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fire & fuels management

Tables for Estimating Canopy Fuel Characteristics from Stand Variables in Four Interior West Conifer Forest Types

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Tables have been constructed for use in making quick estimates of canopy base height, canopy fuel load, and canopy bulk density from visual observations or field measurements of stand height, basal area, and stand density for pure stands of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and a mixed conifer type found in the US interior west. These canopy fuel characteristics are needed for assessing crown fire potential in such fuel complexes. The tabulated values are based on previously published regression equations that have undergone performance evaluations. Both English and metric unit versions of the canopy fuel characteristics tables are presented.

Keywords: canopy base height, canopy bulk density, canopy fuel load, crown fire potential, stand structure

Some, but not all, conifer forest stands are prone to the incidence of crown fires. An assessment of crowning potential in conifer forests, be it for identifying the need for or planning the implementation of a fuel treatment (including the use of prescribed fire) or for the prediction of wildfire behavior, is dependent on the quantification of certain canopy fuel characteristics as inputs into fire behavior modeling systems (Keyes and O'Hara 2002, Affleck et al. 2012, Alexander and Cruz 2014). For example, a prediction of the potential energy release (Rothermel 1991) or maximum spotting distance from a crown fire (Albini et al. 2012) is dependent in part on an estimate of the available canopy fuel load (CFL), i.e., the amount of fuel consumed in the canopy during the crowning process.

For a crown fire to start, a surface fire of sufficient intensity is required. The most commonly used method of determining such a threshold depends on Byram's (1959) fireline intensity, a value that takes into account the combined physical characteristics of the fuel complex and the effects of long- and short-term weather on fuel dryness, wind speed, and slope steepness on surface fire behavior (Alexander and Cruz 2014). Van Wagner (1977) codified the fireline intensity needed to initiate a crown fire in a conifer forest stand as determined by two canopy fuel inputs, namely canopy base height (CBH) and foliar moisture content. He also developed a simple means of determining whether active crown fire propagation was also possible on the basis of the stand's canopy bulk density (CBD) in relation to the spread rate after crowning. CBD values of 0.003 lb/ft^3 (0.05 kg/m^3) and 0.006 lb/ft^3 (0.10 kg/m^3) have come to be recognized as critical threshold values for the onset of crowning and active crown fire spread, respectively (Agee 1996, Powell 2010, Alexander and Cruz 2014).

Under moderate to high burning conditions with respect to dead fuel moisture, wind speed, and slope steepness, accurate estimates of canopy fuel characteristics take on greater importance. Because of the nonlinear response of certain features of wildland fire behavior, namely abrupt changes in the rate of fire spread and fireline intensity to small changes in the fire environment when close to critical thresholds for the onset of crowning and active crown fire spread, relative small errors in the estimation of canopy fuel characteristics can result in large underprediction errors. Guidance with respect to gauging or directly determining the foliar moisture content input in Van Wagner's (1977) crown fire initiation model currently exists (Keyes 2006, Alexander 2010, Jolly and Hadlow 2012). Several authors have provided the means of inferring either the CBH, CFL, or CBD or all three canopy fuel characteristics from general tree and stand characteristics for a given forest cover type (e.g., Alexander 1979, Rothermel 1991, Agee 1996, Keane et al. 1998, Reinhardt et

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Table 1. CBH as a function of BA and SH for pure ponderosa pine stands.

	SH (ft)											
BA (ft^2/ac)	10	15	20	25	30	35	40	45	50	55	60	65
20	5.1	7.1	9.0	11.0	13.0	14.9	16.9	18.9	20.8	22.8	24.8	26.7
40	5.8	7.8	9.8	11.7	13.7	15.7	17.6	19.6	21.6	23.5	25.5	27.5
60	6.6	8.5	10.5	12.5	14.4	16.4	18.4	20.3	22.3	24.3	26.2	28.2
80	7.3	9.3	11.3	13.2	15.2	17.1	19.1	21.1	23.0	25.0	27.0	28.9
100	8.1	10.0	12.0	14.0	15.9	17.9	19.9	21.8	23.8	25.7	27.7	29.7
120	8.8	10.8	12.7	14.7	16.7	18.6	20.6	22.6	24.5	26.5	28.4	30.4
140	9.5	11.5	13.5	15.4	17.4	19.4	21.3	23.3	25.3	27.2	29.2	31.2
160	10.3	12.2	14.2	16.2	18.1	20.1	22.1	24.0	26.0	28.0	29.9	31.9
180	11.0	13.0	14.9	16.9	18.9	20.8	22.8	24.8	26.7	28.7	30.7	32.6
200	11.8	13.7	15.7	17.6	19.6	21.6	23.5	25.5	27.5	29.4	31.4	33.4
220	12.5	14.5	16.4	18.4	20.3	22.3	24.3	26.2	28.2	30.2	32.1	34.1
240	13.2	15.2	17.2	19.1	21.1	23.1	25.0	27.0	28.9	30.9	32.9	34.8

CBH measured in ft.

Table 2. CBH as a function of BA and SH for pure lodgepole pine stands.

	SH (ft)											
BA (ft^2/ac)	10	15	20	25	30	35	40	45	50	55	60	65
20	1.9	5.0	8.1	11.1	14.2	17.3	20.3	23.4	26.5	29.5	32.6	35.7
40	2.6	5.7	8.7	11.8	14.8	17.9	21.0	24.0	27.1	30.2	33.2	36.3
60	3.2	6.3	9.4	12.4	15.5	18.6	21.6	24.7	27.8	30.8	33.9	36.9
80	3.9	6.9	10.0	13.1	16.1	19.2	22.3	25.3	28.4	31.5	34.5	37.6
100	4.5	7.6	10.7	13.7	16.8	19.9	22.9	26.0	29.0	32.1	35.2	38.2
120	5.2	8.2	11.3	14.4	17.4	20.5	23.6	26.6	29.7	32.8	35.8	38.9
140	5.8	8.9	12.0	15.0	18.1	21.2	24.2	27.3	30.3	33.4	36.5	39.5
160	6.5	9.5	12.6	15.7	18.7	21.8	24.9	27.9	31.0	34.1	37.1	40.2
180	7.1	10.2	13.3	16.3	19.4	22.4	25.5	28.6	31.6	34.7	37.8	40.8
200	7.8	10.8	13.9	17.0	20.0	23.1	26.2	29.2	32.3	35.4	38.4	41.5
220	8.4	11.5	14.5	17.6	20.7	23.7	26.8	29.9	32.9	36.0	39.1	42.1
240	9.1	12.1	15.2	18.3	21.3	24.4	27.5	30.5	33.6	36.6	39.7	42.8

CBH measured in ft.

