Coarse Woody Debris in Oak Woodlands of California

William D. Tietje, *Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720;* **Karen L. Waddell**, *USDA Forest Service, Pacific Northwest Research Station, Forest Sciences Laboratory, 620 SW Main, Suite 400, Portland, OR 97205;* **Justin K. Vreeland**, *U.C. Cooperative Extension, 2156 Sierra Way, Suite C, San Luis Obispo, CA 93401; and* **Charles L. Bolsinger** *(retired), USDA Forest Service, Pacific Northwest Research Station, Forest Sciences Laboratory, 620 SW Main, Suite 400, Portland, OR 97205.*

ABSTRACT: *An extensive forest inventory was conducted to estimate the amount and distribution of coarse woody debris (CWD) on 5.6 million ac of woodlands in California that are outside of national forests and reserved areas. Woodlands consist primarily of oak* (Quercus *spp.*) *types and are defined as forestland incapable of producing commercial quantities of traditional forest products because of adverse site and tree morphophysiology. Approximately 671 million ft^3 of CWD were estimated to occur over the study area. Almost 3 million ac of woodland (52% of the sampled area) were estimated to have no CWD. The large-end diameter of CWD was <12 in. on 67% of all logs sampled. Blue oak* (Q. douglasii) *CWD occurred over the largest area and gray pine* (Pinus sabiniana) *produced the most volume (164.1 million ft^3) of CWD. An average of 115 ft^3/ac, 1.2 tons/ac, 21 logs/ac, and 56.8 linear ft/ac were estimated for CWD across all woodland types. The coast live oak* (Q. agrifolia) *type produced the largest per-acre measure of CWD volume (164.1 ft^3/ac). The California laurel* (Umbellularia californica) *type produced the highest log density (48 logs/ac) and the most linear feet per acre of CWD (131.8 ft/ac). CWD was most abundant in the central coast and least abundant in the northeastern portion of the state. Results of this study suggest that CWD is not common across much of California's woodlands. More detailed research is needed to evaluate the amount and distribution of CWD, affects of land-use, and the implications for wildlife. West. J. Appl. For. 17(3):139–146.*

Key Words: Coarse wood, down wood, dead wood, debris, oak woodlands, forest inventory.

Coarse woody debris (CWD) is a component of many forest ecosystems, providing habitat for wildlife (Maser et al. 1979, Bartels et al. 1985, Bull et al. 1997) and long-term storage sites for moisture and nutrients (Harmon et al. 1986). For this study, we defined CWD as down trees, large limbs, and large broken pieces of wood on the forest floor. California's woodland forests occupy land incapable of growing commercial quantities (at least 20 ft^3 of wood vol/ac/year) of traditional forest products (e.g., lumber) because of adverse site and tree morphophysiology. Oak (*Quercus*) species predominate on the estimated 6.5 million ac of unreserved hardwood forests that occur in the woodlands across the state (Waddell and Bassett 1996, 1997a–d). Most of these forests are on the margin of California's Central Valley, and they extend south along the coastal ranges to the Mexican border. Woodlands are widely recognized for their value as livestock grazing land, recreational sites, open space and view sheds, watersheds, and wildlife habitat. They are known to provide food and cover for over 300 terrestrial vertebrate species (Barrett 1980, Verner and Boss 1980). Habitat structures that are created when standing trees and large limbs fall to the ground are highly correlated with wildlife species abundance in the oak woodlands (Block and Morrison 1990, Tietje et al. 1997). A query of Version 5 of the California Wildlife Habitat Relationships System indicated the importance of CWD for feeding, reproduction, and cover by species within all the terrestrial vertebrate classes, but especially its wide use by oak woodland amphibians (68% of 22 species) and reptiles (61% of 38 species) (Timossi et al. 1994). CWD also may function as natural protection for emerging oak seedlings (Barnhart et al. 1991).

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Although CWD is considered critical for many wildlife species, few empirical data were available on amount and characteristics of CWD in California's oak woodlands. This lack of information on CWD across broad landscapes prompted the Forest Inventory and Analysis (FIA) program of the Pacific Northwest Research Station, USDA Forest Service, to include CWD in its 1994[1] inventory of forestland in California. Here, we report the first statewide assessment of the amount, density, and distribution of CWD in hardwood forests on California's woodlands. Knowledge of the CWD component of the ecosystem will provide baseline information to landowners, biologists, resource planners, policy analysts, and land managers to help improve the quality of resource decisions about woodland management and serve as a basis for future research and monitoring efforts.

