Coarse Woody Debris Metrics in a California Oak Woodland[1]

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Abstract

Little information is available on the metrics of coarse woody debris (CWD) in California oak woodland, most notably at the scale of the stand and woodland type. In a remote part of the National Guard Post, Camp Roberts, that has not burned in over a half century, we tallied 314 pieces of CWD in a blue oak (*Quercus douglasii*)-coast live oak (*Q. agrifolia*) woodland with patches of tree-sized bigberry manzanita (*Arctostaphylos glauca*). Compared to its representation in the live tree community, blue oak trees produced only half of the pieces of CWD expected. In contrast, coast live oak trees produced somewhat more pieces than expected, and in sharp contrast, manzanita produced four times more than expected. Among the three species of CWD that we tallied, coast live oak was the most abundant and comprised nearly half (43 percent) of all logs on the study area. Blue oak and manzanita comprised 35 percent and 22 percent of logs, respectively. Although coast live oak logs were more abundant, the largest volume of CWD was blue oak, and the largest logs were blue oak. The largest log measured 0.9 m in diameter, 12.8 m in length, and 3.6 m^3 in volume. Relatively more blue oak logs were hollow than logs of live oak or manzanita, by two times and three times, respectively. Two-thirds of all CWD was found in more advanced stages of decay. This effect was most pronounced for coast live oak and least for manzanita. Information on CWD from remote and relatively unmanaged blue oak-coast live oak woodland that has not burned for >50 years will assist the management and maintenance of this important habitat element.

Keywords: California oak woodland, coarse woody debris, CWD, dead and down wood, downed wood, *Quercus* spp.

Introduction

Coarse woody debris (hereafter, CWD, log, or downed wood) is a key structural component that influences a variety of ecological processes in temperate hardwood and coniferous forests (Harmon and others 1986, McComb and Lindenmayer 1999). In California oak woodland, CWD provides habitat for invertebrates, plants, and fungi and is known to be an important habitat component for a diverse assemblage of vertebrate species (Block and Morrison 1990, Tietje and others 1997b). The California Wildlife Habitat Relationships System (CIWTG 2005) predicts that 56 amphibians, 9 reptiles, 116 birds, and 49 mammals (46 percent of terrestrial vertebrates) use CWD for nesting sites, protective cover, travel lanes, and latrine and viewing sites. Large logs that are hollow are especially valuable for wildlife.

Although studies have examined CWD in hardwood forests elsewhere in North America (for example, McCarthy and Bailey 1994, Muller and Liu 1991, Rubino and McCarthy 2003), baseline data on the abundance, distribution, and characteristics of

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CWD in California oak (*Quercus* spp.) woodlands are relatively scarce. In the one broad-scale study, Tietje and others (2002), using data collected by the U.S. Department of Agriculture, Forest Service (USDA FS) in 1994 on 495 forest inventory and analysis (FIA) plots located throughout California oak woodland (see Waddell 2002), reported that CWD from blue oak (*Quercus douglasii*) occurred over the largest area of California oak woodland. Coast live oak (*Q. agrifolia*), however, produced the largest per-hectare volume. Over half the CWD (67 percent) was relatively small (<31 cm large end diameter) and three quarters (74 percent) was moderately decayed, suggesting that even the current amounts of CWD are not being sustained. This study suggested that CWD was mostly lacking over as much as half of the California oak woodland. The authors concluded that more detailed information was needed on the metrics of CWD by California oak woodland type at the stand scale.

Here, we present baseline data on the amount, size, species composition and characteristics, and decay class of CWD, and the relationship of these metrics to standing live trees. Our study area was located in Central Coastal California in a relatively undisturbed oak woodland that has not burned in >50 years.

