EXTENDED ABSTRACT

Estimating Canopy Bulk Density and Canopy Base Height for Conifer Stands in the Interior Western United States Using the Forest Vegetation Simulator Fire and Fuels Extension

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Author's note: This is a summary of work that is completely described in Ex and others (2016).

The Forest Vegetation Simulator Fire and Fuels Extension (FFE-FVS) is often used to estimate canopy bulk density (CBD) and canopy base height (CBH), which are key indicators of crown fire hazard for conifer stands in the Western United States. Estimated CBD from FFE-FVS is calculated as the maximum 4 m running mean bulk density of predefined 0.3 m thick canopy layers (Sando and Wick 1972). Canopy base height is estimated in a similar fashion as the lowest height at which the running mean bulk density of canopy layers exceeds a predefined threshold of 0.011 kg m^{-3} (Scott and Reinhardt 2001). Because estimates of CBD and CBH from FFE-FVS are derived from estimates of the bulk density of canopy layers, their values depend both on the biomass of canopy fuel and on the manner in which fuel is distributed vertically within the crowns of trees that make up the canopy (Keyser and Smith 2010).

In this work, we evaluated the impact of using alternative crown fuel distributions and crown fuel biomass allometries on CBD and CBH estimation using FFE-FVS. We used the southwestern ponderosa pine sub-model of version 1108 of the Central Rockies (CR) Variant of FVS (Keyser and Dixon 2008) for our analysis. Our approach was to estimate CBD and CBH for mostly pure, even-aged stands of seven conifer species by modifying FFE-FVS to use non-uniform instead of uniform crown fuel distributions, which allowed us to determine whether distribution effects on CBD and CBH estimates were species-specific or general. For two species, we also compared estimates derived using local versus non-local crown fuel biomass allometries to ascertain whether there was a consistent bias in CBD and CBH estimates associated with application of allometries outside their geographic area of origin.

We used crown biomass data from 319 trees in 59 mostly pure, even-aged conifer stands to evaluate the effects of using non-uniform crown fuel biomass distributions on CBD and CBH estimates. Stands were selected to represent broad ranges of average tree size and stand density for each species. Our data come from stands with quadratic mean diameters ranging from 3.3–43.7 cm and densities ranging from 136–25,542 trees ha^{-1}. Coordinates and physical characteristics of most of the stands, which were located throughout the interior Western United States, are reported in Ex and others (2015). Field methods and the remaining stands are described in detail in Ex and others (2015), Long and Smith (1988) and Long and Smith (1989). Data from a subset of 12 of the 59 stands (30 trees) were used to evaluate whether there was consistent bias in CBD and CBH estimates from FFE-FVS that was associated with geographic area. The allometries in FFE-FVS were developed for stands in Montana and northern Idaho (Brown 1978). We developed corresponding allometries using data from ponderosa pine and Douglas-fir stands located in Colorado, New Mexico, Utah, and southern Idaho. Using the non-uniform fuel

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Citation for proceedings: Keyser, Chad E.; Keyser, Tara L., eds. 2017. Proceedings of the 2017 Forest Vegetation Simulator (FVS) e-Conference. e-Gen. Tech. Rep. SRS-224. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 200 p.

distributions and local biomass allometries, we modified the CBD and CBH calculation procedure in FFE-FVS in three ways: (1) we incorporated non-uniform distributions, but retained crown biomass allometries from Brown (1978); (2) we retained the uniform distributions from the production version of FFE-FVS but incorporated local biomass allometries, and; (3) we incorporated both non-uniform distributions and local biomass allometries. For each cover type, we obtained estimates of CBD and CBH using our modifications and compared them to estimates from the production version of FFE-FVS.

The data showed estimates of CBD generated using non-uniform crown fuel biomass distributions were consistently 13–27 percent larger than estimates from the production version of FFE-FVS. The difference was statistically significant for all cover types except pinyon-juniper (table 1). Unlike CBD, estimates of CBH did not always increase. Average differences between estimates of CBH from the production version of FFE-FVS and from versions that used non-uniform crown fuel distributions ranged from -11 percent to +23 percent and were in most cases non-significant (table 1).

Although estimates of CBD and CBH generated using local crown fuel biomass allometries were sometimes substantially different than estimates from the production version of FFE-FVS, there was no statistical difference between estimates from the different methodologies (table 1). This was because in some stands estimates of canopy fuel load from local allometries were larger than estimates from non-local allometries, causing estimates of CBD to increase and potentially causing estimates of CBH to decrease, while in other stands the opposite was true (fig. 1). This suggests allometric relationships vary widely among stands in the southern Rockies.

The major implication of the consistent increase in estimated CBD we observed is a subsequent decrease in estimates of the critical spread rate required to sustain the spread of fire from tree to tree through canopies from fire behavior models (Scott and Reinhardt 2001). An exploratory analysis using our data suggested this decrease was generally on the order of 3 m min^{-1}, but it varied considerably among stands. Non-uniform distributions unquestionably offer more realistic representations of crown fuel distribution than uniform distributions. However, it is not clear that incorporating them in FFE-FVS will improve

Table 1—Average difference in estimated CBD and CBH from modified and production versions of FFE-FVS (average percentage change follows each value in parentheses). Values were calculated as modified – production.

