Biomass and Fuel Characteristics of Chaparral in Southern California

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Abstract

Knowledge of biomass components and fuel characteristics of southern California chaparral plant communities is important for planning prescribed fires, suppressing wildfires, managing the fire regime, and understanding the ecological interactions between fire and chaparral community development and succession. To improve our understanding of the relationship between fuels and fire behavior in chaparral, biomass and fuels were sampled on sites spanning a broad geographic range, as well as a range in age, species composition, and productivity. Total aboveground biomass of chaparral stands greater than 15 years old can range from 10 to 40 Mg/ha (1 Mg/ha = 1000 kg/ha) for *Adenostoma fasciculatum*, with canopy heights of 1.5 to 2.5 m, to as much as 120 Mg/ha for several *Ceanothus* species with canopy height as high as 5.5 to 6 m. Within a stand, coefficients of variation of biomass among plots are commonly 25 to 30 percent, and community structure can vary dramatically in relation to topographic and edaphic gradients over short distances of 5 to 10 m. Foliage accounts for 3 to 25 percent of total biomass in *A. fasciculatum* and *Ceanothus*-dominated stands. The fraction of stand biomass that is considered to be fuel available for fire propagation, which includes foliage, live twigs less than 6 mm in diameter, and dead woody material, ranges from approximately 30 percent to 75 percent in mature chaparral stands. This available fuel fraction is probably related to climatic factors such as prolonged drought periods, as well as species composition, species morphology, and site productivity. Our ongoing work is focused on improving efficiency of biomass and fuels sampling, and relating biomass development through time to site and climatic factors.

Introduction

Site-specific information on fuel characteristics is important for planning prescribed fires and suppressing wildfires in chaparral ecosystems in southern California. Knowledge of how chaparral biomass and fuels change over time, and how these changes are affected by climatic and site variability, will help us to effectively manage chaparral ecosystems to protect human life and property from wildfire and postfire flooding and sedimentation, while maintaining ecosystem productivity and biodiversity.

Although some research has been conducted on chaparral biomass and fuels, remains incomplete. For instance, several studies have reported on biomass components such as live wood and foliage, with no information on the distribution of this biomass among various fuel

1969, Stohlgren and others 1984). Fewer authors have presented detailed fuels information in addition to data on biomass components (Riggan and others 1988). Two limitations of these various studies are that the results represent only a limited number of sites and species, and little attempt has been made to relate differences in biomass or fuels among sites to geographic, topographic, or edaphic differences among sites. Rothermel and Philpot (1973) proposed a set of equations that describe age-dynamic fuel models and would allow estimation of biomass and fuels for different species compositions representative of a broad range of sites in the chaparral ecosystem. However, comparing these models to published data illustrates that the model for total biomass may not account for the wide variability of biomass among sites (fig. 1). This dynamic fuel modeling system also assumes a dramatic increase in dead fuel with increasing age, caused by widespread branch dieback (Rothermel and Philpot 1973). This assumption has been challenged by both Riggan and others (1988), and Paysen and Cohen (1990), who found no evidence that chamise chaparral dead fuel fraction was reliably predicted by age. Paysen and Cohen (1990) found wide variation in dead fraction, irrespective of age, and hypothesized that temporal climatic variability, especially rainfall, may be a primary factor influencing the accumulation of dead fuel in chamise. The opportunistic fungal pathogen *Botryosphaeria dothidea* has also been implicated as a primary cause of branch dieback of drought stressed shrubs, especially *Ceanothus* spp. (Riggan and others 1994).

