97.7	9.6	90.9	15.3	92.4
≥38	5	2.3	100	9.1	100	7.6	100

Diameter class represents the midpoint of the 2-inch diameter class, i.e., 8.0 inches refers to trees with diameter of 7.0 to 8.9 inches diameter at breast height (DBH). Volume refers to cubic-foot volume. Columns may not sum to total due to rounding.

Table 11—Distribution of sampled dead trees in California, their mill-delivered and residue volumes, and 2016 state timber harvest volume by species

Species	Sampled trees	2016 California timber harvest volume	Sampled tree mill-delivered volume	Merchantable bole logging residue volume	Residue proportion of mill-delivered volume
	NUMBER	PERCENT OF TOTAL			
Ponderosa pine	95	23	20.5	32.5	2.3
White fir	55	27	31.9	39.0	2.8
Douglas-fir	29	24	18.5	8.4	0.6
Sugar pine	20	7	21.2	14.5	1.0
Incense cedar	16	3	3.4	2.4	0.2
Other soft-/ hardwoods	6	16	4.4	3.2	0.2
All species	**221**	**100**	**100**	**100**	**7.2**

Columns may not sum to total due to rounding. 2016 California timber harvest source: Marcille et al. (2020).

As in the live-tree study, the merchantable bole residue factor decreased steadily from the 8.0 to 14.0 diameter classes. The proportion of merchantable bole residue to mill-delivered volume among dead trees that were 28 to 38 inches DBH or more exhibited more variability than live trees within the same diameter classes (fig. 8). This finding is due to factors similar to those in the green-tree study: (1) limited observations among a limited number of sites, and (2) logging damage among dead trees accounted for 62 percent of the residue volume, whereas logging damage in the same diameter class range for the green-tree study

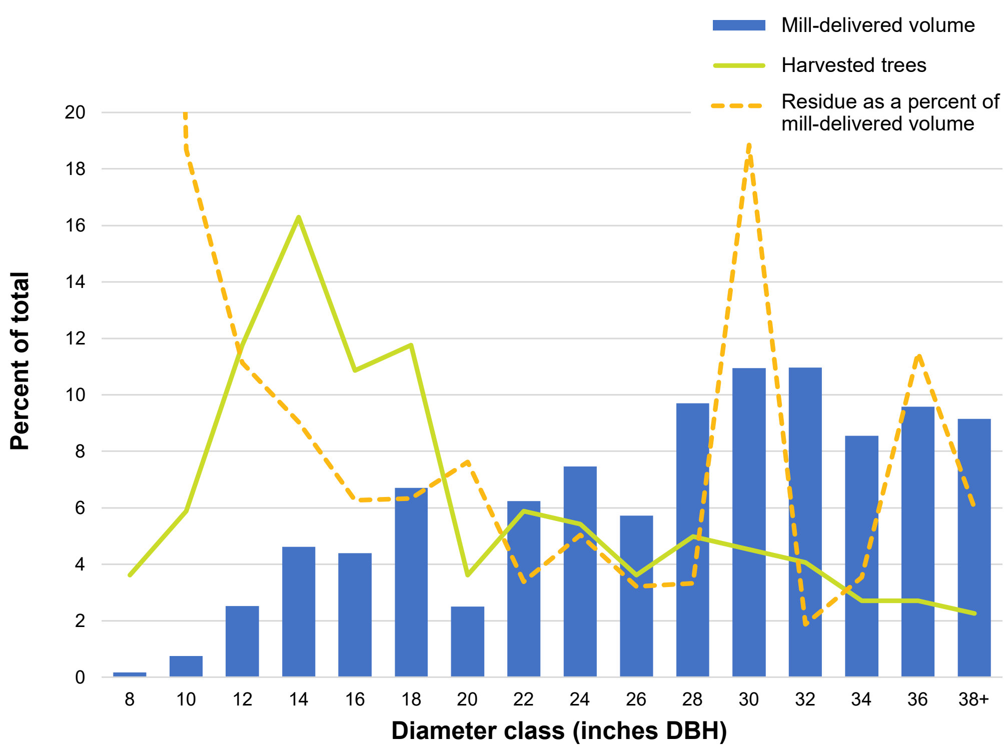

Figure 8—California dead-tree residue factors, harvested trees, and mill-delivered volumes by diameter class, 2018. Diameter class represents the midpoint of the 2-inch diameter class, i.e., 8.0 inches refers to trees with diameter of 7.0 to 8.9 inches diameter at breast height (DBH).

accounted for 20 percent of the logging residue volumes.

