ON ESTIMATING FUEL CHARACTERISTICS IN CALIFORNIA CHAPARRAL[1]

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ABSTRACT: Knowledge of fuel characteristics and their influence on biomass combustion are key elements in understanding and predicting fire behavior, fire emissions, and ecosystem effects of fire. Data on chaparral fuels are scant, largely because of the physical difficulty in obtaining and processing samples and the lack of information on optimal sampling methods. To sample these difficult fuels, researchers in California have taken varied approaches that are extremely time-consuming. Shrub-based approaches may not produce an adequate sample for estimating fuel characteristics on a stand level. And much research has focused on obtaining total shrub or stand biomass, and not on other fuel Characteristics that influence fire behavior. Furthermore, the diversity of sampling and analytical approaches makes synthesis of information among different studies extremely difficult. To improve the quality of fuel estimates while increasing the efficiency of fuel sampling, a pilot study was begun to test a stratified double sampling approach. This approach uses fixed area plots to estimate the stem diameter distribution in a stand, and harvesting a subsample of stems to develop estimates of stem biomass as a function of diameter. Balancing destructive sampling by the approximate contribution to stand biomass of various stem diameter classes shows promise for increasing sampling efficiency. Additional research is required to develop guidelines for appropriate sample sizes; to test applicability of models on a range of sites; to develop models for more species; to improve estimation of fuel size class distribution and live and dead fractions; and to develop methods that can be used by managers to make rapid field estimates or to derive estimates from remotely-sensed data. The ultimate goal should be to develop methods for extending information on fuel characteristics to the stand and landscape levels.
KEYWORDS: fuels; chaparral; biomass; fuel models

INTRODUCTION

Large areas of California wildlands are dominated by chaparral, a vegetation complex characterized by evergreen sclerophyllous shrub species. Chaparral sites experience a Mediterranean-type climate of hot, dry summers and cool, moist winters. Thia climate, together with the flammable nature of the vegetation and extremely steep Slopes on many sites, makes chaparral highly susceptible to periodic wildfires (typically every 20 to 100 years). In some years these fires cover hundreds of thousands of hectares. Chaparral generally burns in crown fires of high intensity, and flame lengths in excess of 30 m are not unusual. The societal impact of chaparral wildfires is disproportionately large because chaparral commonly occurs in the

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wildland/urban interface at low to middle elevations in mountains adjacent to some of California's largest urban areas.

The term "chaparral" refers to a complex of plant associations which is diverse in species composition and structure. Chaparral vegetation consists of one or more species of shrubs, with high overall canopy cover (60 to 100 percent) and little understory. Canopy heights in mature stands range from about 1 to 5 meters, depending on species composition, site characteristics, and stand age. These associations range from the chamise (Adenostoma fasciculatum) dominated vegetation at low elevations to chaparral whitethorn/ bigberry manzanita (*Ceanothus leucodermis/Arctostaphylos glauca*) stands at the interface with the conifer zone.

Many of the several dozen shrub species common in California chaparral (Table 1) have widely divergent fuel characteristics. Chamise, a dominant species on many low to mid-elevation sites, has an abundance of fine fuel, with small (1 to 1.5 cm long) needle-like leaves and very fine twigs (about 1 mm diameter). In contrast, sugar bush (Rhus ovata) has broad sclerophylloua leaves (about 4 to 8 cm long) and stout twigs about 5 mm in diameter. Some species of Ceanothus and manzanita reproduce only from seed after fires, while others sprout from enlarged root crowns or burls. Shrubs of seed origin typically are single-stemmed at the base, whereas sprouters may have many stems of widely differing sizes. All of these structural characteristics will affect the way individual stands burn.

Table 1. Characteristic shrub species in California chaparral.[1]

Genus	Common name(s)	Species in chaparral: Total	Species in chaparral: Common
Adenostoma	chamise, redshank	2	1
Arctostaphylos	manzanita	40	12
Ceanothus	ceanothus	25	12
Heteromeles	toyon, Christmas berry	1	1
Quercus	scrub oaks	7	5
Rhamnus	buckthorn, coffeeberry	8	6
Rhus (Malosma, Toxicodendron)	sugar bush, lemonadeberry squaw bush, poison oak	5	5

[1]Information compiled by the authors from Hickman (1993) and personal observations.