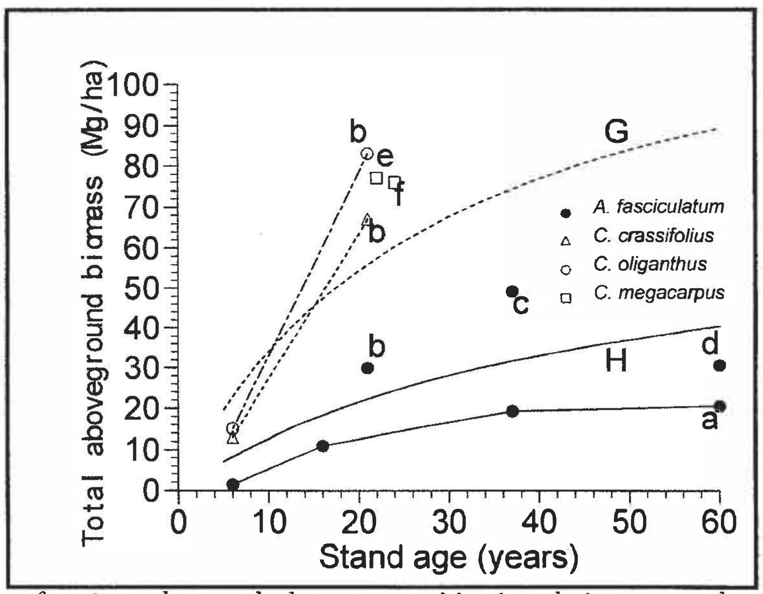

Figure 1. *Biomass of various chaparral plant communities in relation to stand age. Different letters indicate different authors.* ***a*** *= Rundel and Parsons 1979;* ***b*** *= Riggan and others 1988;* ***c*** *= Specht 1969;* ***d*** *= Stohlgren and others 1984;* ***e*** *= Schlesinger and Gill 1980;* ***f*** *= Gray, 1982;* ***G, H*** *= Rothermel and Philpot 1973, fuel models for mixed chaparral and chamise chaparral, respectively.*

Although much work has been focused on chaparral fuel and biomass, land managers and scientists currently lack the means to estimate reliably fuel loading, fuel structure, and biomass components of specific chaparral sites, or how these characteristics of sites will change as a stand regenerates and matures after fire. This paper presents an overview of our ongoing research into the estimation of chaparral fuels and biomass components, including some preliminary results, and to discuss gaps in our knowledge that need to be addressed in future research.

Methods

Study Sites

We have acquired data on chaparral biomass components and fuels from 16 sites in southern California over the past several years, as parts of several different studies. These studies have been conducted to assess smoke emissions from prescribed burning of chaparral, describe chaparral water use in relation to soil and weathered rock water holding capacity, determine efficient sampling and estimation procedures for quantifying chaparral biomass and fuels, and to obtain ground-based data for calibration of remotely sensed data to chaparral stand characteristics, including species composition, canopy water content, and fuel and biomass loading and structure. These sites span a broad range of geographic distribution, species composition, and years since last fire. Eight sites were sampled in each of two of the most important general types of chaparral communities, chamise (*Adenostoma fasciculatum* Hook. & Arn.) chaparral and mixed chaparral, which is commonly dominated by members of the genus *Ceanothus*.