Study Area

The 1994 FIA inventory in California sampled unreserved woodland owned by private individuals and corporations, state and local public agencies, and the Bureau of Land Management (national forests were not sampled; the Pacific Southwest Region of the Forest Service collects data on national forestlands). The inventory sampled over a broad range of woodland types (defined by the species with the plurality of tree stocking) and included all counties where woodland was tallied in our field survey. The FIA inventory did not sample the portion of California's landscape covered by low-density oak-savanna. Savanna is land with less than 10% tree canopy cover and is not considered forestland by FIA.

Woodland communities in California typically occupy dry sites, but some forests extend into more mesic areas. Oak species commonly found in the woodlands include blue oak (*Quercus douglasii*), interior live oak (*Q. wislizenii*), coast live oak (*Q. agrifolia*), canyon live oak (*Q. chrysolepis*), California black oak (*Q. kelloggii*), and valley oak (*Q. lobata*). Because much valley oak woodland occurs as savanna (White 1966), the valley oak type is underrepresented in this statewide FIA inventory. Other hardwoods, including California laurel (*Umbellularia californica*), California sycamore (*Platanus racemosa*), Oregon ash (*Fraxinus latifolia*), black (*Populus trichocarpa*) and Fremont (*P. fremontii*) cottonwood, California walnut (*Juglans californica*), box elder (*Acer negundo*), and several species of willow (*Salix* spp.), can occur with the oaks. Gray pine (*Pinus sabiniana*) is the most common coniferous associate of oaks, especially on dryer sites with soils of granitic origin. Other conifers are found in transition areas between woodland and mesic forests or in inclusions of atypical geological formations or soil types and include California juniper (*Juniperus californica*), cypress (*Cupressus* spp.), Douglas-fir (*Pseudotsuga menziesii*), and Coulter (*Pinus coulteri*), ponderosa (*P. ponderosa*), Jeffrey (*P. jeffreyi*), and knobcone (*P. attenuata*) pines.

Methods

Study Design and Plot Selection

The inventory design for the FIA program was a double sample for stratification similar to the one described by Cochran (1977). The design consisted of a primary (aerial photo, 1:24,000 scale) sample and a secondary (field) sample. Plot locations for the primary sample were selected from a permanent grid overlaid on a map of the state. We chose field plots for the inventory by taking a second sample from the original group of primary plots. A field plot encompassed a circular area of approximately 6 ac. Initially, 542 field plots classified as woodland were selected for this study; however, 47 plots (accounting for 211,000 ac of forest land) were not sampled for CWD because of difficulty with access. Our analysis therefore included 495 woodland plots representing about 5.6 million ac of forestland within 5 resource areas (North Coast, North Interior, Sacramento, Central Coast, and Southern), each consisting of a group of adjacent counties (Figure 1).

Plot Layout

The 495 field plots were laid out in a cluster design consisting of five subplots installed in fixed locations (Figure 2). Tree measurements were taken on each subplot as part of the FIA standard forest inventory. The CWD was sampled along two 56 ft transects on each subplot. To reduce log orientation bias, the transects were established from the subplot center at 0 and 90 degrees (Van Wagner 1968). A transect was terminated when it crossed a forest condition different from the condition at the subplot center. The lengths of the 10 transects on a plot (≤560 ft/plot) were summed to derive the primary sample unit for estimation of plot-level attributes for CWD. Detailed information and documentation about inventory sample designs, field procedures, and compilation methods are available from the FIA program. [2]

Data Collection

Coarse woody debris for our study was defined as dead trees, large limbs, and large pieces of wood lying on the ground and not supported by a live root system. We did not include standing dead trees, stumps, foliage, separated bark,

Figure 1. Distribution of woodland inventory plots across five resource areas in California for the 1994 Forest Inventory and Analysis (FIA) program, Pacific Northwest Research Station, USDA Forest Service.

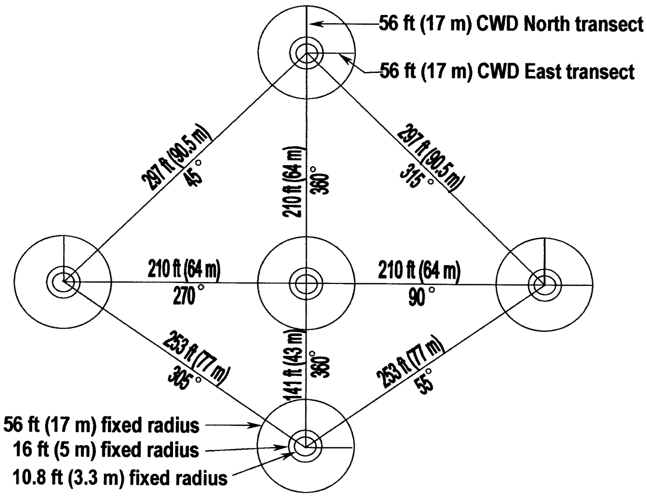

Figure 2. The field plot layout was a cluster of five subplots in the 1994 Forest Inventory and Analysis (FIA) program, Pacific Northwest Research Station, USDA Forest Service. Coarse woody debris (CWD) was sampled on two 56 ft transects installed on each subplot at 0 and 90°.