Study area

We conducted our study on Camp Roberts, a training facility of the California Army National Guard, located 18 km north of Paso Robles, California. This study is part of a long-term project conducted in California oak woodland (1993 to 2014) that examines the effects of experimental manipulations of habitat elements on the small terrestrial vertebrate community and longer-term environmental effects, including predicted climate change (see Hardy and others 2013, Lee and Tietje 2005, Tietje and others 1997a). We conducted the study reported here on 11 of our 22 1.1 ha study plots, each with a permanent 8 x 8 sampling grid with 15 m intersections (fig. 1).

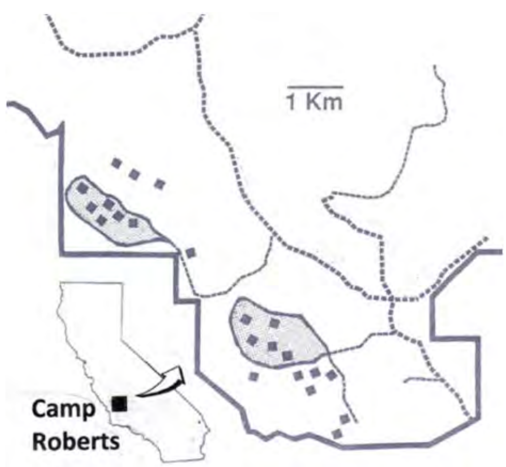

Figure 1—Camp Roberts study area, coastal-central California, showing the 11 1.1 ha study plots on which live trees and CWD was inventoried in 2007. An experimental burn was conducted in 1997 over 203 ha (stippled areas) that enclosed 11 additional 1.1 ha study plots (see Discussion).

Our study area is characterized by cool, wet winters and warm, dry summers. Total annual precipitation, falling as rain mostly between November and March, averages approximately 38 cm (66 year range = 10.8 cm to 74.1 cm; Western

Regional Climate Center 2001). Topography varies from nearly flat to steep hills (>40°). This area is referred to as the 'back country'. Use by military personnel is limited to occasional nighttime reconnaissance training. No military activity or management has altered the amount of CWD and, at the time of the study (2007), fire had not occurred in the 'back country' for 54 years (W. Tietje, personal communication).

The study area is covered by mixed blue oak-coast live oak woodlands (Camp Roberts EMAP 1989). Our 11 study plots are located in open to dense patches of woodland that represent a range of tree stand characteristics. The more dense woodland patches have a well-developed shrub layer composed primarily of toyon (*Heteromeles arbutifolia*), redberry (*Rhamnus crocea*), poison oak (*Toxicodendron diversilobum*), and bigberry manzanita (*Arctostaphylos glauca*). Manzanita often attains tree size on the study area (that is, >10 cm diameter at 1.37 m above ground; DBH) and >10 m in height). Common forbs include deerweed (*Lotus scoparius*), filaree (*Erodium* spp.), fiddleneck (*Amsinckia* spp.), and hummingbird sage (*Salvia spathacea*). The more open woodland patches are dominated by annual grasses, including wild oats (*Avena* spp.), bromes (*Bromus* spp.), and fescues (*Festuca* spp.).

Materials and methods

CWD measurements

Using a modification of the 'numerous shorter transects on a grid system' first tested by Howard and Ward (1972) and further described and applied by Waddell (2002), we measured CWD in January 2007 on each of our 11 study plots at alternate intersections of the 8 × 8 grid (32 points per plot). At each of the 32 sampling points, we recorded logs that were intersected by four 10 m transects (therefore, 1 280 m of transect per plot) laid out in the cardinal directions from the grid point. Recorded logs were at least 7.6 cm in diameter at the point of intersection and ≥1 m in length. We recorded the length of each piece from the 7.6 cm diameter point to the larger end or its junction with a larger piece of downed wood, and the diameter at the small and large ends. Any piece was counted twice that either intersected two lines or that was curved such that it intersected the same line twice. From these measurements, we calculated the number of pieces, percent cover, and the volume (m^3) for each study plot (see Waddell 2002).