Dead-Tree Removals Factors

For every 1,000 cubic feet of salvaged tree volume delivered to mills in the California salvage tree study, 72 cubic feet of merchantable bole volume harvested remained in the harvest unit as logging residue, while 994 cubic feet of merchantable bole was removed and delivered to mills (table 12). In total, removals from the merchantable bole accounted for 1,066 cubic feet of salvaged tree volume, and non-merchantable bole delivered to mills accounted for 6 cubic feet of salvaged tree volume. Dead and green trees exhibit similar residue ratios, with dead trees having slightly more merchantable bole residue per unit of mill-delivered volume (table 13). The additional growing-stock logging residue generated by dead trees was primarily due to more logging damage to the merchantable bole.

Table 12—California logging utilization removals factors of dead trees

Removals factors	Lower bound (95-percent confidence interval)	Estimate (ratio of means)	Upper bound (95-percent confidence interval)	Standard error	Cubic feet per MCF of mill delivered
Nonmerchantable bole product delivered to mills *(utilized non-merchantable bole ÷ total utilized)*	0.0013	0.0065	0.0116	0.0023	6
Merchantable bole product delivered to mills *(utilized merchantable bole ÷ total utilized)*	0.9884	0.9935	0.9987	0.0023	994
Merchantable bole logging residue *(unutilized merchantable bole ÷ total utilized)*	0.0360	0.0721	0.1083	0.0160	72
Removals from merchantable bole volume *(utilized + unutilized merchantable bole) ÷ total utilized)*	1.0277	1.0657	1.1037	0.0168	1,066

MCF = 1,000 cubic feet.

Table 13—Merchantable bole residue factors for each cubic foot of green- and dead-tree material delivered to mills in California, 2018–2022

Factor	Green tree	Dead tree
Nonmerchantable bole product delivered to mills	0.0049	0.0065
Merchantable bole product delivered to mills	0.9951	0.9935
Merchantable bole logging residue	0.0588	0.0721
Removals from merchantable bole	1.0539	1.0

Of harvested salvage tree bole volume, 92.4 percent (from the cut stump to the tip of the tree) was delivered to the mill to be converted into wood products (fig. 9). When compared to 93.6 percent for the green-tree study, this finding indicates that salvage efforts can recover the majority of the cubic volume from suitable trees to be converted into products that will store carbon for decades. This is especially true when salvage efforts occur soon after trees are killed, as the usefulness and value of dead-tree volume can degrade substantially as rapidly as 3 months to 3 years depending on species, elevation, size, and other factors (Fahey et al. 1986).

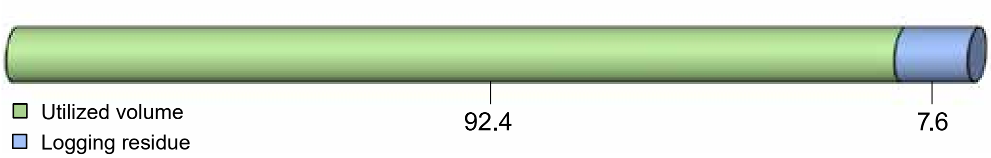

Figure 9—Utilization of salvage tree bole from harvests in California. Note: excludes branches and forked tops.