or roots. Line-intersect sampling was used to tally individual pieces (usually logs) along each transect (Brown 1974, DeVries 1973, Waddell, in press). Every log at least 5 in. in diameter at the point of intersection and at least 3.3 ft (1 m) long was selected for measurement if the central axis of the log crossed the transect line. Diameter was estimated at both the small and large ends of each log to the nearest 0.4 in. (1 cm). On logs with splintered or decomposed ends, diameter was recorded at the point that best represents the majority of the log form and volume. The log length was measured to the nearest 3.3 ft from the large end down to a minimum small-end diameter of 5 in. or to the point where the log was heavily decomposed. If the section of the log between these two points was a minimum of 3.3 ft long, the log was tallied. Logs that were forked or that had large attached branches with both segments intersecting the transect were tallied as separate pieces of CWD. The forked segment with the largest diameter at the fork junction was identified as the main bole on which the log length was measured from the tip to the large end. Other characteristics were recorded, including species, cavities or excavations, and the extent of decay. Decay was categorized into one of four classes based on a 5-class system described by Maser et al. (1979). Logs in decay class 5 were not sampled in this inventory because the lack of structural integrity and clear delineation of log dimensions made these logs difficult to identify and measure repeatedly in the field. Therefore, only logs that field crews identified as classes 1 to 4 were recorded under the following classification system:

1. Sound wood, bark intact, small and large branches present, no invading roots or vegetation growing on log.
2. Sapwood slightly decayed, heartwood sound, bark mostly intact, small and large branches present, no invading roots, little vegetation growing on the log surface.
3. Sapwood decayed or missing; heartwood mostly sound; bark sloughing or absent; large branches present; roots invading sapwood area; few shrubs, mosses, or tree seedlings on the log surface.
4. Heartwood decayed; bark absent or detached; only branch stubs present; roots invading throughout; shrubs, moss, or larger trees growing on the log surface.
5. No structural integrity to the log, wood soft and powdery when dry, branch stubs and pitch pockets rotted away, roots present throughout the log (logs in this advanced stage of decay were not tallied in the inventory).

Data Quality

Field crews attended an intensive 2 wk training session to learn data collection procedures. During the first few weeks of fieldwork, inexperienced crew members were paired with experienced crew members. About 10% of the field plots were revisited, and all items were remeasured to check accuracy and consistency in classification, plot layout, tree measurements, and species identification. Each crew's work was audited about five times during the field season. Data were verified by using computer programs in both the field and the office. Whenever possible, questionable data either were remeasured in the field or corrected in the office.

Data Analysis

Characteristics of the CWD log resource were determined from an analysis of the individual logs tallied on each plot. Summaries of log dimensions by species, type, and diameter class were developed before data were expanded to the broad inventory area. Expansion of CWD plot data to their representation on a per-acre basis for the resource area was accomplished by using procedures described by Waddell (in press) for data collected on plots within extensive inventories. Estimates were derived first for individual pieces of CWD and then accumulated to the plot level. We used plot estimates as the basis for data expansions to the inventory area. Estimates of average per-acre attributes were developed by calculating a weighted average of plot estimates within a desired group, such as woodland type. Individual log volume was calculated with Smalian's formula (Husch et al. 1972) as follows:

$$\text{Log volume (ft}^3) = [(D_S^2 + D_L^2)\ (\pi / 8)\ (\text{log length})] \div 144$$

where

π is the constant 3.1416,

D_S is the diameter (in.) at the small end of the CWD log,

D_L is the diameter (in.) at the large end of the CWD log, and

log length is in feet.

Volume/ac, biomass/ac, logs/ac, and linear ft/ac were estimated for each individual log by dividing the attribute by the sum of all transect lengths established on one plot (after DeVries 1973, Waddell, in press):

$$\text{Log volume in ft}^3\text{/ ac} = \{[\pi / (2\ L)]\ (\text{log volume / log length})\}(43{,}560\text{ ft}^2\text{/ ac})$$

where

π is the constant 3.1416,

L is the sum of all individual transect lengths (ft) on 1 plot,

log length is in feet, and

log volume is the cubic volume (ft^3) for an individual log (previous equation).