Biomass of chaparral stands also varies widely, depending on factors such as age, species composition, and site quality. Dodge (1975), for example, measured stand biomasses ranging from 22 to 34 Mg/ha in "light" brush to 65 to 90 Mg/ha for "heavy" brush stands in San Diego County. Other researchers have found a wide range in total biomass of chaparral stands throughout California (Figure 1).

Factors Affecting Flammability

Although total biomass of chaparral stands is important for predicting emissions from chaparral fires, for quantifying site differences, and for determining total energy release of the fire, a number of other structural and chemical factors affect fire behavior and, ultimately, fuel consumption and fire effects. Structural characteristics of fuels that can affect flammability and fire behavior (Rundel 1981) include fuel loading (mass/area); bulk density (mass/volume); surface area/volume ratio (area/volume); and porosity (canopy volume/fuel volume).

All of these characteristics vary widely among species. For example, surface area/volume (S/V) ratios of chaparral foliage reported in the literature (Table 2) vary threefold from the lowest to the highest. This variation might be expected to show a

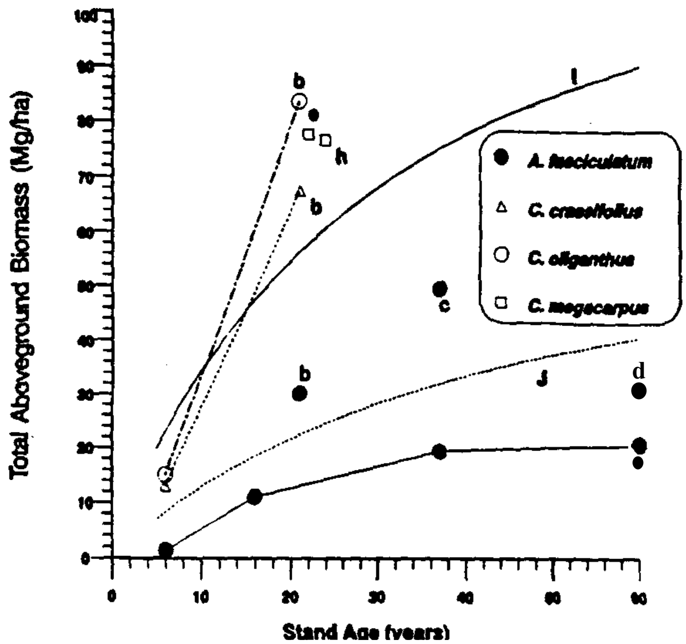


Figure 1. Biomass of various chaparral plant communities in relation to stand age. Sources for data: a Rundel and Parsons 1979; b Riggan et al. 1988; c Specht 1969; d Stohlgren et al. 1984; a Schlesinger and Gill 1980; h Gray 1982; I, J Rothermel and Philpot 1973, fuel models for mixed chaparral and chamise chaparral, respectively. A. fasciculatum = chamise; C. crassifolius = hoaryleaf ceanothus; C. oliganthus = hairy ceanothus; C. megacarpus = bigpod ceanothus.

direct relationship to fire behavior, but several factors confound the issue. Some of the species (e.g. laurel sumac) with the highest leaf S/V ratios have very thick twigs, with twig S/V ratios of about $8cm^2/cm^3$. Chamise, on the other hand, with an intermediate leaf S/V ratio, has a stem ratio of about $40cm^2/cm^3$. Furthermore, factors such as orientation of the foliage or its distribution in the canopy (which tend to be species-specific) may substantially affect the heat flux into the canopy and the ignition probability of fine fuels.

Information on fuel characteristics beyond total fuel loading (or individual shrub biomass), and perhaps canopy height, is scant for moat chaparral species. And when this information is available, it is typically from one or two sites, making generalizations difficult.

Table 2. Surface area/Volume ratios for dried leaves of seven chaparral species.[1]

Species	Surface Area/Volume ratios (cm^2/cm^3)	(ft^2/ft^3)
manzanita (Arctostaphylos densiflora)	38.2	1165
sugarbush (Rhus ovata)	71.7	2186
chamise (Adenostoma fasciculatum)	72.1	2200
toyon (Heteromeles drbutifolia)	80.0	2440
laurel sumac (Rhus (Malosma) laurina)	126.0	3843
scrub oak (Quercus dumosa)	126.0	3843
holly-leaf cherry (Prunus ilicifolia)	133.2	4063

[1] Sources: Montgomery and Cheo (1971) except chamise (Rothermel and Philpot 1973)

Flammability and fire behavior will also be affected by moisture content of live and dead fuels, and by chemical composition of the fuels. This latter can be particularly important for combustibility of live fuele in chaparral, where many species have high levels of terpenes and other flammable compounds in their foliage (Countryman and Philpot 1970, Rundel 1981). Few data are available on flammability characteristics of specific species of chaparral plants (Countryman and Philpot 1970), and these characteristics have not yet been incorporated into fire behavior models.