Decay class and wildlife sign

For each piece of CWD, we recorded whether it was hollow (in other words, cavity ≥1 m long and ≥¼ the length of the end diameter of the log; Waddell 2002) and we collapsed the five decay classes described by Waddell into the following four:

- 1 = Sound Throughout: bark covering >50 percent, sound sapwood and heartwood; fine limbs present; big limbs not pull out.
- 2 = Mostly Sound: bark covering <50 percent, sound sapwood, heartwood soft; most fine limbs gone; big limbs not pull out easily.
- 3 = Mostly Decay: little or no bark; soft sapwood, heartwood mostly missing, big limbs lost or pull out easily; piece will support its weight.
- 4 = Soft Throughout: integrity, sapwood very soft, heartwood missing; no big limbs; piece will not support its weight.

As measures of animal use of CWD, we recorded the following:

- Wildlife food (for example, acorns or berry seeds) or scat on the logs.
- Whether a big-eared woodrat (*Neotoma macrotis*; see Matocq 2002) house was incorporated into the CWD or the house was within the hollow of a log. Woodrat dwellings are conspicuous piles of sticks, twigs, leaves, and herbs collected by the woodrats from the surrounding area.

Live tree sampling

To describe select features of stand structure, we sampled live trees on our 11 study plots using the point-center-quarter method (PCQ Method; Cottam and Curtis 1956) in June and July 2007. We randomly selected two non-adjacent intersections on alternate grid lines on each of the 11, 8 x 8 study plots (n = eight sampling points per study plot). Within a 10 m radius about each intersection, we measured the distance to the nearest live tree ≥10 cm DBH and ≥1.5 m tall in each of the four quadrants (NE, SE, SW, NW), and recorded DBH and species. To account for quarters in which we did not detect a live tree (136 of 704 quarters were treeless; 19 percent of total), we used the correction described by Warde and Petranka (1981). We standardized each measure as the number of live trees per hectare.

Statistical analyses

We wanted to explore two questions. First, what is the relationship between live tree attributes and several attributes of CWD on our study area at Camp Roberts? Second, how do CWD metrics differ among the species of CWD? For the first question, we ran an ANOVA to compare the DBH of the live trees to the large-end diameter of the downed wood. To determine differences between species of downed wood, we ran several tests. Using a likelihood ratio test, we compared the proportion of logs to live trees for the three species of CWD (blue oak, coast live oak, and bigberry manzanita). We also compared decay classifications among CWD species using likelihood ratio tests. We compared size (length, large-end diameter, and volume) of CWD by species using one-way ANOVAs. When ANOVA results were significant ($p \leq 0.05$), we used Tukey multiple comparison HSD tests to identify important interspecific differences and report the p value we computed for each comparison (Wright 1992). We performed tests at $\alpha = 0.05$ using R version 2.12.1 (The R Foundation for Statistical Computing 2010) and SAS JMP, Version 11 (JMP® Pro 11, SAS Institute Inc., Cary, NC).

Results

CWD metrics

We tallied a total of 314 logs comprised of three species (coast live oak, blue oak, and bigberry manzanita). Coast live oak logs comprised 43 percent (134/314) of all logs tallied. Blue oak and manzanita comprised 35 percent (109/314) and 22 percent (71/314) of logs, respectively. Due to small sample size (n = 11), we did not conduct statistical analyses on our calculations of the mean density or the mean volume of CWD. Combined log density on the 11 study plots ranged from 58.24 to 325.96 logs per ha and combined log volume across the plots ranged from 2.82 to 21.02 m^3 per ha. By species (data from the 11 study plots combined; table 1), coast live oak logs were the most common (71.73 logs per ha), but blue oak logs comprised the most volume (3.77 m^3 per ha). Although the density of manzanita CWD pieces was higher than blue oak, the volume of manzanita (1.66 m^3 per ha) on our study area was less than half that of either blue oak (3.77 m^3/ha) or coast live oak (3.59 m^3 per ha). With the three species of logs combined, mean log density was 155.16 logs per ha and mean volume of logs was 8.24 m^3 per ha (n = 11; table 1).