Table 3. CBH as a function of BA and SH for pure Douglas-fir stands.

	SH (ft)											
BA (ft^2/ac)	10	15	20	25	30	35	40	45	50	55	60	65
20	0.4	3.2	5.9	8.7	11.5	14.3	17.0	19.8	22.6	25.3	28.1	30.9
40	1.1	3.9	6.6	9.4	12.2	14.9	17.7	20.5	23.2	26.0	28.8	31.6
60	1.8	4.5	7.3	10.1	12.8	15.6	18.4	21.2	23.9	26.7	29.5	32.2
80	2.4	5.2	8.0	10.8	13.5	16.3	19.1	21.8	24.6	27.4	30.1	32.9
100	3.1	5.9	8.7	11.4	14.2	17.0	19.7	22.5	25.3	28.0	30.8	33.6
120	3.8	6.6	9.3	12.1	14.9	17.6	20.4	23.2	26.0	28.7	31.5	34.3
140	4.5	7.2	10.0	12.8	15.6	18.3	21.1	23.9	26.6	29.4	32.2	34.9
160	5.2	7.9	10.7	13.5	16.2	19.0	21.8	24.5	27.3	30.1	32.9	35.6
180	5.8	8.6	11.4	14.1	16.9	19.7	22.5	25.2	28.0	30.8	33.5	36.3
200	6.5	9.3	12.0	14.8	17.6	20.4	23.1	25.9	28.7	31.4	34.2	37.0
220	7.2	10.0	12.7	15.5	18.3	21.0	23.8	26.6	29.3	32.1	34.9	37.7
240	7.9	10.6	13.4	16.2	18.9	21.7	24.5	27.3	30.0	32.8	35.6	38.3

CBH measured in ft.

al. 2006, Powell 2010). Still others have examined indirect methods of estimating CBD in the field (e.g., Keane et al. 2005), including a stereo pair photo guide (Scott and Reinhardt 2005) which the authors readily admitted had limited capability.

Other means of estimating canopy fuel characteristics are available to fire and fuel managers in the United States. For example, spatial data on CBH and CBD produced by the LANDFIRE wildland fuel mapping project[1] is available, although CBH values were found to be unreliable and generally too high for accurate simulation of surface to crown fire transition, and CBD values appeared to too low for simulating the occurrence of active crown fires (Reeves et al. 2009). Nevertheless, improvements in the LANDFIRE canopy fuel characteristics continue to be sought after (Nelson et al. 2013).

The other common approach to estimating canopy fuel characteristics involves using the Fire and Fuels Extension to the Forest Vegetation Simulator (FFE-FVS) (Rebain 2010) based on data either collected during a stand examination by the user or extracted from an existing database (e.g., McRoberts et al. 2005). However, on the basis of 16 sampled ponderosa pine stands in South Dakota, Keyser and Smith (2010) found that FFE-FVS underpredicted the

Table 4. CBH as a function of BA and SH for mixed conifer stands.

	SH (ft)											
BA (ft^2/ac)	10	15	20	25	30	35	40	45	50	55	60	65
20	1.4	4.3	7.2	10.0	12.9	15.8	18.7	21.6	24.5	27.4	30.3	33.2
40	1.8	4.7	7.5	10.4	13.3	16.2	19.1	22.0	24.9	27.8	30.7	33.6
60	2.2	5.0	7.9	10.8	13.7	16.6	19.5	22.4	25.3	28.2	31.1	33.9
80	2.5	5.4	8.3	11.2	14.1	17.0	19.9	22.8	25.7	28.6	31.4	34.3
100	2.9	5.8	8.7	11.6	14.5	17.4	20.3	23.2	26.1	28.9	31.8	34.7
120	3.3	6.2	9.1	12.0	14.9	17.8	20.7	23.6	26.5	29.3	32.2	35.1
140	3.7	6.6	9.5	12.4	15.3	18.2	21.1	24.0	26.8	29.7	32.6	35.5
160	4.1	7.0	9.9	12.8	15.7	18.6	21.5	24.3	27.2	30.1	33.0	35.9
180	4.5	7.4	10.3	13.2	16.1	19.0	21.8	24.7	27.6	30.5	33.4	36.3
200	4.9	7.8	10.7	13.6	16.5	19.3	22.2	25.1	28.0	30.9	33.8	36.7
220	5.3	8.2	11.1	14.0	16.8	19.7	22.6	25.5	28.4	31.3	34.2	37.1
240	5.7	8.6	11.5	14.4	17.2	20.1	23.0	25.9	28.8	31.7	34.6	37.5

CBH measured in ft.

Table 5. CFL as a function of BA and SD for pure ponderosa pine stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
40	0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09
60	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13
80	0.13	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16
100	0.15	0.16	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20	0.20
120	0.18	0.19	0.20	0.21	0.21	0.22	0.22	0.22	0.23	0.23	0.23	0.23
140	0.20	0.22	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.26	0.26	0.27
160	0.23	0.25	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.29	0.30	0.30
180	0.25	0.27	0.28	0.29	0.30	0.31	0.31	0.32	0.32	0.32	0.33	0.33
200	0.28	0.30	0.31	0.32	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.36
220	0.30	0.32	0.34	0.35	0.36	0.37	0.37	0.38	0.38	0.39	0.39	0.39
240	0.32	0.35	0.37	0.38	0.39	0.39	0.40	0.41	0.41	0.42	0.42	0.43

CFL measured in lb/ft^2.

Table 6. CFL as a function of BA and SD for pure lodgepole pine stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
40	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
60	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.11
80	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.14	0.14
100	0.12	0.13	0.14	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.17	0.17
120	0.14	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20
140	0.16	0.18	0.19	0.20	0.20	0.21	0.21	0.22	0.22	0.22	0.23	0.23
160	0.19	0.20	0.21	0.22	0.23	0.24	0.24	0.24	0.25	0.25	0.25	0.26
180	0.21	0.23	0.24	0.25	0.26	0.26	0.27	0.27	0.28	0.28	0.28	0.29
200	0.23	0.25	0.26	0.27	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.32
220	0.25	0.27	0.29	0.30	0.31	0.31	0.32	0.33	0.33	0.34	0.34	0.34
240	0.27	0.29	0.31	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.37

CFL measured in lb/ft^2.