$$\text{Biomass in ovendry tons / ac} =$$
$$(\text{ft}^3 / \text{ac})\,(SG)\,(DCR)\,(62.4 \text{ lb / ft}^3 / 2000 \text{ lb / ton})$$

where SG is the specific gravity of green wood for the species (Forest Products Laboratory 1987) and DCR is a decay class reduction factor (see Waddell, in press)

$$\text{Number of logs / ac} =$$
$$\{[(\pi / (2 \times L)](1.0 / \text{log length})\}(43{,}560 \text{ ft}^2 / \text{ac}),$$

where

π is the constant 3.1416,

L is the sum of all individual transect lengths (ft) on one plot, and

log length is in feet.

$$\text{Linear feet of log / ac} = (\text{log length})(\text{number of logs / ac}).$$

These log estimates were summed to the plot level (within groups, e.g., decay class) before any analysis was conducted. Estimates of volume and abundance across broad areas were calculated by expanding the per-acre plot-level estimates by the number of acres that each inventory plot represented. This allowed an estimate to be developed for the total amount of a characteristic of CWD logs for a county, resource area, or for the state. A weighted average was used to estimate the average volume/ac, logs/ac, or linear ft/ac with plot acres as the weight. Additional information about methods and procedures used in the FIA forest inventory are available from the FIA program and are described, in part, by Waddell and Bassett (1996).

Results

Woodland Characteristics

Woodland Area

We sampled 5.6 million ac of unreserved woodland in California, outside the national forests, for CWD. We found no CWD on 61% of the sampling plots (Table 1), representing 2.9 million ac in the inventory. Of the 21 woodland types identified in this study, 8 were oak types (Table 1). Approximately 90% of the 495 woodland plots (representing 5.1 million ac) were classified as one of the oak types, and, except for valley oak and Engelmann oak (*Q. engelmannii*), each of the oak types was sampled by at least 15 plots. Blue oak was the most extensive woodland type we sampled, covering 2.6 million ac. The gray pine type was the most prevalent of the nonoak types, occupying 1.9 million ac.

Live Tree Volume

We estimated that 5,285.7 million ft^3 of live tree volume (i.e., the volume of all trees ≥5 in. dbh, including trees of poor form, that are not culled as a result of excessive rot) occurs on unreserved woodland outside national forests (Table 2). Most of the volume is in the Central Coast (1,744.2 million ft^3) and Southern (1,427.6 million ft^3) resource areas (Figure 1). Almost 50% of the total live tree volume (5,285.7 million ft^3) was

Table 1. Estimated area, sample size, and dimensions of CWD logs, by woodland type, on unreserved woodland outside National Forests, California, 1991–1994.

Woodland types	Area (1,000 ac)	Plots sampled	Logs tallied	Plots w/no CWD (%)	Ave. large-end diameter (in.)	Ave. log length (ft)
		············(no.)············				
Oak types						
Blue oak (*Quercus douglasii*)	2,622	226	197	65	12.0	13.7
California black oak (*Q. kelloggii*)	148	15	13	67	11.5	11.9
Canyon live oak (*Q. chrysolepis*)	228	23	31	78	11.3	13.9
Coast live oak (*Q. agrifolia*)	773	72	96	51	11.4	17.3
Engelmann oak (*Q. engelmannii*)	60	5	3	60	8.0	6.6
Interior live oak (*Q. wislizenii*)	897	71	51	58	12.9	14.2
Oregon white oak (*Q. garryana*)	274	29	23	59	13.4	22.4
Valley oak (*Q. lobata*)	108	8	10	38	10.8	13.5
Total, oak types	5,110	449	424	62	11.9	14.9
Other woodland types						
Gray pine (*Pinus sabiniana*)	187	20	15	55	11.8	14.2
California buckeye (*Aesculus californica*)	78	6	5	50	13.9	18.4
California laurel (*Umbellularia californica*)	65	5	13	20	9.6	12.6
Other types[1]	172	15	23	53	13.2	20.9
Total, other types	502	46	56	50	12.1	16.9
Total, all types	5,612	495	480	61	11.9	15.2

[1] Other types include 10 woodland types represented by a sample size of <5 plots.

Table 2. Estimated cubic volume of live trees and CWD logs, by species and resource area, on unreserved woodland outside National Forests, California 1991-94. Alpha level of CIs is 0.10.