Table 1—Mean and standard deviation (sd) of the density (logs per ha) and volume (m^3 per ha) of coarse woody debris (CWD) by species and overall on eleven 1.1 ha study plots (n) in blue oak-coast live oak woodland with patches of tree-sized manzanita at Camp Roberts, California, 2007

		logs per ha		volume (m^3 per ha)	
Species	**n**	**mean**	**sd**	**mean**	**sd**
Coast live oak (*Quercus agrifolia*)	11	71.73	47.18	3.59	2.96
Blue oak (*Quercus douglasii*)	11	46.42	21.13	3.77	3.39
Manzanita (*Arctostaphylos glauca*)	11	59.85	49.17	1.66	1.79
Overall (species combined)	11	155.16	75.18	8.24	5.36

We found numerous significant differences among CWD species in the characteristics of the individual logs that we inventoried (n = 314; table 2). First, large-end diameter varied by species (F = 7.773, p <0.001). Blue oak logs were significantly larger in diameter (21.85 cm) than both manzanita (15.65 cm, p <0.001) and coast live oak (18.53 cm, p = 0.038). The two latter species were similar in diameter (p = 0.151). Log length also varied appreciably among species (F = 15.01, p <0.001). Blue oak logs were significantly longer (3.80 m) than coast live oak (3.12 m, p = 0.018) and manzanita logs (2.19 m, p <0.001). Coast live oak logs were significantly longer than manzanita logs (p = 0.003). Finally, the mean volume of individual logs differed among species (F = 7.012, p = 0.001), with blue oak logs being larger (0.18 m^3) than coast live oak (0.09 m^3, p = 0.028) and manzanita logs (0.04 m^3, p = 0.001). Coast live oak and manzanita logs were similar in volume (p = 0.305). With species combined, logs on our study area averaged 19.03 cm in diameter at the large end, 3.15 m in length, and 0.11 m^3 in volume (table 2).

Table 2—Mean and standard deviation (sd) of the large end diameter (cm), length (m), and volume (m^3) of 314 pieces (logs) of coarse woody debris (CWD), by species and overall, inventoried on eleven 1.1-ha study plots in blue oak-coast live oak woodland with patches of tree-sized manzanita at Camp Roberts, California, 2007

		diameter (cm)		length (m)		volume (m^3)	
Species	**n**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
Coast live oak (*Quercus agrifolia*)	134	18.53	8.75	3.12	1.93	0.09	0.17
Blue oak (*Quercus douglasii*)	109	21.85	13.65	3.80	2.32	0.18	0.40
Manzanita (*Arctostaphylos glauca*)	71	15.65	7.56	2.19	1.06	0.04	0.04
Overall (species combined)	314	19.03	10.73	3.15	2.01	0.11	0.26

Approximately 27 percent (29/109) of blue oak logs, 15 percent (20/134) of coast live oak logs, and 10 percent (7/71) of manzanita logs were hollow. Relative to availability, hollow blue oak logs were more numerous than hollow logs of other species (Fisher's exact test, $p = 0.009$). Two-thirds (67 percent) of all CWD was found in more advanced stages of decay. Decay classification differed among species (Chi-square = 16.88, $p = 0.0002$). In general, coast live oak was the most decayed and manzanita the least decayed of the three species (fig. 2).