Large amounts of dead biomass are found in some chaparral stands (Hanes 1971). Rothermel and Philpot (1973) presented a hypothetical model for the relationship between age and the fraction of dead material. This commonly accepted model indicates that dead fraction increases as stands age, however, the model is based on data from only a few chaise-dominated stands. This model has been questioned by Paysen and Cohen (1990), who sampled individual shrubs in a wide range of chamise stands in southern California. They found no significant relationship between fraction dead and age, and the variability among shrubs in single-age stands was similar to the variability among shrubs from different-age stands. The average percent dead was around 30% over all stands and ages, and virtually no samples approached the 50% dead prediction at 50 years of the Rothermel and Philpot model. Of course, if total biomass is increasing with age, as available data indicate, then the amount of dead material would be expected to increase a0 stands age even if the fraction dead does not. This result may be an important consideration for predicting fire intensity and the ability of a fire to carry primarily in dead fuel. Paysen and Cohen's data also do little to clarify the patterns in development of dead material within a particular stand over time. clearly, substantially more data are needed on a range of species and sites before we can characterize the contribution of dead material to chaparral fuels with any reliability.

The most widely used fire behavior modeling system in California is probably BEHAVE, which was operationally implemented by the USDA Forest Service's Intermountain Research Station in 1984 (Burgan and Rothermel, 1984). Users of this program can implement one of several standard fuel models (including one for chaparral), or tailor their own fuel inputs through the FUEL subsystem (Burgan and Rothermel 1984). Fuel parameters used by BEHAVE include: dead fuel loads (mass per unit ground area) of < 1/4 in (1-hour), 1/4 to 1 in (10-hour), and 1 to 3 in (100-hour) fuels; fuel loads of fine (less than 1/4 in (6mm) diameter) live fuels; fuel surface area/volume ratio; and depth of fuel bed (canopy height for chaparral). These values can be either input directly or estimated by comparison with a shrub type and density photo series--which is particularly difficult to use for the shrub types typical of chaparral (Types 4 and 5 in Burgan and Rothermel 1984).

FIRECAST, a program designed specifically for use in southern California fuels (Cohen 1986), incorporates many of the same basic fire behavior models as the BEHAVE system, but has a number of additional options for chaparral fuel models. Two of these are based on Rothermel and Philpot (1973), in which fuel models are presented for both chamise and mixed chaparral types. FIRECAST also allows user input of percent dead and stand height information. As discussed above, however, some of the basic assumptions of these models are questionable for chaparral fuels (e.g. models estimating percent dead). The fire behavior models are also explicitly designed for fires where the fuelbed is in contact with the ground, which may be a reasonable approximation for young chaparral stands, and for many stands dominated by chamise. Many species and many older stands, however, have canopies well separated from the ground, often with little ground fuel in the form of litter or understory vegetation. The fires in these stands are typically crown fires. Thus, the applicability of these models of surface fire behavior to chaparral crown fires is unclear.

Existing Fuel and Biomass Models and Approaches to Gathering Data

Various investigators have measured biomass of chaparral as part of ecological or fuels studies. These studies have often used the approach of sampling individual shrubs, but with little or no information on the spatial distribution of shrubs of various size or form (countryman and Philpot 1970, Wakimoto 1977, Rundel and Parsons 1979, and Paysen and Cohen 1990), which is a necessary component for deriving estimates of stand-level biomass. Total stand biomass on a unit-area basis has been described by using basal area regressions to estimate biomass on fixed-area plots (Schlesinger and Gill 1980, Gray 1982, Stohlgren et al. 1984, Riggan et al. 1988). The emphasis has typically been on total shrub or stand biomass, Occasionally partitioned into live and dead material (Countryman and Philpot 1970, Wakimoto 1977, Riggan et a1. 1988, Paysen and Cohen 1990). A few studies have partitioned biomass into fuel size classes (Countryman and Philpot 1970, Rundel and Parsons 1979, Gray 1982. and Riggan et al. 1988). and Rundel and Parsons (1979) and Riggan and others (1988) described the vertical distribution of biomass in the canopy. The result has been that. except for chamise, for which detailed data are available at least for a few stands, we have little information on the spatial distribution of biomass (fuel structure) within chaparral stands, or how fuel structure changes with stand age. Recent data on a sample of shrubs from chamise stands suggests a high variability in the fraction of dead fuel both within and among stands (Paysen and Cohen 1990). Little is known about how this variability is controlled or about how other fuel characteristics (such as bulk density, S/V ratio, or fuel sire class distribution) may vary as well. Therefore, even for chamise, which is the most widely studied of the chaparral shrub species, fuel information is inadequate to meet the needs of managers in predicting fire behavior and planning prescribed fires. For other species many of the Characteristics that may be most important for predicting fire behavior are essentially undescribed.