CBD by 47%. Reinhardt et al. (2006) also pointed out a large underprediction bias in the estimation of CFL for this method as implemented by Carlton (2005). The Fuel Characteristic Classification System (FCCS) allows for the calculation of CFL and CBD but, as per FFE-FVS, requires detailed stand data, e.g., tree height, height to live crown, stand density (SD), dbh, species, and cover (Prichard et al. 2013).

In our opinion, none of the tools developed to date provide for a simple means of quickly obtaining reliable estimates of canopy fuel characteristics in the field for a particular stand as inputs into crown fire predictive models. In fact, most tools require extensive postprocessing time to obtain either a direct estimate based on summarizing tree level data using allometric equations (e.g., Brown 1978) or to properly format the data to input into another program (e.g., FVS-FFE).

The purpose of this article is to present a set of tables that will allow for the quick and reliable estimation of CBH, CFL, and CBD values in the field from three basic stand variables for four conifer forest stand types found in the US interior west and also adjacent areas in Canada. The construction of the tables is based on

Table 7. CFL as a function of BA and SD for pure Douglas-fir stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.03	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
40	0.06	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10
60	0.09	0.10	0.10	0.11	0.11	0.12	0.12	0.12	0.13	0.13	0.13	0.13
80	0.11	0.12	0.13	0.14	0.15	0.15	0.15	0.16	0.16	0.16	0.17	0.17
100	0.13	0.15	0.16	0.17	0.17	0.18	0.19	0.19	0.19	0.20	0.20	0.20
120	0.15	0.17	0.19	0.20	0.20	0.21	0.22	0.22	0.23	0.23	0.23	0.24
140	0.17	0.20	0.21	0.22	0.23	0.24	0.24	0.25	0.26	0.26	0.26	0.27
160	0.19	0.22	0.24	0.25	0.26	0.27	0.27	0.28	0.29	0.29	0.30	0.30
180	0.21	0.24	0.26	0.27	0.28	0.29	0.30	0.31	0.31	0.32	0.33	0.33
200	0.23	0.26	0.28	0.30	0.31	0.32	0.33	0.34	0.34	0.35	0.36	0.36
220	0.25	0.29	0.31	0.32	0.34	0.35	0.36	0.36	0.37	0.38	0.38	0.39
240	0.27	0.31	0.33	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.41	0.42

CFL measured in lb/ft^2.

Table 8. CFL as a function of BA and SD for mixed conifer stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.03	0.04	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08
40	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.12	0.12	0.13	0.13
60	0.08	0.10	0.11	0.13	0.14	0.14	0.15	0.16	0.17	0.17	0.18	0.18
80	0.10	0.13	0.14	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.22	0.23
100	0.12	0.15	0.17	0.19	0.20	0.22	0.23	0.24	0.25	0.26	0.27	0.27
120	0.14	0.17	0.20	0.22	0.24	0.25	0.27	0.28	0.29	0.30	0.31	0.32
140	0.16	0.20	0.23	0.25	0.27	0.29	0.30	0.31	0.33	0.34	0.35	0.36
160	0.17	0.22	0.25	0.28	0.30	0.32	0.33	0.35	0.36	0.38	0.39	0.40
180	0.19	0.24	0.28	0.31	0.33	0.35	0.37	0.38	0.40	0.41	0.43	0.44
200	0.21	0.26	0.30	0.33	0.36	0.38	0.40	0.42	0.44	0.45	0.47	0.48
220	0.23	0.28	0.33	0.36	0.39	0.41	0.43	0.45	0.47	0.49	0.50	0.52
240	0.24	0.31	0.35	0.38	0.41	0.44	0.46	0.48	0.50	0.52	0.54	0.55

CFL measured in lb/ft^2.

Table 9. CBD as a function of BA and SD for pure ponderosa pine stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.003	0.005	0.006	0.008	0.009	0.010	0.010	0.011	0.012	0.013	0.014	0.014
40	0.005	0.007	0.009	0.010	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019
60	0.005	0.008	0.010	0.012	0.014	0.015	0.017	0.018	0.020	0.021	0.022	0.023
80	0.006	0.009	0.012	0.014	0.016	0.018	0.019	0.021	0.022	0.024	0.025	0.026
100	0.007	0.010	0.013	0.015	0.017	0.019	0.021	0.023	0.024	0.026	0.027	0.029
120	0.007	0.011	0.014	0.017	0.019	0.021	0.023	0.025	0.026	0.028	0.030	0.031
140	0.008	0.012	0.015	0.018	0.020	0.022	0.024	0.026	0.028	0.030	0.032	0.033
160	0.008	0.013	0.016	0.019	0.021	0.024	0.026	0.028	0.030	0.032	0.034	0.035
180	0.009	0.013	0.017	0.020	0.022	0.025	0.027	0.029	0.032	0.033	0.035	0.037
200	0.009	0.014	0.017	0.021	0.023	0.026	0.029	0.031	0.033	0.035	0.037	0.039
220	0.010	0.014	0.018	0.021	0.024	0.027	0.030	0.032	0.034	0.037	0.039	0.041
240	0.010	0.015	0.019	0.022	0.025	0.028	0.031	0.033	0.036	0.038	0.040	0.042

CBD measured in lb/ft^3.

regression equations previously developed by Cruz et al. (2003) and evaluated by Cruz and Alexander (2012). The reasons for their selection are described in the following section. Some familiarity with the role that canopy fuel characteristics play in crown fire modeling on the part of the reader is presumed (Affleck et al. 2012, Alexander and Cruz 2014).

Background Information

Cruz et al. (2003) developed regression equations for estimating CBH, CFL, and CBD from stand height (SH), stand basal area (BA), and SD for use in assessing crown fire potential in four broad conifer forest types based on data collected in 475 permanent plots in five western states (i.e., Arizona, Colorado, Idaho, Montana, and New Mexico). The data represented a wide range of stand and site conditions. All of the regression equations are graphically illustrated in Alexander and Cruz (2013). Trees with a height of <6.5 ft (<2 m) are considered to be part of the understory (i.e., the surface fuel stratum) and are not incorporated in canopy fuel structure calculations).