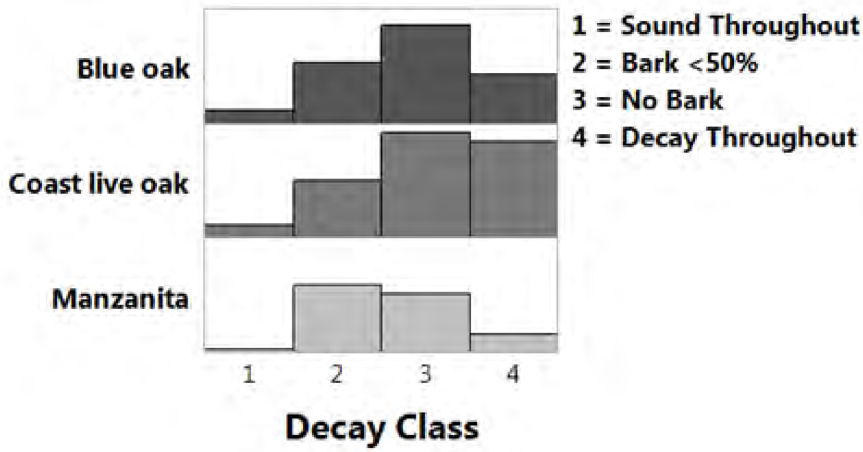

Figure 2—Decay class distribution histograms for blue oak, coast live oak, and manzanita tallied at Camp Roberts, California, 2007.

Live tree and snag metrics vs. CWD metrics

Live tree density on our 11 study plots ranged from 84.43 to 361.71 trees per ha (n = 11 plots, mean = 248.16, sd = 89.81) and mean tree DBH ranged from 18.33 – 28.26 cm (n = 11 plots), mean = 22.27, sd = 3.23). The ratio of the count of live trees to the number of CWD pieces was significantly different among species (Chi-square = 122.71, $p < 0.001$; fig 3). Specifically, we found that the live tree to CWD ratio for blue oak was different than live tree to CWD ratios for both manzanita and coast live oak (Chi-square = 106.43, $p < 0.001$; fig. 3). Blue oak produced only half (35 percent) of the pieces of CWD expected based on its representation in the live tree community (66 percent of live trees). In contrast, coast live oak produced 1.7 times more than expected (43 percent of the pieces) compared to its live tree representation (28 percent). In sharp contrast, manzanita produced nearly four times more CWD (23 percent of the pieces) than expected based on its presence in the live tree community (6 percent of trees). The volume of CWD produced by the three tree species followed this same pattern (fig. 3).

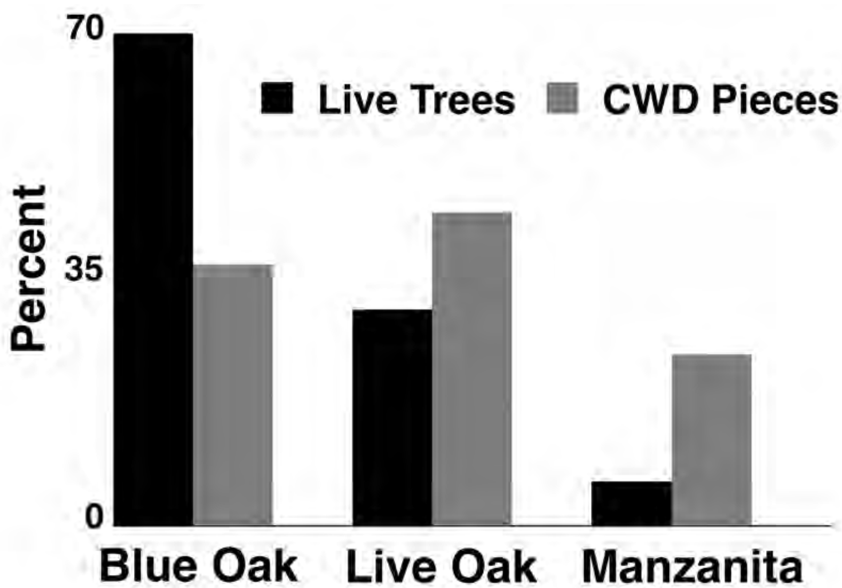

Figure 3—Histogram showing the relationships between the number of live trees and the number of pieces of coarse woody debris (CWD) for blue oak, coast live oak, and manzanita tallied on eleven 1.1 ha study plots at Camp Roberts, California, 2007.