Another problem in synthesizing the available data is that both field methods and analytical approaches have often varied widely among investigators. Not only have a wide range of variables been explored as predictors of biomass, but the methods by which these variables have been measured have differed. For example, some investigators have measured total (living and dead) biomass, others have distinguished live and dead biomass components, and still others have measured only living biomass. Some measure diameter at ground level and others at 50cm. Some estimate accumulated stem biomasees based on regressions with stem basal area (or diameter), while others estimate total shrub biomass based on canopy dimensions. In addition, many different model forms have been used for developing regression models, including log-linear, linear, and exponential models. The result is a tremendous difficulty in synthesizing results from numerous studies into a common data base.

Undoubtedly one reason for both the paucity of information on many chaparral fuels and the lack of research to determine the most effective sampling methods has been the intensive labor and time requirements for sampling these fuels. The rugged terrain on which chaparral occurs and the extreme difficulty of maneuvering in dense chaparral contribute to a difficult work environment. Few scientists have persisted long enough to produce more than one or two papers on biomass or fuel characteristics in California chaparral.

Combined with the intractability of chaparral fuel types, funding has been difficult to obtain or sustain to study these non-timber, non-commodity ecosystems in recent years. As a result of all these factors, few recommendations have been developed for the most effective and efficient sampling and analytical methods for quantifying chaparral fuels. Currently, then, we have very little information to help managers accurately predict fire behavior, emissions, and fire effects of a major fire-prone ecosystem, one that is in close contact with urban areas containing millions of people and property values of many billions of dollars.

Clearly, additional data and modeling of chaparral characteristics are needed to address some of the unanswered questions in modeling of chaparral fuels for fire behavior, emissions, and stand development. We have started a research program to develop appropriate sampling strategies for more efficient and economical collection of fuel data and development of models. Our first attempt was part of a cooperative study with the USDA Forest Service's Pacific Northwest Research Station to assess emissions from chaparral fuels. Our primary goals were to increase the efficiency of data collection by stratifying destructive sampling according to the expected contribution of various size stems to total stand biomass, and to improve our knowledge of adequate sample sire required for developing models for prediction of various fuel characteristic.

MEHTHODS

Our study was conducted on three sites in southern California which supported chaparral stands of varying species composition and structure. The Bear Creek site was in southwestern Riverside County, at 550 m (1,800 ft) elevation, with prefire stand composition dominated by hoary-leaf ceanothus and chamise. The Newhall site, at 520 m (1,700 ft) elevation in northern Los Angeles County, supported a pure stand of chamise. The Santa Rosa site was in southwestern Riverside County at 640 m (2,100 ft) elevation. The stand was composed of chamise, scrub oak, and holly-leaf redberry (Rbamnus ilicifolia).

On each site a relatively homogeneous area of chaparral was subdivided into three plots for replication of burning for emissions testing. To characterize fuels, we established two 20 m^2 subplots in each plot. On each subplot we tallied all shrubs by species and height, and recorded the diameter and status (live or dead) of every stem of each shrub at 10 cm above groundline.