	Live tree[1] volume (million ft^3) in resource area							Coarse woody debris[2] volume (million ft^3) in resource areas						
Woodland species	North Coast	Central Coast	North Interior	Sacra-mento	Southern	Total	90% CI for total	North Coast	Central Coast	North Interior	Sacra-mento	Southern	Total	90% CI for total
Oak species														
Blue oak	35.7	343.8	129.8	538.5	584.9	1,632.7	(±178.4)	1.8	62.6	6.3	39.3	35.6	145.5	(±28.8)
California black oak	91.4	15.8	37.0	78.5	9.0	231.7	(±27.2)	22.4	0	3.9	5.0	0.5	31.9	(±17.1)
Canyon live oak	58.3	7.2	39.5	85.8	83.3	274.1	(±24.1)	2.0	0	2.9	0	28.0	32.9	(±21.0)
Coast live oak	83.9	835.9	0	0	78.8	998.6	(±263.3)	7.9	64.5	0	0	4.7	77.1	(±22.9)
Engelmann oak	0	0	0	0	50.5	50.5	(NA)	0	0	0	0	1.3	1.3	(NA)
Interior live oak	17.1	37.8	20.0	122.8	336.3	534.0	(±99.5)	7.1	12.2	2.4	19.7	27.6	69.0	(±24.2)
Oregon white oak	192.8	21.2	50.8	0	12.1	276.9	(±58.2)	10.3	2.5	2.2	0	0.5	15.5	(±6.6)
Valley oak	33.4	90.6	22.1	32.1	20.3	198.5	(±21.3)	11.1	4.3	14.1	0	9.8	39.3	(±17.9)
Total, oak species	512.6	1,352.3	299.2	857.7	1,175.2	4,197.0		62.6	146.1	31.8	64.0	108.0	412.5	
Other woodland species														
Gray pine	1.5	56.0	65.3	141.2	164.7	428.7	(±58.3)	0	30.3	11.4	58.1	64.3	164.1	(±38.3)
California buckeye	8.1	5.7	0	6.7	29.1	49.6	(±8.2)	2.1	0	0	0	7.6	9.7	(±4.1)
California laurel	57.6	83.8	1.8	0	0	143.2	(±29.1)	2.4	7.7	0	0	0	10.1	(±7.5)
Pacific madrone	78.8	51.3	0	0	0	130.1	(±27.1)	1.0	17.3	0	0	0	18.3	(±7.5)
Bigleaf maple	12.0	26.7	0	8.6	0	47.3	(±8.1)	0	10.6	0	0	0	10.6	(±9.0)
California sycamore	0	45.2	0	0	0	45.2	(±14.9)	0	6.5	0	0	0	6.5	(±7.5)
Knobcone pine	2.7	0	0	0	2.6	5.3	(±1.1)	0	5.6	0	0	1.0	6.6	(±4.6)
Ponderosa pine	3.2	0	3.9	12.1	19.2	38.4	(±1.3)	0	0	1.3	0	11.9	13.2	(±8.8)
Other species[3]	5.1	123.2	19.1	16.7	36.8	200.9	(±35.2)	1.4	1.3	3.6	2.5	11.0	19.8	(±10.0)
Total, other species	169.0	391.9	90.1	185.3	252.4	1,088.7		6.9	79.3	16.3	60.6	95.8	258.9	
Total, all species	681.6	1,744.2	389.3	1,043.0	1,427.6	5,285.7	(±402.3)	69.5	225.4	48.1	124.6	203.8	671.4	(±74.1)

1 Volume includes all live trees, including trees of poor form, that were ≥5 in. dbh, but excludes trees culled as a result of excessive rot. Live tree volume was calculated only on the 495 plots where CWD was measured in this study.
2 Includes CWD ≥5 in. diameter at the large end from 495 plots where CWD was measured on woodland.
3 Other species include 10 woodland species represented by a sample size of <5 plots.

comprised of blue oak (1,632.7 million ft^3) and coast live oak (998.6 million ft^3). Each of the eight oak species, with the exception of Engelmann oak, was represented by at least 198 million ft^3 of live tree volume. Five of the eight oak species and gray pine were recorded in all five of the resource areas. Blue oak had the highest live tree volume in three of the five resource areas.

CWD Characteristics

CWD Number and Size

Table 1 contains summary statistics for individual logs tallied in the inventory before data were expanded to the study area. A total of 480 pieces of CWD was tallied on 3,316 transects in the 495 woodland plots. Coarse woody debris was not tallied in the eucalyptus, Oregon ash, cottonwood (black and Fremont spp.), bigleaf maple (*Acer macrophyllum*), and the California walnut types. Nearly half of all the pieces (41%) of CWD tallied were in the blue oak type, followed by the coast live oak (20% of the pieces) and the interior live oak (11% of the pieces) types. Among the 8 oak types, the largest average large-end diameter (13.4 in) and the longest average log length (22.4 ft) were found in the Oregon white oak (*Q. garryana*) type. In contrast, the smallest average large-end diameter (8.0 in.) and log length (6.6 ft) were recorded in the Engelmann oak type. An 82-ft-long gray pine log in a blue oak type in Mariposa County was the longest CWD log recorded in the study, and an interior live oak log in Nevada County had the largest diameter (39.4 in. in diameter at the large end).