Sampling and Estimation Procedures

The specific data collection, processing, and analytical procedures differ somewhat among sites because these data were collected as part of several different studies (Regelbrugge and Conard, in press). Detailed description of methodology and rationale for each study is beyond the scope of this paper, but we will briefly describe in general terms the different approaches used. The methods used in all of the studies allow estimation of total aboveground biomass of the dominant shrub community, and the partitioning of this biomass into live wood, dead wood, and foliage components. Because herbaceous plants are not common in mature chaparral (Hanes 1971), we made no attempt to quantify them in our study. Accumulated surface litter, or forest floor, also tends to be very sparse under many mature chaparral stands, particularly stands dominated by *A. fasciculatum*. Although litter accumulations are greater in stands dominated by *Ceanothus spp.* and *Quercus spp.*, we were primarily interested in canopy fuels that dominate fire behavior; thus, we did no sampling of surface litter. Because one of the goals of our ongoing research into chaparral ecosystems was to quantify patterns of fuel loading with respect to species composition, site factors, and age, we further partitioned the live and dead woody material of a subsample of shrubs into size classes related to fuel particle surface to volume ratio (Burgan and Rothermel 1984). This partitioning allowed the development of site-specific, or more general, fuel models for chaparral sites that can be used to simulate fire behavior with the Rothermel fire spread model (Rothermel 1972) by using the BEHAVE system (Andrews 1986) or the spatially explicit implementation of the Rothermel model, FARSITE (Finney 1994). Detailed analyses comparing various fuel models is beyond the scope of this paper, although some general fuel parameters will be discussed, such as total fuel loading, fuel dead fraction, and foliage fraction. We used the definition of total fuel available for fire propagation described in Burgan and Rothermel (1984), i.e., dead woody material less than 76 mm (3 in) in diameter, live wood less than 6.3 mm (.25 in) in diameter, and foliage. We acknowledge that in some stands, such as those dominated by scrub oak (*Quercus berberidifolia*), accumulated leaf litter may be an important component of the available fuel, as would be grasses and other herbaceous plants in very young stands up to 5 to 10 years old. However, these issues are not a concern for many chaparral sites, including those we sampled.

Results and Discussion

Total Biomass

Total aboveground biomass of all sites ranged between 16 and 118 Mg/ha (Figure 2A), with an overall mean of 50 (± 7.5, standard error of the mean (SE)) Mg/ha (1 Mg/ha = 1000 kg/ha). Aboveground biomass of *A. fasciculatum*-dominated stands ranged from 16 to 40 Mg/ha, with an average of 26 (± 2.6, SE) Mg/ha, while *Ceanothus*-dominated chaparral had much higher biomass, ranging from 50 to 118 Mg/ha, with an average of 74 (± 8.6, SE) Mg/ha (fig. 2A). Age of the stands sampled ranged from 10 to 55 years (fig. 2A), with stands of both species spanning a similar range. Any clear relationship between biomass and age is not apparent, which may not be surprising given the broad range of site conditions these stands represent. These stands represent a broad geographic range, with some stands being within a few kilometers of the Pacific Ocean, and others lying as much as 200 km inland. Average annual rainfall within the study area may vary between 300 and 800 mm/yr, depending on the site. Differences in site factors such as aspect may be reflected in species composition, but other studies have noted large differences in total stand biomass among sites of identical age and species composition (Riggan and others 1988, Schlesinger and Gill 1980). We suspect that water balance and nutrients may account for differences in site productivity that are reflected in the wide variability in stand biomass. These factors will be related to soil depth, soil chemical and physical properties, and topographic influences such as slope aspect, inclination, and position, as well as rainfall. The manner in which site factors influence productivity, and therefore biomass yield, is understood only in a general sense for chaparral. Although further analysis of our data and that found in the literature (e.g. Riggan and others 1988, Schlesinger and Gill 1980) will help to elucidate the relationship of site factors and productivity, we believe that additional data need to be collected to address this question specifically.

Available Fuel

Because available fuel contains only dead wood less than 76 mm in diameter, live wood less than 6.3 mm in diameter, and foliage, total available fuel is somewhat less than total aboveground biomass for most stands, but otherwise displays similar trends with respect to stand age. An important question is what fraction of total biomass comprises available fuel, and is this