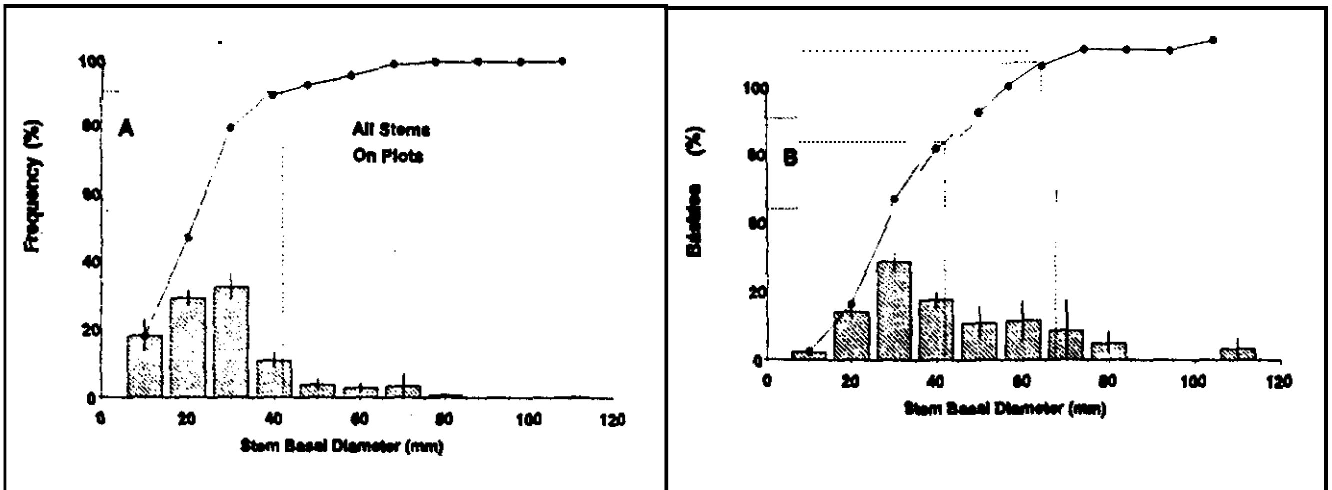
We used double sampling to estimate biomass and fuel characteristics for each site. This sampling used fixed-area plots to estimate the abundance and size class distribution of live and dead stems of each species at each site. we assumed that stems of different size would contribute to stand biomass in approximate proportion to their contribution to stand basal area. Therefore, we attempted to stratify our destructive sample among diameter classes corresponding to percentiles in the cumulative distribution of stand basal area. The stem diameter data from the fixed area plots were used to estimate the cumulative distribution of stand basal area by stem diameter for each of the dominant Species present on each site (Figure 2B). Cumulative basal area distributions were determined separately for live and dead stems.

We then determined intervals in the range of stem diameter that corresponded to 20th percentiles in the cumulative distribution of basal area, and attempted to destructively sample equal numbers of stems from each quintile. We randomly selected 10 live stems and 5 dead stems from each of their respective quintiles for each of the dominant species on each site (Figure 2C). Where it was not possible to find 10 stems from the largest diameter class, we harvested as many stems as possible. We measured stem diameter (10 cm above groundline) on these harvested stems, which were then separated into live wood, dead wood, and foliage components, oven-dried, and weighed. A subsample of two stems from each diameter class for each combination of species and status was further partitioned into fuel particle size classes of < 6 mm (1/4 in), 6 to 25 mm (1/4 to 1 in), 25 to 76 mm (1 to 3 in), and > 76 mm Regression and ratio estimators were developed to estimate biomass and fuel characteristics from dimensional variables on a sample of stems harvested from each site. These estimators were applied to data from the fixed-area plots to estimate biomass and fuel characteristics of each site.

RESULTS AND DISCUSSION

Stand summary statistics calculated from the plot data illustrate differences in structure and composition among the three sites (Table 3). Live basal area ranged from 11.4 m^2/ha at Santa Rosa to 27.5 m^2/ha at the Bear Creek site. Dead basal area ranged from 14% of the total at Bear Creek to 45% at Santa Rosa (Table 3). Field observations indicated that most of the dead material at the Bear Creek and Newhall sites resulted from self-thinning, whereas much of the dead material at Santa Rosa appeared to be residual large dead stems from the Murrieta Fire of 1980. This fact is illustrated by the lack of any dead shrubs at Santa Rosa (Table 3). Spatial variation in stand structure and composition within stands in shown by the coefficients of variation in shrub density and basal area, which range from 8 to 127% (Table 3).

Both shrub density and stand basal area are likely to influence fuel structure of chaparral stands. For example, live basal area is quite similar for the Newhall and Santa Rosa sites, yet shrub density at Santa Rosa is more than five times that at Newhall (Table 3). Fuel parameters such as porosity and surface/volume ratio may differ considerably between stands composed of few large shrubs and those composed of many small ahrubs, even though total fuel loading may be quite similar.