Of all logs sampled, 67% were <12 in. in diameter at the large end and only 4.3% of all logs tallied were ≥24 in. in diameter (Figure 3). The average log length was greatest in the 20 to 23.9 in. diameter class, but the largest average volume per log was in the ≥24 in. diameter class (the largest diameter class).

Although the average large-end log diameter, log length, and volume per log were greatest in decay class 1, 74% of the individual logs tallied were in decay classes 3 and 4, the most advanced stages of decay (Figure 4). An average density of 38 logs/ac was estimated in decay class 3 compared to 22, 23, and 27 logs/ac in decay classes 1, 2, and 4, respectively.

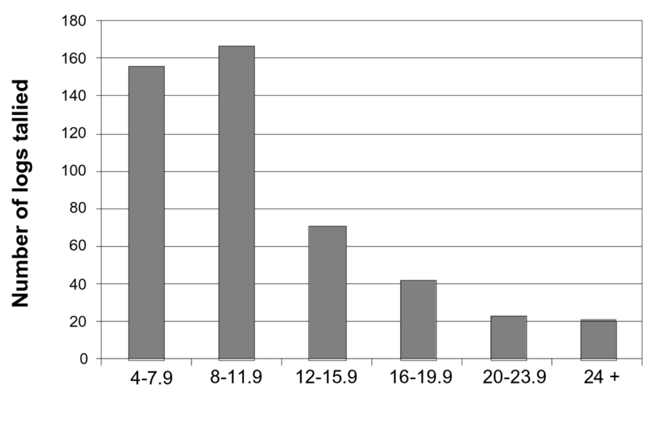

Figure 3. Number of logs, by diameter class, that were tallied on unreserved woodland outside national forests in the 1994 Forest Inventory and Analysis (FIA) program, Pacific Northwest Research Station, USDA Forest Service.

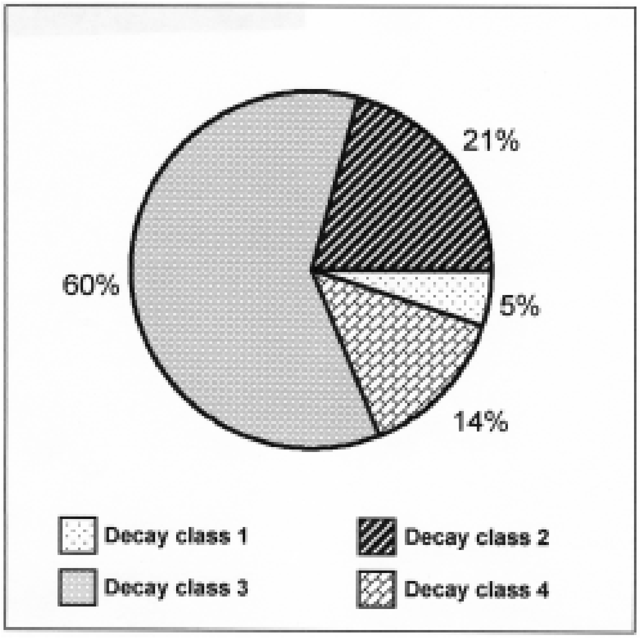

Figure 4. Proportion of logs, by decay class, on unreserved woodland outside national forests that were tallied in the 1994 Forest Inventory and Analysis (FIA) program, Pacific Northwest Research Station, USDA Forest Service.

CWD Volume

We estimated 671.4 million ft^3 of CWD to occur in California on unreserved woodland outside national forests (Table 2). Most of the volume was in the Central Coast (225.4 million ft^3) and Southern (203.8 million ft^3) resource areas, and least in the North Interior (48.1 million ft^3) (Figure 1). Of the 45 counties surveyed, 25 had at least 10 million ft^3 of CWD in woodlands, in contrast to 8 counties that had no CWD tallied on any plots. Blue oak CWD was prevalent in 20 counties, followed by interior live oak and coast live oak, which were abundant in more than 10 counties. Engelmann oak was recorded in only San Diego County.

Over half of the CWD volume (58%) was in three species: gray pine (164.1 million ft^3), blue oak (145.5 million ft^3), and coast live oak (77.1 million ft^3) (Table 2). Gray pine was among the three most abundant species in four of the surveyed regions and was greatest in two regions. Each of the eight oak species, with the exception of Engelmann oak, was represented by at least 15 million ft^3 of CWD volume. Among the oak species (Table 2), volume of blue oak CWD was greatest in two of the five resource areas. Although more blue oak logs were tallied in the study area compared to the number of logs for any other type, the longer average log length recorded for gray pine (14.2 vs. 13.7 ft; Table 1) was one reason gray pine exceeded blue oak in the overall volume estimate (164.1 million ft^3 vs. 145.5 million ft^3; Table 2).