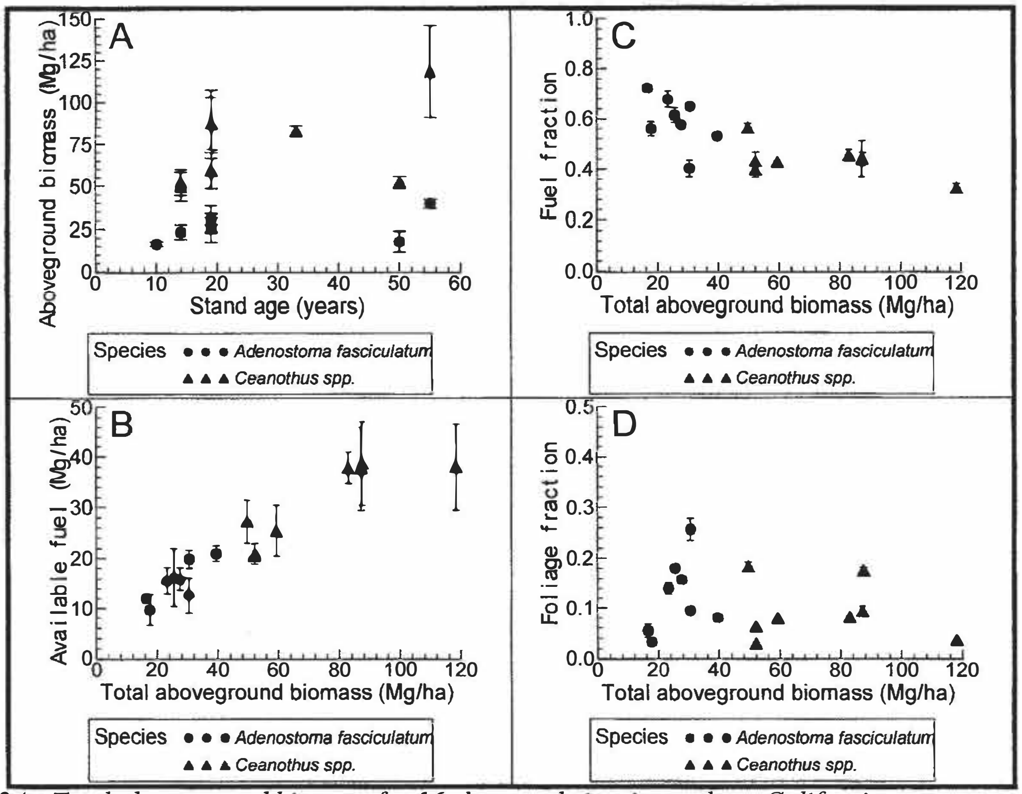

Figure 2A*. Total aboveground biomass for 16 chaparral sites in southern California versus stand age.*
Figure 2B*. Total aboveground biomass for 16 chaparral sites in southern California versus available fuel.*
Figure 2C*. Total aboveground biomass for 16 chaparral sites in southern California versus fraction of stand biomass that constitutes available fuel.*
Figure 2D*. Total aboveground biomass for 16 chaparral sites in southern California versus foliage as a fraction of stand biomass.*

fraction related to variables like species composition, stand age, or total stand biomass. These relationships could be used to estimate total fuel, or perhaps fuel components, without the need for costly, labor intensive partitioning of shrub samples into components. Total available fuel increases with total biomass (fig. 2B), but total available fuel does not appear to be a constant proportion of total biomass (fig. 2B, 2C). *Ceanothus* species tend to grow larger diameter stems and branches than does *A. fasciculatum*, and this is illustrated in the lower fuel fraction in *Ceanothus*-dominated stands (fig. 2C) where more of the total stand biomass is concentrated in large diameter woody material which is not considered to be available fuel. Average fuel fraction was 59 (± 4, SE) percent for *A. fasciculatum* stands, and 43 (±2, SE) percent for *Ceanothus*-dominated stands (fig. 2C). We suspect that the relative dominance, i.e., proportion of total biomass, of species with different physical structure, in stands of mixed composition will be related to the fuel fraction. For example, the *Ceanothus*-dominated stand with the highest fuel fraction in our study, 56 percent, had a larger *A. fasciculatum* component than any other *Ceanothus* stands we observed (fig. 2C). Future analyses will incorporate any published data available to investigate variability in fuel fraction within species, and in relation to species proportion in mixed stands.