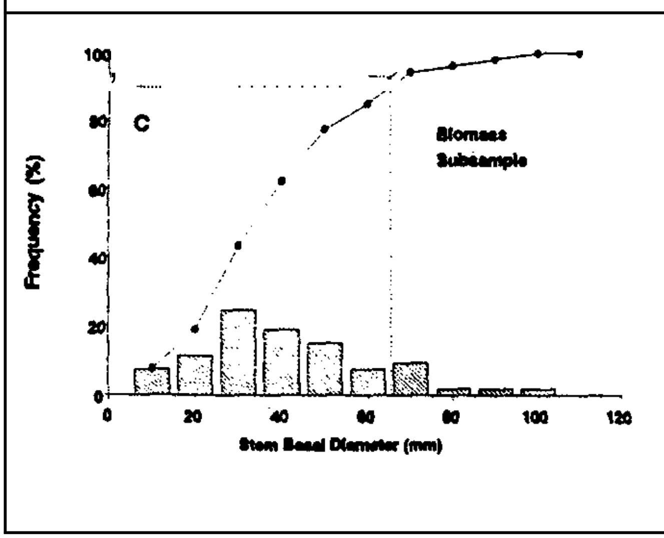


Figure 2. Relative and cumulative frequency distribution of live stems by diameter class (A, C), and percent of stand basal area by diameter class (B), for the monospecific chamise stand at the Newhall Site. A and B show data from fixed-area plots, while C shows the distribution of stem diameters in the sample harvested for development of biomass estimation models. Note that the 90th percentile of the stem diameter distribution corresponds to Only 63% of the cumulative stand basal area.

Other aspects of stand structure have implications for design of sampling methods for estimating fuel characteristics of chaparral stands. The diameter distributions of many chaparral stands tend to contain many small stems and relatively few large stems (Figure 2A). However, theme large stems account for a disproportionately large proportion of stand basal area, and presumably. biomass (Figure 2B). For example, 90% of live chamise stems at Newhall are less than 45 mm in diameter, yet these stems account for less than 65% of stand basal area (Figure 2). If one were to harvest fixed area plots to sample fuels, the spatial variation in structure of chaparral stands would necessitate sampling a fairly large area, which would be extremely time-consuming. This approach would also mean that an unnecessarily large sample of small sterna would be collected. These facts suggest that double sampling is probably a more efficient means of estimating chaparral fuel characteristics. Several nondestructive sample plots can be established throughout the stand(s) of interest much more rapidly. A subsample of stems can then be harvested for development of models relating dimensional measures of shrubs to fuel characteristics. This sample can be stratified by diameter class in proportion to the contribution to stand basal area. This type of stratification ensures obtaining an adequate sample of relatively large stems, which are inherently variable and exert an important contribution to fuel loading, and to fine fuels as well. Ongoing phases of this study involve developing regression models to estimate stand-level live and dead biomass and fuel size class distributions for individual species.

Table 3. Stand structure summary statistics for three chaparral stands in southern California. Values are means of three 40 m^2 plots per site. Totals combining live and dead stems are shown ± SE.

Site and Species	..... Shrub Density			.... Basal Area..........		
	Live	Dead	Total[1]	Live	Dead	Total[1]
	.... #/ha			.... m^2/ha		
Bear Creek						
chamise	2,083	167	2,250 ± 250 (19.2)	5.22	2.39	7.60 ± 2.41 (56.3)
hoary-leaf ceanothus	3,667	500	4,167 ± 1502 (62.4)	22.33	2.02	24.35 ± 2.96 (21.1)
Stand Total	5,150	667	6,417 ± 1746 (47.1)	27.54	4.40	31.94 ± 1.50 (8.1)
Newhall						
chamise	4,583	0	4,583 ± 1064 (40.2)	13.55	3.14	16.69 ± 5.48 (56.9)
Santa Rosa						
chamise	21,583	0	21,583 ± 5600 (44.9)	7.14	5.86	13.00 ± 2.35 (31.3)
scrub oak	2,333	0	2,333 ± 1024 (76.1)	3.80	3.28	7.08 ± 3.19 (78.0)
holly-leaf redberry	333	0	333 ± 220 (114.6)	0.42	0.05	0.70 ± 0.34 (126.7)
Stand Total	24,250	0	24,250 ± 4639 (33.1)	11.36	9.18	20.55 ± 1.83 (15.4)

[1] Coefficient of variation is shown in parentheses.