CWD/Ac and Live Tree/Ac Characteristics

Characteristics of CWD are presented as average per-acre estimates for each woodland type (Table 3). This measure often is used in conjunction with log dimensions by biologists to determine if adequate levels of CWD are present within a stand for wildlife habitat. Overall, an average of 115 ft^3/ac, 1.2 tons/ac, 21 pieces/ac, and 56.8 linear ft/ac of CWD were estimated to occur across all types and resource areas in the

Table 3. Stand-level characteristics of standing live trees and CWD logs, by woodland type, on unreserved woodland outside national forests, California, 1991–1994.

	Live trees[1]/ac				Coarse woody debris[2]/ac							
	Ave. volume		Ave. basal area		Ave. volume		Ave. biomass		Ave. log density		Ave. linear feet	
Woodland types	(ft^3/ac)	(SE)	(ft^2/ac)	(SE)	(ft^3/ac)	(SE)	Tons/ac	(SE)	(Logs/ac)	(SE)	(ft/ac)	(SE)
Oak types												
Blue oak	642.8	37.0	36.2	1.8	106.2	15.0	1.1	0.4	20	3	49.8	5.5
Canyon live oak	1,348.5	181.4	75.0	8.2	151.8	73.3	1.6	0.8	28	14	83.4	38.6
California black oak	1,161.5	232.5	55.4	11.6	105.3	34.1	0.9	0.3	24	9	59.7	21.8
Coast live oak	1,576.0	104.5	85.6	5.2	164.1	33.3	2.1	0.4	28	5	85.9	13.8
Engelmann oak	1,081.5	237.3	62.8	10.8	40.3	20.8	0.6	0.4	40	28	50.0	27.7
Interior live oak	780.2	67.9	43.6	3.7	81.5	20.8	0.9	0.2	12	2	35.4	5.9
Oregon white oak	1,186.9	196.5	62.6	8.1	114.2	42.3	1.1	0.4	14	5	53.0	15.3
Valley oak	787.3	191.8	39.2	8.8	96.3	37.1	1.0	1.4	20	11	60.5	23.1
Other woodland types												
Gray pine	554.2	153.9	27.0	6.5	87.2	26.4	0.9	0.3	22	7	46.9	11.3
California buckeye	625.7	197.2	37.7	7.1	120.8	79.7	1.2	0.8	9	5	39.0	19.4
California laurel	1,435.0	493.1	63.1	17.6	150.7	65.4	1.6	0.7	48	11	131.8	54
Other types[3]	1,678.9	393.3	73.5	16.2	221.6	69.2	2.0	0.6	25	8	106.2	36.3
Mean, all types	905.9	36.1	49.0	1.7	115.0	10.2	1.2	0.1	21	2	56.8	4.2

[1] Includes all live trees, including trees of poor form, that were ≥5 in. dbh, but excludes trees culled as a result of excessive rot. Live tree volume was calculated only on the 495 plots where CWD was measured in this study.
[2] Includes CWD ≥5 in. diameter at the large end from 495 plots where CWD was measured on woodland.
[3] Other types include 10 woodland types represented by a sample size of <5 plots.

study. The coast live oak type had the greatest average per-acre volume (164.1 ft^3/ac) and biomass (2.1 tons/ac) of CWD. The California laurel type produced the highest log density (48 logs/ac) and the most per-acre linear feet of CWD (131.8 ft/ac). Average per-acre measures of volume (40.3 ft^3/ac) and biomass (0.6 tons/ac) were lowest for the Engelmann oak type. Approximately 1.5 million ac of woodland had between 10 logs/ac and 49.9 logs/ac. For each type except Engelmann oak, the average volume of CWD was between 9% (California black oak) and 19% (California buckeye [*Aesculus californica*]) of the live tree volume (Table 3).