Three of the types involved relatively pure stands of ponderosa

Table 10. CBD as a function of BA and SD for pure lodgepole pine stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.002	0.003	0.004	0.005	0.006	0.006	0.007	0.008	0.009	0.009	0.010	0.011
40	0.002	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.013
60	0.003	0.004	0.006	0.007	0.008	0.009	0.011	0.012	0.013	0.014	0.015	0.015
80	0.003	0.005	0.006	0.008	0.009	0.010	0.012	0.013	0.014	0.015	0.016	0.017
100	0.003	0.005	0.007	0.008	0.010	0.011	0.013	0.014	0.015	0.016	0.017	0.018
120	0.003	0.006	0.007	0.009	0.011	0.012	0.013	0.015	0.016	0.017	0.019	0.020
140	0.004	0.006	0.008	0.010	0.011	0.013	0.014	0.016	0.017	0.018	0.020	0.021
160	0.004	0.006	0.008	0.010	0.012	0.013	0.015	0.016	0.018	0.019	0.020	0.022
180	0.004	0.006	0.008	0.010	0.012	0.014	0.015	0.017	0.019	0.020	0.021	0.023
200	0.004	0.007	0.009	0.011	0.013	0.014	0.016	0.018	0.019	0.021	0.022	0.024
220	0.004	0.007	0.009	0.011	0.013	0.015	0.017	0.018	0.020	0.021	0.023	0.024
240	0.004	0.007	0.009	0.011	0.013	0.015	0.017	0.019	0.020	0.022	0.024	0.025

CBD measured in lb/ft^3.

Table 11. CBD as a function of BA and SD for pure Douglas-fir stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.008	0.009	0.009	0.010	0.011
40	0.003	0.005	0.006	0.007	0.009	0.010	0.010	0.011	0.012	0.013	0.014	0.015
60	0.004	0.006	0.008	0.009	0.010	0.012	0.013	0.014	0.015	0.016	0.017	0.018
80	0.004	0.007	0.009	0.010	0.012	0.013	0.015	0.016	0.017	0.018	0.019	0.020
100	0.005	0.007	0.010	0.011	0.013	0.015	0.016	0.018	0.019	0.020	0.022	0.023
120	0.005	0.008	0.010	0.013	0.014	0.016	0.018	0.019	0.021	0.022	0.024	0.025
140	0.006	0.009	0.011	0.013	0.015	0.017	0.019	0.021	0.022	0.024	0.025	0.027
160	0.006	0.009	0.012	0.014	0.017	0.019	0.020	0.022	0.024	0.025	0.027	0.029
180	0.006	0.010	0.013	0.015	0.017	0.020	0.022	0.023	0.025	0.027	0.029	0.030
200	0.007	0.010	0.013	0.016	0.018	0.021	0.023	0.025	0.027	0.028	0.030	0.032
220	0.007	0.011	0.014	0.017	0.019	0.022	0.024	0.026	0.028	0.030	0.031	0.033
240	0.007	0.011	0.015	0.017	0.020	0.022	0.025	0.027	0.029	0.031	0.033	0.035

CBD measured in lb/ft^3.

Table 12. CBD as a function of BA and SD for mixed conifer stands.

	SD (trees/ac)											
BA (ft^2/ac)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000
20	0.002	0.004	0.005	0.007	0.008	0.010	0.011	0.012	0.014	0.015	0.016	0.018
40	0.003	0.005	0.007	0.009	0.010	0.012	0.014	0.016	0.017	0.019	0.020	0.022
60	0.003	0.005	0.008	0.010	0.012	0.014	0.016	0.018	0.020	0.021	0.023	0.025
80	0.003	0.006	0.008	0.011	0.013	0.015	0.017	0.019	0.021	0.023	0.025	0.027
100	0.003	0.006	0.009	0.011	0.014	0.016	0.019	0.021	0.023	0.025	0.027	0.029
120	0.004	0.007	0.010	0.012	0.015	0.017	0.020	0.022	0.024	0.027	0.029	0.031
140	0.004	0.007	0.010	0.013	0.015	0.018	0.021	0.023	0.026	0.028	0.030	0.033
160	0.004	0.007	0.010	0.013	0.016	0.019	0.022	0.024	0.027	0.029	0.032	0.034
180	0.004	0.008	0.011	0.014	0.017	0.020	0.022	0.025	0.028	0.030	0.033	0.036
200	0.004	0.008	0.011	0.014	0.017	0.020	0.023	0.026	0.029	0.031	0.034	0.037
220	0.004	0.008	0.012	0.015	0.018	0.021	0.024	0.027	0.030	0.032	0.035	0.038
240	0.005	0.008	0.012	0.015	0.018	0.021	0.025	0.028	0.030	0.033	0.036	0.039

CBD measured in lb/ft^3.

pine (*Pinus ponderosa* Dougl. ex Laws.), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). A mixed conifer type was also identified, which consisted of several forest cover types: Engelmann spruce (*Picea engelmannii* Parry ex Engelm), Engelmann spruce-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), white fir (*Abies concolor* Lindl. ex Hildebr.), and grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), western redcedar (*Thuja plicata* Donn ex D. Don), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), mountain hemlock (*Tsuga mertensiana* [Bong.] Carrière)-subalpine fir, and western larch (*Larix occidentalis* Nutt.)-Douglas-fir.

Cruz et al. (2003) defined CBH as the average height to the live crown base in a stand. They defined the CBD as the CFL divided by the canopy depth representing the SH minus the CBH. CFL represents the needle foliage weight per unit area and SH represents the average of all trees in the stand, in other words, not the dominant or top tree height (Cruz et al. 2010). All of these definitions are compatible with the canopy fuel characteristics used in Van Wagner's

Table 13. CBH as a function of BA and SH for pure ponderosa pine stands.