Cover type[a]	FFE-FVS modification	CBD Δ (kg m^{-3})	CBH Δ (m)
Ponderosa pine	Local allometries	0.023 (16)	-0.46 (-17)
Douglas-fir		0.034 (21)	-0.25 (-19)
Subalpine fir	Non-uniform distributions	0.074 (23)*	0.24 (22)
Ponderosa pine		0.028 (27)*	0.64 (17)*
Pinyon-juniper		0.019 (13)	-0.10 (-11)
Lodgepole pine		0.018 (13)*	0.19 (9)*
Engelmann spruce		0.055 (17)*	0.15 (23)
Douglas-fir		0.038 (24)*	0.41 (18)
Ponderosa pine	Local allo. & Non-uni. dist.	0.053 (48)*	-0.10 (-9)
Douglas-fir		0.066 (44)*	-0.05 (-7)

[a]After Eyre and others (1980), excepting the Engelmann spruce-subalpine fir type which has been split into its constituent species here.

Significant differences from zero at $\alpha = 0.05$ are denoted by *.

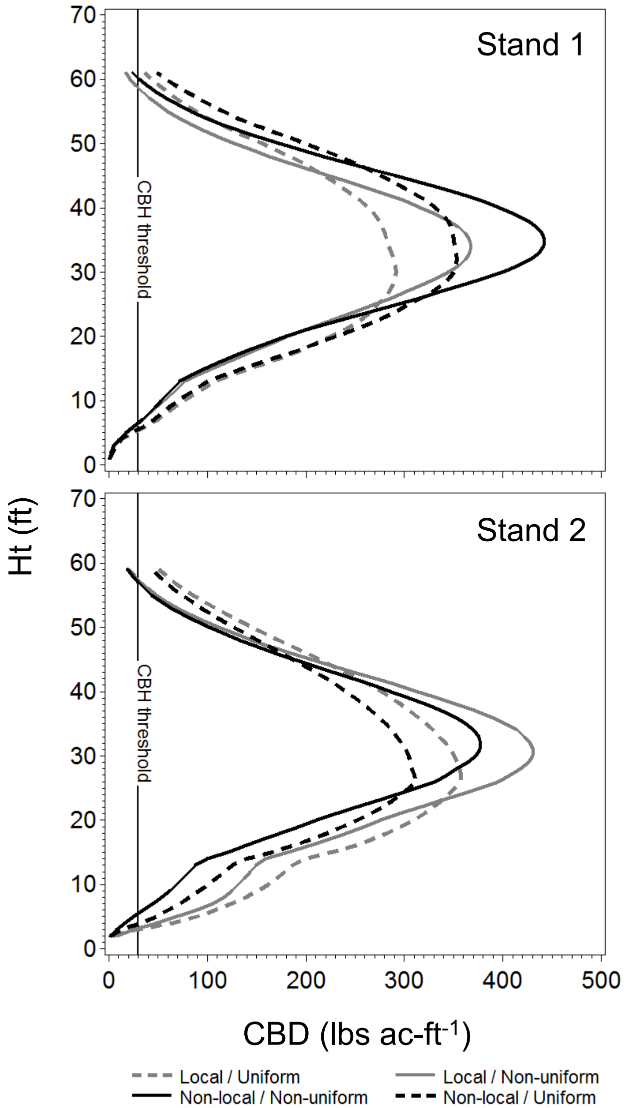

Figure 1—Canopy fuel profiles for two Douglas-fir stands created using modified CBD and CBH calculations that incorporated local biomass allometries and uniform crown fuel distributions, local allometries and non-uniform distributions, non-local allometries and uniform distributions, and non-local allometries and non-uniform distributions. Local allometries decreased the estimate of crown fuel biomass for Stand 1 and increased the estimate for Stand 2.

predictions of potential fire behavior unless the fire behavior and spread models in FFE-FVS are also re-parameterized for compatibility with the improved canopy fuel characterization methodology (Cruz and Alexander 2010). Percent changes in CBH from incorporating non-uniform distributions can be of a similar order of magnitude as changes in CBD and occasionally much larger, but the direction and amount of change are difficult to predict for a given stand. This highlights the need to re-evaluate the method used to delineate CBH in FFE-FVS, as it is clearly sensitive to assumptions regarding the distribution of fuel within tree crowns.

Adopting local biomass allometries in FFE-FVS could potentially change estimates of CBD and CBH as much as adopting non-uniform crown fuel distribution assumptions. However, good estimates of CBD and CBH for southern Rocky Mountain stands require the use of allometric models that are capable of accounting for stand to stand variation in the relationship between d.b.h. and crown fuel biomass. This will likely require incorporating tree height or live crown ratio as predictor variables in allometric models, and argues for routine measurement of both tree and live crown base heights during inventories to permit use of allometries that incorporate this information (Tinkham and others, in press).

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