Discussion

Many factors lead to the production and character of CWD and its use by wildlife, including inherent tree characteristics, insects, diseases, fire, windstorm, stand thinning, harvest, drought, and old age. For example, production of CWD may be a natural characteristic of valley oak trees, which apparently build up water in the limbs when leaf stomata close in late summer during the heat of the day. This added weight can result in limb breakage (Dias 1988) and the production of CWD. Some species, such as gray pine, are shorter lived than others and therefore more likely to produce woody debris at a faster rate. California oaks are susceptible to fungi (*Inonotus dryophilus*, *Hydnum erinaceum*, *Ganoderma applanatum*, and *Laetiporus sulphureus*) that decay the inner heartwood of living trees (McDonald 1990). Over time, these hollow, live trees die and eventually fall to the ground as hollow CWD logs suitable for wildlife use (Bull et al. 1997). Fire also can create hollow trees or work in concert with decay organisms to create hollow spaces in trees (Agee 1993). Some wood-mining invertebrates (e.g., carpenter ants [*Camponotus* spp.]) may weaken trees, causing them to fall and become downed wood. Prolonged drought and unrelenting low rainfall may also weaken trees and allow them to succumb to other damaging agents that result in early mortality (Tietje et al. 1993). Precipitation data collected in Sacramento (Riddle 1999) indicate that a 4 yr period from 1946 to 1950 had an average rainfall of 11.8 in., well below the long-term average of about 17.7 in., and the period had no single year of normal rainfall. This severe drought, which occurred approximately 50 yr ago, may account for the high amount of CWD (74%) that we found in the advanced stages of decay (stages 3 and 4).

The wide distribution of blue oak woodland, covering 2.9 million ac (Bolsinger 1988), and the common occurrence of this species within other oak types, underscore the importance of blue oak as a contributor of CWD to the woodland ecosystem. However, gray pine was a large component of the CWD species mix within the blue oak type, representing about one-fourth of the logs found in this type. Because of the relatively large size of gray pine CWD logs, they accounted for almost half (45%) of the total estimated CWD volume for the blue oak type, and surpassed the oak volume in three resource areas. Also, because of the generally higher per-acre live tree volume of coast live oak and California laurel, their per-acre contributions of CWD are greater than for blue oak. Wherever they occur, these species are important contributors of CWD.

Our study did not detect CWD on over half (61%) of the plots, representing almost 3 million ac of woodland. This cannot be interpreted literally to mean there is no CWD over this large area, but rather that our sampling technique did not intersect every piece that might have been on a plot and that plots were located far apart. One plot, or only a few plots, therefore, provided data and information for a broad area (1 plot/11,313 ac). Accuracy and precision decline when the data are extrapolated to smaller and smaller areas (i.e., statewide vs. county, timberland vs. woodland, all types vs. blue oak type) (Waddell and Bassett 1997a). Woodland types with just a few plots may not necessarily be representative of the overall type. Therefore, caution must be exercised in interpreting the numbers reported from this survey, and discussions should occur at the appropriate scale. The apparent lack of CWD might be appropriately stated in terms of relatively little CWD occurring over much of the California oak woodlands, rather than within a given county, for example. In spite of these shortcomings, the estimates of CWD density and volume presented here are the best estimates available for the woodlands in California and provide a baseline against which future trends can be evaluated.

The apparently small amount of CWD on much of the state's oak woodlands may have important implications for wildlife diversity and abundance. The California Wildlife Habitat Relationships (CWHR) System, Version 5 (Timossi et al. 1994), predicts that 21% of the 313 known terrestrial vertebrate species that occur in oak woodland statewide use CWD at least sometime during their life cycle. In a mixed blue-coast live oak woodland in coastal-central California, the study plots with the greatest accumulation of CWD supported the greatest diversity of vertebrate species and higher abundances of individuals (Tietje and Vreeland 1997). Data from this statewide survey begin to quantify the specific characteristics of CWD that may be important to wildlife. The quality of woodland, in terms of wildlife habitat, often is characterized by the average number of logs/ac, linear ft/ac, and dimensions of logs sampled within the stand (Bull et al. 1997). The per-acre estimates of CWD in Table 3 for unreserved woodland are the first summary of this kind for California. Not surprisingly, these data suggest that live tree volume at the stand level may be a good indicator of CWD volume. Land use and woodland management practices are likely of equal importance.

Before we can manage lands for a certain amount of CWD, estimates are needed for the current status of this resource within a range of natural conditions. New research is needed with more intensive sampling to allow characterization of the amount and distribution of CWD within smaller areas of the California oak woodlands and to determine the reasons for the apparently little CWD estimated in this study for much of the woodland area. Because 70% of the California oak woodland is used for livestock production (Tietje and Schmidt 1988), and intensive agriculture and other forms of development are increasingly common, research also is necessary to assess the effects of management on occurrence and characteristics of CWD. Future research efforts that define levels of CWD needed to maintain wildlife diversity, and elucidation of relationships between CWD and woodland type, stand conditions (basal area, crown and shrub cover), management activity, woodland enterprise, and development would be significant contributions.

Endnotes

[1] The inventory took place between 1991 and 1994 and will be referenced by the nominal date of 1994.

[2] Forest Inventory and Analysis program, USDA Forest Service, Pacific Northwest Research Station, Forest Sciences Laboratory, 620 SW Main, Suite 400, Portland, OR 97205; 503-808-2046; website: www.fs.fed.us/pnw/fia.

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