Foliage Biomass

Foliage of chaparral plants has very high surface-to-volume ratios (σ), which means it is rapidly dehydrated and ignited by a flame front, and is therefore a very important fuel for fire propagation in chaparral. Foliage as a fraction of total stand biomass ranged from 3 to 25 percent, with an average of 11 (± 2, SE) percent (fig. 2D), and did not appear different between *A. fasciculatum* and *Ceanothus* stands. However, the two *Ceanothus* stands with the lowest foliage fractions, about 3 percent, were composed of *Ceanothus oliganthus* and *Ceanothus spinosus*, species with very thin, mesophytic leaves compared to the thick, sclerophyllous leaves of many *Ceanothus* species (fig. 2D). Foliage has high σ compared to woody fuels, which gives foliage strong influence on fire behavior in simulations; thus, it may be necessary to consider the influence of leaf morphology on foliage biomass if constructing site-specific fuel models. Observations of actual fires also indicates that propagation of fire through the chaparral canopy is strongly dependent on foliage.

Dead Fraction

Dead woody biomass in chaparral originates from two distinctly different sources. The first, and that most commonly described in the literature, is from mortality of branches and plants during stand development. This mortality likely results from shading and competition for soil water, and perhaps nutrients. The other source is from residual "skeletons" of shrubs that were not burned in the last fire. Dead biomass varied widely in our study, ranging from 12 to 46 percent of total stand biomass (fig. 3A), and showed no clear trends with respect to species composition or stand age. Although several authors have previously indicated that chaparral dead fraction increases strongly as stands age, (e.g. Green 1981, Rothermel and Philpot 1973), our data are consistent with the findings of Paysen and Cohen (1990), in which chaparral dead fraction is not reliably predicted by age. Distinguishing whether dead fuel is expressed as a fraction of total fuel, or of total stand biomass, is important for clarity, but this distinction is rare in the literature. In our study, virtually all dead wood was within the size range to be considered fuel, but if this dead fuel mass is expressed as a fraction of available fuel, we get a range of 27 to 72 percent, considerably higher than dead fuel as a fraction of stand biomass (fig. 3B). We do not know whether this ambiguity in terminology is responsible for part of the confusion over dead fuel fraction in the literature but hope that future authors will define and use terminology clearly. Although most dead fuel is assumed to result from branch and shrub mortality during stand development, we caution that this may not always be the case. The youngest stand in our study appears to have an extremely high proportion of dead fuel, 63 percent of total fuel (fig. 3B). We observed that this stand contained many dead shrub stems 25 to 76 mm in diameter, with no fine branchwood attached, that appeared to be residual from a fire 10 years earlier. Although this situation may be atypical, it will influence fuel bed geometry in potentially significant ways.