Wildlife use and woodrats

Approximately a third (32 percent) of the CWD logs showed signs of wildlife use, mostly remains of scat (28 percent) or food (5 percent, seed or nut fragments). Woodrat houses were associated with 15 percent of the CWD pieces. The piece provided a support for the house or in a few cases a house was entirely within the hollow of the piece. The remaining pieces of CWD (68 percent) had no visible signs of wildlife use. (The sum of the percentages is >100 percent due to multiple associations for some logs.)

Discussion

Our study results are likely representative of the maximum amount of coarse woody debris (CWD) that can occur in remote, mostly unmanaged, and therefore relatively natural blue-coast live oak woodland with abiotic and biotic factors, tree and stand characteristics, and land-use activities similar to those described here. Livestock grazing or land use that would alter the amount or distribution of CWD has not occurred since the California Army National Guard Post, Camp Roberts, was established in 1941, and the area has not burned for >50 years (see fig. 1). We therefore suspect that the CWD metrics we describe are somewhat higher than the unknown amounts of CWD that occurred historically when burning by Native Americans was a common management activity (Agee 1996, Anderson and Moratto 1996, Keeley 2002). How do the CWD metrics from blue oak-coast live oak woodland at Camp Roberts compare to inventories conducted in woodlands in San Luis Obispo and nearby counties, statewide, and elsewhere?

On a relatively xeric study area dominated by chaparral and blue oak woodland in south San Luis Obispo County and northern Santa Barbara County, Borchert and others (1993) reported a density of 15 logs per ha, far fewer than at Camp Roberts. In contrast, on relatively mesic study sites dominated by coast live oak and California

Bay (*Umbellularia californica*) with small amounts of tan oak (*Lithocarpus densiflorus*) and Pacific madrone (*Arbutus menziesii*) in coastal San Luis Obispo County west of Camp Roberts, the volume of CWD was 1.4 times more than at Camp Roberts (Tempel and others 2006). Identical sampling techniques were used on both study areas, thereby increasing the likelihood that the more CWD near the coast can be attributed to the environmental factors that produced a more diverse and dense tree community with total basal area over three times that at Camp Roberts.

Of eight species of oak (*Quercus* spp.) tallied in California by the USDA FS forest inventory and assessment (FIA) in 1994, the greatest volume of CWD was in coast live oak (11.49 m^3 per ha), followed by canyon live oak (*Quercus chrysolepis*) (10.62 m^3 per ha), Oregon white oak (***Q.*** *garryana*) (7.98 m^3 per ha), and blue oak (7.44 m^3 per ha) (Tietje and others 2002). The statewide average volume of coast live oak was over three times the volume tallied at Camp Roberts (11.49 m^3 per ha vs. 3.59 m^3 per ha, respectively) and blue oak volume was twice the volume observed at Camp Roberts (7.44 m^3 per ha vs. vs. 3.77 m^3 per ha, respectively). Coast live oak logs and blue oak logs were also somewhat larger on the FIA plots. Differences in CWD tallied in the California assessments can be attributed in part to the different sampling methodologies and different geographic scales, but the differences are probably due largely to natural variation among geographic locations and the management histories of the areas sampled.

Finally, the studies we reviewed from other areas of the United States (for example, McCarthy and Bailey 1994, Muller and Liu 1991, Rubino and McCarthy 2003) reported more CWD than we tallied at Camp Roberts. Coniferous forests generally have greater accumulations of CWD than temperate hardwood woodlands (see, for example, Gora and others 2014, Harmon and Hui 1991), oftentimes an order of magnitude greater (Harmon and others 1986), for several reasons. Compared to hardwood woodlands, there are relatively more snags in coniferous forests (Chave and others 2009) and conifer logs are generally larger and more decay resistant than oak logs. Also, coniferous forests most often occur in a climate less favorable to decay organisms than do most hardwood woodlands (Harmon and others 1986). Harmon and others (1986) provide further examples of CWD from temperate hardwood and coniferous forests in the United States and from other parts of the world (see especially table 1, pages 138 and 139).