	SH (m)											
BA (m^2/ha)	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	18.0	19.5
5	1.6	2.1	2.7	3.3	3.9	4.5	5.1	5.7	6.3	6.9	7.5	8.0
10	1.8	2.4	3.0	3.6	4.2	4.8	5.3	5.9	6.5	7.1	7.7	8.3
15	2.0	2.6	3.2	3.8	4.4	5.0	5.6	6.2	6.8	7.4	7.9	8.5
20	2.3	2.9	3.5	4.1	4.7	5.2	5.8	6.4	7.0	7.6	8.2	8.8
25	2.5	3.1	3.7	4.3	4.9	5.5	6.1	6.7	7.3	7.8	8.4	9.0
30	2.8	3.4	4.0	4.6	5.1	5.7	6.3	6.9	7.5	8.1	8.7	9.3
35	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.7	8.3	8.9	9.5
40	3.3	3.9	4.5	5.0	5.6	6.2	6.8	7.4	8.0	8.6	9.2	9.8
45	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.6	8.2	8.8	9.4	10.0
50	3.8	4.4	4.9	5.5	6.1	6.7	7.3	7.9	8.5	9.1	9.7	10.2
55	4.0	4.6	5.2	5.8	6.4	7.0	7.5	8.1	8.7	9.3	9.9	10.5
60	4.3	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6	10.1	10.7

CBH measured in m.

Table 14. CBH as a function of BA and SH for pure lodgepole pine stands.

	SH (m)											
BA (m^2/ha)	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	18.0	19.5
5	0.6	1.5	2.4	3.3	4.3	5.2	6.1	7.0	7.9	8.9	9.8	10.7
10	0.8	1.7	2.6	3.6	4.5	5.4	6.3	7.2	8.2	9.1	10.0	10.9
15	1.0	1.9	2.8	3.8	4.7	5.6	6.5	7.4	8.4	9.3	10.2	11.1
20	1.2	2.1	3.1	4.0	4.9	5.8	6.7	7.7	8.6	9.5	10.4	11.3
25	1.4	2.4	3.3	4.2	5.1	6.0	7.0	7.9	8.8	9.7	10.6	11.6
30	1.7	2.6	3.5	4.4	5.3	6.3	7.2	8.1	9.0	9.9	10.8	11.8
35	1.9	2.8	3.7	4.6	5.5	6.5	7.4	8.3	9.2	10.1	11.1	12.0
40	2.1	3.0	3.9	4.8	5.8	6.7	7.6	8.5	9.4	10.4	11.3	12.2
45	2.3	3.2	4.1	5.1	6.0	6.9	7.8	8.7	9.7	10.6	11.5	12.4
50	2.5	3.4	4.4	5.3	6.2	7.1	8.0	9.0	9.9	10.8	11.7	12.6
55	2.7	3.6	4.6	5.5	6.4	7.3	8.2	9.2	10.1	11.0	11.9	12.8
60	2.9	3.9	4.8	5.7	6.6	7.5	8.5	9.4	10.3	11.2	12.1	13.1

CBH measured in m.

Table 15. CBH as a function of BA and SH for pure Douglas-fir stands.

	SH (m)											
BA (m^2/ha)	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	18.0	19.5
5	0.1	0.9	1.8	2.6	3.4	4.3	5.1	5.9	6.8	7.6	8.4	9.3
10	0.3	1.2	2.0	2.8	3.7	4.5	5.3	6.2	7.0	7.8	8.7	9.5
15	0.6	1.4	2.2	3.1	3.9	4.7	5.6	6.4	7.2	8.0	8.9	9.7
20	0.8	1.6	2.5	3.3	4.1	4.9	5.8	6.6	7.4	8.3	9.1	9.9
25	1.0	1.8	2.7	3.5	4.3	5.2	6.0	6.8	7.7	8.5	9.3	10.2
30	1.2	2.1	2.9	3.7	4.6	5.4	6.2	7.1	7.9	8.7	9.6	10.4
35	1.5	2.3	3.1	4.0	4.8	5.6	6.5	7.3	8.1	8.9	9.8	10.6
40	1.7	2.5	3.4	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	10.8
45	1.9	2.7	3.6	4.4	5.2	6.1	6.9	7.7	8.6	9.4	10.2	11.1
50	2.1	3.0	3.8	4.6	5.5	6.3	7.1	8.0	8.8	9.6	10.5	11.3
55	2.4	3.2	4.0	4.9	5.7	6.5	7.4	8.2	9.0	9.8	10.7	11.5
60	2.6	3.4	4.3	5.1	5.9	6.7	7.6	8.4	9.2	10.1	10.9	11.7

CBH measured in m.

(1977) semiempirical models for crown fire initiation and propagation (Cruz and Alexander 2010, 2012).

In contrast to the above definitions, others such as Keane et al. (2005), Scott and Reinhardt (2005), and Reinhardt et al. (2006) have defined CBD as the maximum 10-ft (3-m) running mean of a vertical canopy fuel profile and CBH as the lowest point in the profile where CBD is ≥0.000749 lb/ft^3 (0.012 kg/m^3). They have also considered the CFL as constituting the needle foliage plus the <0.12 in. (0.3 cm) diameter live and <0.24 in. (0.6 cm) diameter dead twig material. These definitions of CBH and CBD, as used in various fire behavior modeling systems such as FFE-FVS and Fuel Management Analyst Plus (FMAPlus) (Carlton 2005) are not compatible with Van Wagner's (1977) models (Cruz and Alexander 2010, 2012).

Cruz and Alexander (2012) subjected the canopy fuel regression equations to two different evaluations. The first involved a random selection of 10 stands each from the four data sets used in the original study by Cruz et al. (2003). These were subjected to two simulated "low thinning" regimes. A second evaluation, involving only the canopy fuel regression equations for ponderosa pine stands,

Table 16. CBH as a function of BA and SH for mixed conifer stands.