CONCLUSIONS

The results indicate that the two-staged, biomass (basal-area) stratified approach to sampling shows considerable promise as an efficient method for developing models for quantifying chaparral fuel characteristics. In our study, a larger sample sire--particularly for larger size classes and for dead material--would have been desirable. But because of the intensive labor needed for partitioning biomass samples into fuel sire classes. it is desirable to obtain a sample no larger than is actually needed to develop adequate models. More research is needed to determine optimum sample sizes for this type of research. The best sampling methods should also be determined to meet various needs.

We are beginning a new project in which we will critically compare the performance of several alternate sampling methods for fuels estimation on a validation dataset to address some of these concerns. Another question that has yet to be addressed adequately for chaparral is the validation of fuel and biomass estimation models--either on the sites where they were developed or in terms of their applicability to other sites. It is also crucial to make models accessible to managers by linking them to easily-measured variables (such as cover and canopy height). Only then will managers and researchers be able to use fuel models easily to generate inputs for fire behavior models, estimate emissions, and better predict ecosystem effects of fire. In the future we anticipate the development of linkages between ground-based sampling and remotely sensed data. These linkages will provide efficient means of obtaining and easily updating fuel characterietics across the landscape.

ACKNOWLEDGMENTS

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LITERATURE CITED

Burgan. R. E., and R. C Rothermel. 1984. BEHAVE: Fire behavior prediction and fuel modeling system--FUEL subsystem. USDA For. Serv. Gen. Tech. Rep. INT-167. 126 p.

Cohen, J. D. 1986. Estimating fire behavior with FIRECAST: user's manual. USDA For. Serv. Gen. Tech. Rep. PSW-90. 11 p.

Countryman C. M., and C. W. Philpot. 1970. Physical characteristics of chamise as a wildland fuel. USDA For. Serv. Res. Pap. PSW-66. 16 p.

Dodge, J. M. 1975. Vegetational changes associated with land use and fire history in San Diego County. Ph.D. diss. Univ. California, Riverside, CA. 216 p.

Gray, J. T. 1982. Community structure and productivity in Ceanothus chaparral and coastal sage scrub of Southern California. Ecol. Monogr. 52(4): 415-435.

Hanes, T. L. 1971. Succession after fire in the chaparral of southern California. Ecol. Monogr. 41(1): 27-52.

Hickman, J. C. 1993. The Jepson Manual: Higher Plants of California. University of California Press, Berkeley. 1400 p.

Montgomery, K. R., and P.C. Cheo. 1971. The effect of leaf thickness on ignitability. For. Sci. 17:475-478.

Paysen, T. E., and J. D. Cohen. 1990. Chamise chaparral dead fuel fraction is not reliably predicted by age. West. J. of Appl. For. 5(4):127-131.

Riggan, P. J., S. Goode. P. M. Jacks, and R. N. Lockwood. 1988. Interaction of fire and community development in chaparral of southern California. Ecol. Monogr. 58(3):155-176.

Rothermel, R. C., and C. W. Philpot. 1973. Predicting changes in chaparral flammability. J. For. 71(1):640-643.

Rundel, P. W. 1981. Structural and chemical components of flammability. P. 183-207 in H. A. Mooney et al. tech. coord., Proc. Fire Regimes and Ecosystem Properties. USDA For. Serv. Gen. Tech. Rep. WO-26.

Rundel, P. W., and D. J. Parsons. 1979, Structural changes in chamise (Adenostoma fasciculatum) along a fire-induced age gradient. Jour. Range Manage. 32(6):462-466.

Schlesinger, W. H., and D. S. Gill.1980. Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, Ceanothus megacarpus, after fire. Ecology 61(14):781-789.

Specht, R. L. 1969. A comparison of sclerophyllous vegetation characteristic of Mediterranean-type climates in France, California, and southern Australia. 11. Dry matter, energy and nutrient accumulation. Aust. J. Bot. 48:293-308.

Stohlgren, T. J., D. J. Parsons,and P. W. Rundel. 1984. Population structure of *Adenostoma* fasciculatum in mature stands of chamise chaparral in the southern Sierra Nevada, California. Oecologia 64: 87-91.

Wakimoto, R. H. 1977. Chaparral growth and fuel assessment in southern California. P. 412-418 In Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, CA, August 1-5, 1977. USDA For. Serv. Gen. Tech. Rep. WO-3.