In our study at Camp Roberts, the ratios of live trees to the amount of CWD contributed by the trees differed substantially among the three species we inventoried. The occurrence of blue oak logs was relatively low compared to its representation in the live tree community. Nonetheless, several factors underscore the importance of blue oak downed wood in woodland habitats. Blue oak is the most widely distributed oak (*Quercus* spp.) in California (Griffin and Critchfield 1972) and is a predominant contributor of CWD throughout California oak woodland (Tietje and others 2002). In our study, blue oak contributed the greatest overall volume of CWD. Individual blue oak logs had larger average diameter, length, and volume than coast live oak or manzanita logs, and a greater proportion of blue oak logs were hollow. Hollow logs provide key habitat structures that are used by many kinds of wildlife for denning and refuge, as evidenced in this study by woodrat utilization of hollow logs for their houses and for escape cover. Also, because of their generally larger size, and because they predominate in drier areas less favorable to decomposer fungi, blue oak logs decay more slowly and therefore last longer than coast live oak logs. Collectively, these factors demonstrate the importance of blue oak logs in the oak woodland community.

Coast live oak, which made up approximately a third of the live tree community, contributed relatively more CWD and, of the three species, the most logs to our inventory. CWD pieces were also more numerous within 6 m of the trunks of coast live oak trees than were logs under blue oak trees on 11 ranches surveyed in 1995 in four central coast counties (Tietje and others 1997a). Although coast live oak CWD was used more than other species by woodrats as support for their houses, this observed 'preference' may simply be an artifact of coast live oaks' greater occurrence in preferred woodrat habitat, that is, in the more mesic areas of the woodlands with a well-developed shrub understory (see Lee and Tietje 2005). The more moist microclimate they prefer may have been the reason that coast live oak logs were in a more advanced state of decay than the other species of logs, but a complex interplay of factors, including the heaver bark that tends to slough sooner and the level of extractives in coast live oak (compared to blue oak or manzanita), may also have been involved (Harmon and others 1986). Highly decayed logs cannot support a cavity and therefore may be of less value for vertebrate wildlife. Fauteux and others (2013), however, reported that several species of boreal small mammals benefit from 'late-decay CWD' due to the protective cover and nesting sites it provides, and the food (mushrooms, insects) it oftentimes offers.

Manzanita, the third of the 'tree' species inventoried at Camp Roberts, comprised a small proportion of the live trees, but provided well over half as many pieces of CWD (71 pieces) as did both blue oak (109) and coast live oak (134). As indicated by its generally less advanced decay, manzanita persists on the ground longer than either coast live oak or blue oak. Although pieces accumulate and are available to wildlife for a long time, they are relatively small and rarely hollow, providing comparatively little value other than as latrine, travel, and lookout sites. Furthermore, manzanita is not usually a dominant species in oak woodland.

Most California oak woodland is privately owned and used primarily for livestock production (Tietje and Schmidt 1988). Active ranch management may remove CWD incidental to livestock management priorities. In California, prescribed fire is often the tool of choice for enhancing livestock forage production and limiting fuel (that is, downed wood) accumulation (California Department of Forestry and Fire Protection 1996, Griffin and Muick 1984). The experimental burn conducted on some of our study plots at Camp Roberts in 1997 removed 35 percent of the CWD (Vreeland and Tietje 2002). Our inventory of CWD in a blue oak-coast live oak woodland, largely unaltered by fire or land use for more than half a century, provides a measure with which to compare future research on the effects of land-use and fire on CWD in California oak woodland of the stand characteristics that we describe. As expressed by Harmon and others (1986; p. 275), "In some cases, human influences have been so pervasive that natural conditions are difficult to define". CWD is an integral component of California oak woodland that is essential for the maintenance of the full complement of invertebrate and vertebrate wildlife. Information from this study can assist in the prudent management and retention of this important resource.

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