ESTIMATING BIOMASS YIELD FOR SUB-MERCHANTABLE PONDEROSA PINE OF NORTHCENTRAL COLORADO

*Kurt H. Mackes**†

Assistant Professor

Debra A. Lozinski

Research Assistant
Department of Forest, Rangeland, and Watershed Stewardship
Colorado State University
Fort Collins, CO 80523-1472

(Received April 2006)

Abstract. Volume, mass, and moisture content data were collected for 28 sub-merchantable ponderosa pine trees harvested in northcentral Colorado. The average green bulk density of these trees was 280 kg/m^3. The average oven-dry bulk density was 169 kg/m^3. Average green moisture content (oven-dry mass basis) was 91%. A multiple regression analysis was conducted using diameter at breast height (DBH), tree height, and crown vigor class to identify which of these variables could be used to predict biomass yield (oven-dry tree mass). Based on an analysis of variance at $\alpha = 0.05$ level-of-significance, only DBH was a significant predictor of oven-dry tree mass. Therefore, oven-dry mass estimates were calculated based on a regression line fitted to ln(oven-dry mass) vs ln(DBH) data. The R-square value for the regression line was 0.897. Although differences between actual and predicted oven-dry tree mass ranged up to 57.8%, the average difference was 2.9%.

Keywords: Biomass yield, ponderosa pine, sub-merchantable.

INTRODUCTION

Western ponderosa pine (*Pinus ponderosa*) forests are typically comprised of dense, overstocked stands of smaller diameter trees. In Colorado thinning projects evaluated by Lynch and Mackes (2003) revealed that up to 90% of trees removed to improve ecological conditions or to reduce fire risks were less than 30.5-cm diameter at breast height (DBH). A majority of trees removed were usually sub-merchantable with a DBH of less than 10.2 cm and generally were not utilized.

Lynch and Mackes (2002) identified uses for small diameter ponderosa pine timber, including mine props, firewood, post and poles, rough sawn lumber and timber; oriented strandboard (OSB), and renewable energy. A consistent and sufficient low-cost wood supply continues to be a barrier to developing infrastructure for processing small diameter trees into products. Precise estimates of biomass that could potentially be generated from forest management activities are an important step in determining wood availability and ultimately in developing wood processing infrastructure.

Equations for predicting biomass yield (oven-dry tree mass) were developed by Gholz et al (1979) for tree species, including ponderosa pine, found in the Pacific Northwest. Biomass-yield equations for ponderosa pine were based on 9 sample trees between 15.5 and 79.5 cm DBH taken from the Fort Valley Experimental Forest near Flagstaff, AZ. Since the smallest tree selected had a DBH of 15.5 cm, estimating biomass yields for trees with a smaller DBH requires extrapolating outside the range of data collected. In this research, biomass yield data were collected for ponderosa pine trees that had a DBH <12.7 cm. The principal objective was to generate a regression equation for predicting

* Corresponding author: kmackes@warnercnr.colostate.edu
† SWST member

oven-dry biomass yield for sub-merchantable ponderosa pine based on the data collected. The prediction equation was also compared with other prediction equations in the literature.

METHODOLOGY

The ponderosa pine trees used in this study were harvested from the Ben Delatour Scout Ranch (BDSR) located northwest of Fort Collins near Red Feather Lakes in northcentral Colorado. A total of 28 trees that ranged 2.7–12.7 cm DBH were selected. Harvested trees came from both suppressed and more open-grown stands. These trees were harvested during the month of May, and were taken from locations within the boundary of the 1400-ha ranch. The trees harvested generally exhibited typical form for trees growing in the area.

DBH, height, and crown vigor class of each selected tree were measured prior to felling. Tree height was measured from the base of the main stem flush with the ground line to the treetop, with an average stump height < 5 cm. Crown vigor class was assigned for each tree based on crown length, crown area, and overall crown vigor using a classification system delineated by Lynch (2005). Using this system, trees were assigned a crown vigor designation, A, B, C, or D, with class A being the most vigorous and class D the least. Trees from each crown vigor class were selected at random from several sites at BDSR. Selected trees were also flagged and numbered for future identification. Of the 28 trees selected, 4 were identified as vigor class A, 6 were B, 9 were C, and 9 were D.

Selected ponderosa pine trees were felled manually using a chainsaw. Each tree was then im-

TABLE 1. *Green biomass mass and volumes for sub-merchantable ponderosa pine trees from northcentral Colorado.*