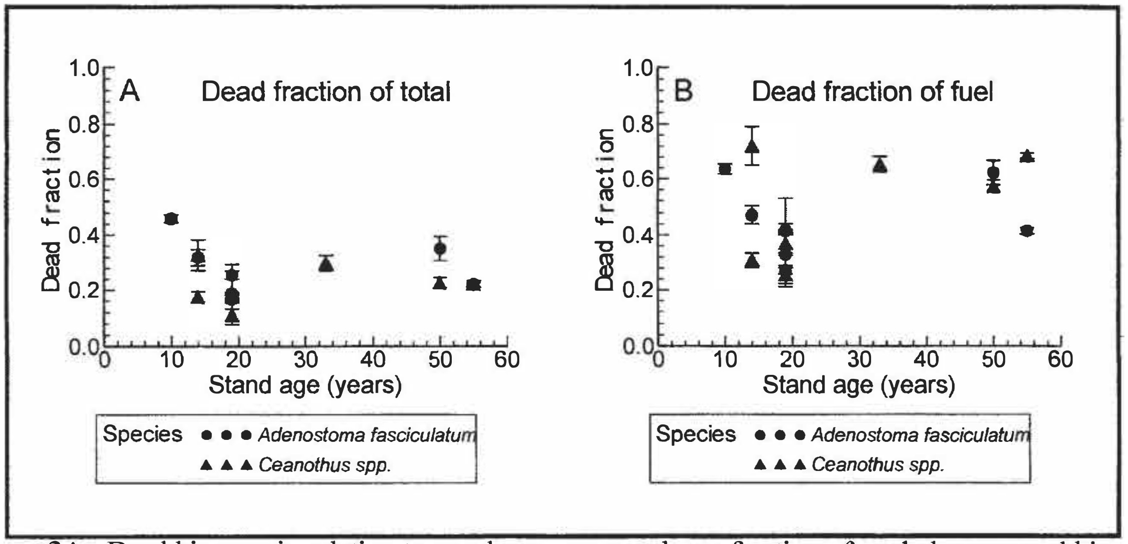

Figure 3A. Dead biomass in relation to stand age, expressed as a fraction of total aboveground biomass of 16 chaparral sites in southern California.

Figure 3B. *Dead biomass in relation to stand age, expressed as a fraction of available fuel of 16 chaparral sites in southern California.*

Spatial Variation of Biomass and Fuels

Although variation in biomass and fuels among chaparral sites has been well documented, much less information has been published on variability within a site. Several of our studies have involved sampling multiple plots within a given stand. Compared to surrounding areas, these stands were relatively homogeneous within an area between 0.5 and 5 ha. The coefficient of variation among plots in estimated stand biomass was often as high as 25 or 30 percent (fig. 4). For the stand of *A. fasciculatum* with *Arctostaphylos glandulosa* Eastw. (Eastwood manzanita) as an associated species at the North Mountain Experimental Area, biomass of 5 by 5 m subplots ranged between 20 and 60 Mg/ha (fig. 4), with a mean of 39 (± 2.6, SE) Mg/ha. This variability in biomass is readily apparent from the variable structure of the plant community as one explores this site. The topography of this area is highly dissected, and variability in soil depth to bedrock and the degree of weathering of the bedrock are also quite variable (Sternberg and others 1996). These factors could very well influence microsite productivity, and consequently, biomass and fuel accumulation, through their influence on water availability for plant growth.

Variable fuel structure may well have an important effect on both model predicted and actual fire behavior (Fujioka 1985). The degree to which spatial variation in fuels will affect fire behavior is unclear for several reasons. Although it is possible to assess the sensitivity of the Rothermel model to changes in chaparral fuel, we still do not have a good sense of how well predictions from the Rothermel model correspond to actual fire behavior in chaparral fuels. This uncertainty is due at least in part to the difficulty of collecting data on fire spread where all of the required inputs for fire modeling are accurately known (Albini and Anderson 1982). Secondly, we do not know clearly at what spatial scale the variability in fuels becomes important. There may well be a spatial scale below which variability in fuels does not affect fire behavior in an