	SH (m)											
BA (m^2/ha)	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	18.0	19.5
5	0.4	1.3	2.1	3.0	3.9	4.7	5.6	6.5	7.3	8.2	9.1	9.9
10	0.5	1.4	2.3	3.1	4.0	4.9	5.7	6.6	7.5	8.3	9.2	10.1
15	0.7	1.5	2.4	3.3	4.1	5.0	5.9	6.7	7.6	8.5	9.3	10.2
20	0.8	1.7	2.5	3.4	4.3	5.1	6.0	6.9	7.7	8.6	9.5	10.3
25	0.9	1.8	2.7	3.5	4.4	5.3	6.1	7.0	7.9	8.7	9.6	10.5
30	1.1	1.9	2.8	3.7	4.5	5.4	6.3	7.1	8.0	8.9	9.7	10.6
35	1.2	2.0	2.9	3.8	4.6	5.5	6.4	7.2	8.1	9.0	9.9	10.7
40	1.3	2.2	3.0	3.9	4.8	5.6	6.5	7.4	8.2	9.1	10.0	10.8
45	1.4	2.3	3.2	4.0	4.9	5.8	6.6	7.5	8.4	9.2	10.1	11.0
50	1.6	2.4	3.3	4.2	5.0	5.9	6.8	7.6	8.5	9.4	10.2	11.1
55	1.7	2.6	3.4	4.3	5.2	6.0	6.9	7.8	8.6	9.5	10.4	11.2
60	1.8	2.7	3.6	4.4	5.3	6.2	7.0	7.9	8.8	9.6	10.5	11.4

CBH measured in m.

Table 17. CFL as a function of BA and SD for pure ponderosa pine stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.22	0.23	0.24	0.24	0.25	0.25	0.26	0.26	0.26	0.26	0.27	0.27
10	0.40	0.42	0.43	0.44	0.45	0.46	0.46	0.47	0.48	0.48	0.49	0.49
15	0.57	0.59	0.61	0.63	0.64	0.65	0.66	0.67	0.68	0.68	0.69	0.70
20	0.73	0.76	0.78	0.80	0.82	0.83	0.85	0.86	0.87	0.88	0.88	0.89
25	0.88	0.92	0.95	0.97	0.99	1.01	1.03	1.04	1.05	1.06	1.07	1.08
30	1.03	1.08	1.11	1.14	1.16	1.18	1.20	1.22	1.23	1.24	1.26	1.27
35	1.18	1.23	1.27	1.30	1.33	1.35	1.37	1.39	1.41	1.42	1.43	1.45
40	1.32	1.38	1.43	1.46	1.49	1.52	1.54	1.56	1.58	1.59	1.61	1.62
45	1.46	1.53	1.58	1.62	1.65	1.68	1.70	1.73	1.75	1.76	1.78	1.80
50	1.60	1.68	1.73	1.77	1.81	1.84	1.87	1.89	1.91	1.93	1.95	1.97
55	1.74	1.82	1.88	1.92	1.96	2.00	2.03	2.05	2.08	2.10	2.12	2.14
60	1.88	1.96	2.02	2.07	2.12	2.15	2.18	2.21	2.24	2.26	2.28	2.30

CFL measured in kg/m^2.

Table 18. CFL as a function of BA and SD for pure lodgepole pine stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.17	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.21	0.21	0.21	0.21
10	0.31	0.33	0.34	0.35	0.36	0.37	0.37	0.38	0.39	0.39	0.39	0.40
15	0.45	0.48	0.49	0.51	0.52	0.53	0.54	0.55	0.56	0.56	0.57	0.58
20	0.59	0.62	0.64	0.66	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.75
25	0.72	0.76	0.79	0.81	0.83	0.85	0.86	0.88	0.89	0.90	0.91	0.92
30	0.85	0.90	0.93	0.96	0.98	1.00	1.02	1.03	1.05	1.06	1.07	1.08
35	0.98	1.03	1.07	1.10	1.13	1.15	1.17	1.19	1.21	1.22	1.23	1.25
40	1.10	1.16	1.21	1.24	1.27	1.30	1.32	1.34	1.36	1.38	1.39	1.41
45	1.23	1.30	1.34	1.38	1.42	1.45	1.47	1.49	1.51	1.53	1.55	1.57
50	1.35	1.43	1.48	1.52	1.56	1.59	1.62	1.64	1.67	1.69	1.71	1.72
55	1.47	1.55	1.61	1.66	1.70	1.74	1.77	1.79	1.82	1.84	1.86	1.88
60	1.60	1.68	1.75	1.80	1.84	1.88	1.91	1.94	1.97	1.99	2.02	2.04

CFL measured in kg/m^2.

relied on an independent data set of 16 stands in the Black Hills of South Dakota based on the work of Keyser and Smith (2010). Mean absolute errors for the CBH, CFL, and CBD were <20%. Reinhardt et al. (2006), in their analysis of various CFL estimation methods, also found the Cruz et al. (2003) models to have the lowest mean absolute error of the methods tested.

The results of the evaluations undertaken by Cruz and Alexander (2012) clearly showed that the stand-level models developed by Cruz et al. (2003) are, considering their simplicity, quite robust. This should increase user confidence in the value of the canopy fuel characteristics tables presented here as well as the software application that is also available for making calculations (Alexander and Cruz 2010, Cruz and Alexander 2013). Nevertheless, caution should be used in application of the CFL and CBD models to highly overstocked stands. The allometric equations used reflect mean relationships that might not hold for situations in which the growing space has been restricted by excessive competition (Cruz et al. 2003, Keyser and Smith 2010). It is expected that in these situations the use of the models can result in overestimates of CFL and CBD.

Table 19. CFL as a function of BA and SD for pure Douglas-fir stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.21	0.23	0.24	0.25	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.30
10	0.38	0.41	0.43	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53
15	0.53	0.57	0.60	0.62	0.64	0.66	0.68	0.69	0.70	0.71	0.73	0.74
20	0.67	0.72	0.76	0.79	0.81	0.84	0.86	0.87	0.89	0.91	0.92	0.93
25	0.81	0.87	0.91	0.95	0.98	1.01	1.03	1.05	1.07	1.09	1.11	1.12
30	0.94	1.01	1.06	1.10	1.14	1.17	1.20	1.22	1.25	1.27	1.29	1.30
35	1.07	1.15	1.21	1.25	1.29	1.33	1.36	1.39	1.41	1.44	1.46	1.48
40	1.19	1.28	1.35	1.40	1.44	1.48	1.52	1.55	1.58	1.61	1.63	1.65
45	1.31	1.41	1.48	1.54	1.59	1.64	1.67	1.71	1.74	1.77	1.80	1.82
50	1.43	1.54	1.62	1.68	1.74	1.78	1.83	1.86	1.90	1.93	1.96	1.99
55	1.55	1.66	1.75	1.82	1.88	1.93	1.98	2.02	2.05	2.09	2.12	2.15
60	1.67	1.79	1.88	1.96	2.02	2.07	2.12	2.17	2.21	2.25	2.28	2.31

CFL measured in kg/m^2.