Disposition of Logging Residues and Biomass Utilization

While Bureau of Business and Economic Research crews collected information on land managers' plans for treatments of logging residues, they did not observe treatments concurrent with logging operations nor did they ascertain later if expected treatments were carried out. Logging residue, from both growing and nongrowing stock, was planned to be either broadcast burned or burned in piles on 21 of the 30 green-tree sites. On five sites, residue was left scattered where trees were processed or redistributed from processor piles for nutrient replenishment. Biomass utilization of logging residues was anticipated on four sites. Timber harvesting activities on these sites generated about 3.3 cubic feet of growing-stock logging residue for every 1,000 cubic feet delivered to the mill, compared to 65 cubic feet of growing-stock logging residue for every 1,000 cubic feet for the other sites. For sites where residue was used for biomass energy, the small proportion of logging residue left over was burned (piled or broadcast) or left scattered throughout the unit.

Using data from 2016 timber product output calculations developed by the Bureau of Business and Economic Research, and relying on 2016 timber harvest and state-level logging residue factors from the 2004 California logging utilization study, we calculated that about 2 green tons (2,000 pounds of harvested material, including moisture content) of gross logging residue is generated for every 1,000 board feet Scribner of green timber harvested for commercial wood products in California. The growing-stock logging residue ratio has decreased marginally since 2004 (table 13), likely resulting in fractionally smaller volumes of gross logging residue being generated under current conditions.

On nine of ten dead tree sites, residue was left scattered on the forest floor where trees were felled/processed or accumulated in processor piles that were subsequently scattered for nutrient replenishment. On one salvage site, biomass utilization and scattering for nutrient replenishment were indicated as possible postharvest treatments of logging residues. At several sites, land managers indicated that they may permit access to processor piles on logging sites for firewood gathering.

Conclusions

This study identified the changes in California logging methods and felled tree attributes since 2004, including growing-stock utilization. The results provide land managers with information about commercial timber harvest removals and logging residues for both green and salvage trees. Logging residue ratios can be used with projected treatment volumes to help inform managers of probable residue volumes at varying spatial scales.

The salvage logging portion of this study provides insight into understanding fire-killed timber harvest effects on woody residue and potential effects on carbon dynamics. The study characterizes the logging methods used in California salvage logging and residue factors from active salvage-tree logging sites.

Results suggest that the merchantable bole removals factors in California for both salvage and live trees showed little difference between the two study populations. Although utilization differed site by site, tree by tree, and to some extent, study by study, the effects of the differences on the aggregate appear to be minimal.

Logging utilization studies repeated at different time periods suggest that mechanized logging systems with tree-length skidding have largely replaced hand felling and merchandising at the stump. Current tree-length yarding and skidding practices tend to concentrate logging residue at the landing where trees are mechanically processed. Some branch, broken bole, and foliar residues are still scattered throughout the unit as a product of felling and yarding/skidding but substantially less than in the past. A better understanding of how much residual material remains scattered throughout logging sites postharvest could be gained by updated postyarding logging residue measurements similar to those performed by Howard (1973).

Acknowledgments

The authors gratefully acknowledge the financial support of the California Department of Forestry and Fire Protection and the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis program. Other cooperators included numerous industrial private landowners, California state demonstration forests, foresters, and loggers without whose assistance this analysis could not have been accomplished.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	0.305	Meters
Acres	0.405	Hectares
Cubic feet	0.0283	Cubic meters
Tons	907	Kilograms
Tons	0.907	Tonnes or megagrams

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APPENDIX 1
Species Referenced in This Report

Common name	Scientific name	Authority
White fir	*Abies concolor*	(Gord. & Glend.) Lindl. ex Hildebr.
California red fir	*Abies magnifica*	A. Murray bis
Incense cedar	*Calocedrus decurrens*	(Torr.) Florin
Sugar pine	*Pinus lambertiana*	Douglas
Ponderosa pine	*Pinus ponderosa*	Lawson & C. Lawson
Douglas-fir	*Pseudotsuga menziesii*	(Mirb.) Franco
Coast redwood	*Sequoia sempervirens*	(Lamb. ex D. Don) Endl.
Western hemlock	*Tsuga heterophylla*	(Raf.) Sarg.

Pacific Northwest Research Station

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