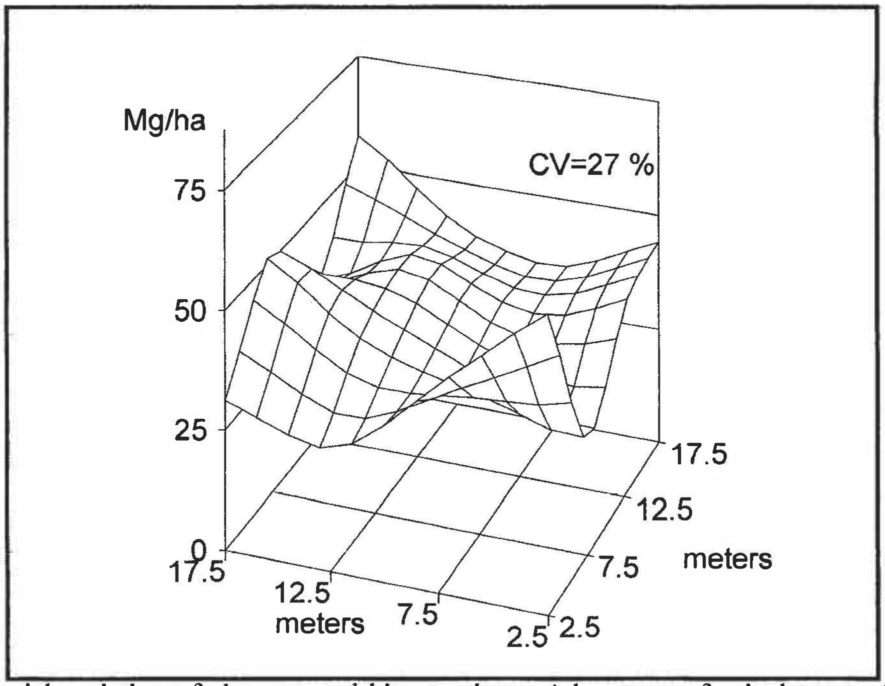

Figure 4. Spatial variation of aboveground biomass in an Adenostoma fasciculatum - Arctostaphylos glandulosa stand at the North Mountain Experimental Area in the San Jacinto Mountains of southern California. The surface shows a spline interpolation of biomass values estimated for 16 contiguous subplots (5 by 5 m in size), and the x and y axes show relative position of subplot centers at 2.5 m intervals. Coefficient of variation of total aboveground biomass among these subplots was 27 percent.

observable manner; therefore, the average condition of such a unit would be sufficient knowledge. Above this scale, however, variability could strongly influence fire behavior as the flame front moved through fuel zones with different physical structure. This topic requires much investigation to answer these questions.

Future Research Needs

A computerized fuels database with sufficient accuracy, accessibility, and geographic coverage is a necessary element for fire modeling for both strategic and tactical applications (Albini and Anderson 1982). To implement such a system, we need to elucidate further patterns of chaparral growth through time and in relation to site characteristics. We also need to correlate ground-based measures of chaparral fuels and biomass with remotely sensed data. This would allow mapping chaparral fuels at broad landscape levels, facilitate incorporation of fuels data with other pertinent landscape attributes via GIS, and allow relatively easy updating and modification of the database as needed to account for growth or disturbances such as fires or episodes of dieback related to drought and pathogens such as *Botryosphaeria dothidea*. Although remote sensing is vital to the development of an extensive fuels database, several important knowledge gaps can be filled only through ground-based sampling. These questions mostly relate to quantifying the effects of site productivity on chaparral growth, and relating the accumulation of dead woody fuel to causal, or perhaps only associative, factors. Identifying the causal mechanism of deadwood accumulation would be ideal, but an associative relationship potentially could be exploited in a predictive manner as well.

Fuel bed geometry is probably also very important to the manner in which fire propagates in chaparral. Unlike forest floor fuels, chaparral fuel particles typically are oriented vertically, and chaparral fuel beds have very high porosity compared to many other wildland fuel types. Fine twigs and foliage tend to be stratified vertically, and the height of greatest concentration of these most flammable fuels above the ground surface varies both within and among species. These and other structural properties of chaparral fuel beds have only been described in a very cursory, simplistic fashion. Yet, practical experience indicates that these may have a profound influence on fire behavior. *A. fasciculatum* stands, with many fine branches in relatively compact crowns, which tend to be close to the ground, seem relatively easy to burn under prescribed burning conditions, while mature *Ceanothus* stands, with taller canopies composed of fuels with lower σ, often seem able to sustain combustion only under extreme conditions. Although many fire professionals have an intuitive sense of these types of phenomena, quantitative descriptions of thresholds such as these have not been developed, in spite of their potential utility. Not only do we lack understanding of where spread thresholds may occur, we can't describe the relative influence of σ versus fuel bed porosity or fuel particle arrangement on spread thresholds. Experimental fires, in which fire behavior can be closely monitored and related to measured fuels and weather information, would help to describe thresholds which separate conditions where fires either will or will not spread, and help to detect the scale in which variability in fuels affect fire spread and intensity in a detectable fashion.

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