Table 20. CFL as a function of BA and SD for mixed conifer stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.23	0.27	0.29	0.31	0.33	0.35	0.37	0.38	0.40	0.41	0.42	0.43
10	0.41	0.46	0.51	0.55	0.58	0.62	0.64	0.67	0.69	0.71	0.74	0.76
15	0.56	0.64	0.71	0.76	0.81	0.85	0.89	0.93	0.96	0.99	1.02	1.05
20	0.71	0.81	0.89	0.96	1.02	1.07	1.12	1.17	1.21	1.25	1.28	1.32
25	0.85	0.97	1.07	1.15	1.22	1.28	1.34	1.40	1.45	1.49	1.54	1.58
30	0.98	1.12	1.23	1.33	1.41	1.49	1.56	1.62	1.68	1.73	1.78	1.83
35	1.11	1.27	1.40	1.51	1.60	1.68	1.76	1.83	1.90	1.96	2.02	2.07
40	1.24	1.41	1.56	1.68	1.78	1.87	1.96	2.04	2.11	2.18	2.24	2.30
45	1.36	1.55	1.71	1.84	1.96	2.06	2.15	2.24	2.32	2.40	2.47	2.53
50	1.48	1.69	1.86	2.01	2.13	2.24	2.35	2.44	2.53	2.61	2.68	2.76
55	1.60	1.83	2.01	2.17	2.30	2.42	2.53	2.63	2.73	2.82	2.90	2.98
60	1.71	1.96	2.16	2.32	2.47	2.60	2.72	2.82	2.92	3.02	3.11	3.19

CFL measured in kg/m^2.

Table 21. CBD as a function of BA and SD for pure ponderosa pine stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.10	0.12	0.14	0.16	0.18	0.20	0.21	0.23	0.24	0.26	0.27	0.28
10	0.13	0.16	0.19	0.22	0.24	0.27	0.29	0.31	0.33	0.35	0.36	0.38
15	0.15	0.19	0.23	0.26	0.29	0.32	0.34	0.37	0.39	0.41	0.43	0.45
20	0.17	0.22	0.26	0.30	0.33	0.36	0.39	0.42	0.44	0.47	0.49	0.51
25	0.19	0.24	0.29	0.33	0.36	0.40	0.43	0.46	0.49	0.52	0.54	0.57
30	0.21	0.26	0.31	0.35	0.39	0.43	0.46	0.50	0.53	0.56	0.59	0.61
35	0.22	0.28	0.33	0.38	0.42	0.46	0.50	0.53	0.56	0.60	0.63	0.66
40	0.24	0.30	0.35	0.40	0.44	0.49	0.53	0.56	0.60	0.63	0.66	0.70
45	0.25	0.31	0.37	0.42	0.47	0.51	0.55	0.59	0.63	0.67	0.70	0.73
50	0.26	0.33	0.39	0.44	0.49	0.54	0.58	0.62	0.66	0.70	0.73	0.77
55	0.27	0.34	0.40	0.46	0.51	0.56	0.60	0.65	0.69	0.73	0.76	0.80
60	0.28	0.36	0.42	0.48	0.53	0.58	0.63	0.67	0.71	0.75	0.79	0.83

CBD measured in kg/m^3.

Methods

The canopy fuel tables were constructed in a manner reminiscent of that for stand volume tables commonly used in the field of forest mensuration (e.g., Shepperd and Mowrer 1984). The range in tree and stand structure variables used in the tables was designed to match as closely as possible the range in the sample data used in the development of the regression equations across all four of the forest cover types. Both English and metric unit versions of the canopy fuel characteristics tables were prepared for CBH (ft and m), CFL (lb/ft^2 and kg/m^2), and CBD (lb/ft^3 and kg/m^3).[2] The increment range used for the three stand variables (i.e., 5 ft or 1.5 m for CBH, 20 ft^2/ac or 5 m^2/ha for stand BA, and 500 trees/ac or 250 trees/ha for SD) was a compromise in simplicity and sensitivity. For the most part, the outputs are given to at least two significant digits.

Results and Discussion

The resulting tabulations for estimating CBH from BA and SH and CFL and CBD from stand BA and SD for the four conifer forest types are presented in Tables 1 through 24. Table 25 presents a table finding key.

Table 22. CBD as a function of BA and SD for pure lodgepole pine stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.16	0.18	0.19	0.20	0.21
10	0.07	0.10	0.12	0.14	0.16	0.18	0.19	0.21	0.23	0.24	0.26	0.27
15	0.08	0.11	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.31
20	0.09	0.12	0.15	0.18	0.20	0.22	0.25	0.27	0.29	0.31	0.33	0.35
25	0.10	0.13	0.16	0.19	0.22	0.24	0.27	0.29	0.31	0.33	0.35	0.38
30	0.11	0.14	0.17	0.20	0.23	0.26	0.28	0.31	0.33	0.36	0.38	0.40
35	0.11	0.15	0.18	0.21	0.24	0.27	0.30	0.33	0.35	0.38	0.40	0.42
40	0.12	0.16	0.19	0.22	0.26	0.28	0.31	0.34	0.37	0.39	0.42	0.44
45	0.12	0.16	0.20	0.23	0.27	0.30	0.33	0.36	0.38	0.41	0.44	0.46
50	0.13	0.17	0.21	0.24	0.28	0.31	0.34	0.37	0.40	0.42	0.45	0.48
55	0.13	0.17	0.21	0.25	0.29	0.32	0.35	0.38	0.41	0.44	0.47	0.49
60	0.13	0.18	0.22	0.26	0.29	0.33	0.36	0.39	0.42	0.45	0.48	0.51

CBD measured in kg/m^3.

Table 23. CBD as a function of BA and SD for pure Douglas-fir stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.07	0.08	0.10	0.12	0.13	0.14	0.16	0.17	0.18	0.19	0.20	0.21
10	0.09	0.12	0.14	0.16	0.18	0.20	0.22	0.23	0.25	0.27	0.28	0.29
15	0.11	0.14	0.17	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36
20	0.13	0.16	0.20	0.23	0.25	0.28	0.30	0.33	0.35	0.37	0.39	0.41
25	0.14	0.18	0.22	0.25	0.28	0.31	0.34	0.36	0.39	0.41	0.43	0.46
30	0.15	0.20	0.24	0.27	0.31	0.34	0.37	0.40	0.42	0.45	0.47	0.50
35	0.17	0.21	0.26	0.30	0.33	0.36	0.40	0.43	0.46	0.48	0.51	0.54
40	0.18	0.23	0.27	0.31	0.35	0.39	0.42	0.45	0.49	0.52	0.54	0.57
45	0.19	0.24	0.29	0.33	0.37	0.41	0.45	0.48	0.51	0.54	0.58	0.60
50	0.20	0.25	0.30	0.35	0.39	0.43	0.47	0.51	0.54	0.57	0.61	0.64
55	0.21	0.27	0.32	0.37	0.41	0.45	0.49	0.53	0.57	0.60	0.63	0.67
60	0.22	0.28	0.33	0.38	0.43	0.47	0.51	0.55	0.59	0.63	0.66	0.69

CBD measured in kg/m^3.

Table 24. CBD as a function of BA and SD for mixed conifer stands.

	SD (trees/ha)											
BA (m^2/ha)	500	750	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750	3,000	3,250
5	0.07	0.11	0.14	0.16	0.19	0.22	0.25	0.27	0.30	0.32	0.35	0.37
10	0.09	0.13	0.17	0.20	0.24	0.27	0.31	0.34	0.37	0.40	0.43	0.47
15	0.11	0.15	0.19	0.23	0.27	0.31	0.35	0.39	0.42	0.46	0.49	0.53
20	0.12	0.16	0.21	0.26	0.30	0.34	0.38	0.42	0.46	0.50	0.54	0.58
25	0.12	0.18	0.23	0.27	0.32	0.37	0.41	0.45	0.50	0.54	0.58	0.62
30	0.13	0.19	0.24	0.29	0.34	0.39	0.44	0.48	0.53	0.57	0.62	0.66
35	0.14	0.20	0.25	0.31	0.36	0.41	0.46	0.51	0.55	0.60	0.65	0.69
40	0.15	0.21	0.26	0.32	0.37	0.43	0.48	0.53	0.58	0.63	0.68	0.72
45	0.15	0.21	0.27	0.33	0.39	0.44	0.50	0.55	0.60	0.65	0.70	0.75
50	0.16	0.22	0.28	0.34	0.40	0.46	0.51	0.57	0.62	0.67	0.73	0.78
55	0.16	0.23	0.29	0.35	0.41	0.47	0.53	0.58	0.64	0.69	0.75	0.80
60	0.17	0.23	0.30	0.36	0.42	0.48	0.54	0.60	0.66	0.71	0.77	0.82

CBD measured in kg/m^3.

Table 25. Table finding key.

	English/metric table number		
Conifer forest stand type	CBH	CFL	CBD
Ponderosa pine	1/13	5/17	9/21
Lodgepole pine	2/14	6/18	10/22
Douglas-fir	3/15	7/19	11/23
Mixed conifer	4/16	8/20	12/24

The numerical values for the stand variables needed in Tables 1–24, namely SH, stand BA, and SD, can be acquired in one of two ways. For persons who have developed the innate ability to make reliable judgments of these input values, a visual estimate may suffice. When detailed information on canopy fuel characteristics is desired, then tree measurements at a given point(s) in the stand of interest will necessarily be required. The SH, stand BA, and SD can be determined with a minimal amount of relatively inexpensive equipment and effort, i.e., a wedge prism to determine the stand BA,

a steel diameter tape to determine a reference average dbh for trees in the stand, which together with the stand BA allows for computation of SD, and finally a clinometer and a 30-m length steel tape for determining SH (Avery 1967). Users may elect to visually estimate or measure CBH directly in the field.

The tables presented here are limited to the four forest cover types as described earlier. Undoubtedly, some judgment maybe required in determining which table applies based on the species dominance or, for example, how to handle a mixed ponderosa pine/Douglas-fir stand. The same applies to judging what the average reference dbh and SH are. Mental interpolation of canopy fuel values between columns and rows in a table will invariably be required.

The estimated values derived from the canopy fuel characteristic tables based on "spot checks" of stand structure conditions can be used in a number of fire and fuel management applications, e.g., as direct inputs into line 8 of Rothermel's (1991) Crown Fire Worksheet and in various fire behavior modeling systems such as BehavePlus (Andrews et al. 2008, 2011), the Crown Fire Initiation and Spread (CFIS) system (Alexander et al. 2006), and NEXUS (Scott and Reinhardt 2001) and in fire planning and/or in the near-real time prediction of free-burning wildland fire behavior. Thus, both fire behavior analysts and fire behavior field observers involved in monitoring wildfire and prescribed fire use incidents, will find the tables valuable in their work. The tables could also be used in post-fire situations to estimate CBH after stand-replacing crown fires, where this would be difficult if not impossible to do otherwise (Alexander 1998, Cram et al. 2006).

Concluding Remarks

Given that, except for CBH, direct nondestructive measurements of CFL and CBD are not possible, a quick, reliable, and simple method of making estimates of these two canopy fuel characteristics from simple stand variables would be of great value in wildland fire and fuel management (Powell 2010). The tables presented in this article are seen as addressing a critical need of silviculturalists and fuels management specialists (D.C. Powell, USDA Forest Service, Umatilla National Forest, Pendleton, OR, pers. comm., May 3, 2013). The concepts presented in this article may undoubtedly be applicable to other forest cover types for which regression equations similar to those of Cruz et al. (2003) exist for estimating canopy fuel characteristics from stand variables (e.g., Fernández-Alonso et al. 2013).

Endnotes

1. For more information, please visit the LANDFIRE wildland fuel mapping project at www.landfire.gov.
2. The approximate conversion factors are as follows: meter (m) = 3.3 feet; square meter per hectare (m^2/ha) = 4.4 square feet per acre (ft^2/ac); trees per hectare (trees/ha) = 2.5 tree per acre (trees/ac); kilogram per square meter (kg/m^2) = 0.2 pound per square foot (lb/ft^2); and kilogram per cubic meter (kg/m^3) = 0.6 pounds per cubic foot (lb/ft^3). Note also that 1.0 kg/m^2 = 10 tonnes/ha and in turn 1.0 lb/ft^2 = 21.78 tons/ac.

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