DBH (cm)	Height (m)	Crown vigor*	Total green mass (kg)	Total green volume (m^3)	Green bulk density (kg/m^3)	Moisture content (%)
2.8	2.23	B	4.08	0.016	254	76
3.3	2.29	B	7.17	0.024	293	113
3.6	2.41	C	5.26	0.022	237	71
4.1	2.62	A	9.98	0.039	256	108
4.3	3.47	C	7.44	0.032	232	66
4.6	2.59	B	10.89	0.041	264	104
4.6	3.11	D	5.17	0.021	242	46
5.1	2.68	D	7.98	0.036	222	49
5.6	2.68	A	14.70	0.052	283	100
6.1	3.08	C	12.61	0.037	337	123
6.6	5.58	D	12.61	0.051	246	57
7.1	3.26	B	19.50	0.061	319	116
7.1	4.79	D	14.97	0.050	301	76
7.1	3.75	C	15.33	0.047	329	142
7.6	4.63	D	18.33	0.082	224	81
7.6	3.51	B	21.50	0.070	306	94
7.9	4.72	D	11.70	0.050	232	52
8.1	3.35	D	19.23	0.073	262	66
8.4	3.96	D	23.13	0.083	280	74
8.4	4.11	C	37.19	0.119	314	96
9.1	3.05	A	56.70	0.234	242	97
9.1	5.33	C	31.03	0.107	290	64
9.9	5.21	C	32.02	0.104	308	83
9.9	7.59	C	33.47	0.112	298	98
10.4	4.75	A	38.83	0.113	343	136
10.9	4.91	B	45.27	0.157	289	128
11.9	9.42	D	64.41	0.193	334	104
12.7	7.41	C	65.86	0.208	317	129
Mean					280	91

* Crown vigor used tree vigor classes described by Lynch (2005)

mediately measured in the green condition using a digital lithium scale, with 22-g precision and then run through a chipper. Chipped material for each individual tree, including bole, bark, branch wood, and needles, was collected in a bin and bagged separately. Bags were labeled with the appropriate tree number for identification and tracking.

Bags of green biomass were transported to the Fire Science Laboratory at Colorado State University, where contents from each bag were packed into separate metal pans. Bag contents were not compacted beyond that which occurred during the collection and transportation process. Because the same process was used repeatedly, it was assumed that all the green biomass collected had attained the same level of compaction. Although some disparity in the level of compaction probably occurred, considerable differences in the percentage of needles, stem wood, and bark comprising the biomass likely contributed more significantly to bulk density variation.

The green biomass in each pan was measured using an electronic scale with 2.2 g precision and the volume determined. Each pan of green biomass was then placed in an oven at 103°C to dry. After drying 24 h, the pans of biomass were periodically measured until there was no additional moisture loss and the material was completely dry. A final mass measurement was then taken and the volume of the oven-dry biomass was also remeasured. Average green moisture content (oven-dry mass basis) was calculated for each tree. Biomass yield data were analyzed using the regression analysis option in SPSS (Version 15.0 for Windows).

TABLE 2. *Oven-dry biomass mass and volumes for sub-merchantable ponderosa pine trees from northcentral Colorado.*

DBH (cm)	Height (m)	Crown vigor*	Total oven-dry mass (kg)	Total oven-dry volume (m^3)	Oven-dry bulk density (kg/m^3)
2.8	2.23	B	2.31	0.015	159
3.3	2.29	B	3.36	0.021	157
3.6	2.41	C	3.08	0.018	168
4.1	2.62	A	4.81	0.029	165
4.3	3.47	C	4.49	0.026	173
4.6	2.59	B	5.35	0.034	156
4.6	3.11	D	3.54	0.021	171
5.1	2.68	D	5.35	0.034	156
5.6	2.68	A	7.35	0.046	160
6.1	3.08	C	5.67	0.033	172
6.6	5.58	D	8.03	0.050	159
7.1	3.26	B	9.03	0.056	162
7.1	4.79	D	8.53	0.044	196
7.1	3.75	C	6.35	0.036	177
7.6	4.63	D	10.16	0.066	155
7.6	3.51	B	11.11	0.063	175
7.9	4.72	D	7.71	0.042	183
8.1	3.35	D	11.57	0.063	184
8.4	3.96	D	13.34	0.078	171
8.4	4.11	C	19.01	0.106	180
9.1	3.05	A	28.76	0.177	163
9.1	5.33	C	18.91	0.101	187
9.9	5.21	C	17.46	0.096	183
9.9	7.59	C	16.92	0.102	166
10.4	4.75	A	16.47	0.106	155
10.9	4.91	B	19.87	0.129	154
11.9	9.42	D	31.62	0.174	182
12.7	7.41	C	28.76	0.182	158
Mean					169

* Crown vigor used tree vigor classes described by Lynch (2005)

RESULTS AND DISCUSSION

Green mass and volumes for 28 small diameter ponderosa pine trees ranging 2.8–12.7 cm DBH are presented in Table 1. Green tree mass varied 4.08–65.86 kg, and the mean bulk density of chips was 280 kg/m^3 or 3.57 m^3 of green chipped biomass per tonne. The mean green moisture content was 91%. Oven-dry mass and volume for the same trees are presented in Table 2. Oven-dry tree mass varied 2.31–31.62 kg. The bulk density of oven-dry ponderosa pine biomass averaged 169 kg/m^3 or 5.92 m^3 of oven-dry biomass per tonne.

Oven-dry data were analyzed using multiple regression analysis, where the dependent variable was oven-dry tree mass, and the independent variables were tree DBH, height, and crown vigor class. A regression line was fitted to tree data, and an analysis of variance (ANOVA) table was generated. Based on the ANOVA, tree height and crown vigor class were not significant predictors of oven-dry tree mass at the $\alpha = 0.05$ level of significance. DBH was significant at the $\alpha = 0.05$ level. A plot of ln(oven-dry tree mass) vs ln(DBH) is shown in Fig 1. The regression line fitted to the data takes the form:

$$\ln(\text{oven-dry tree mass}) = -1.046 + 1.708 \times \ln(\text{DBH}) \tag{1}$$

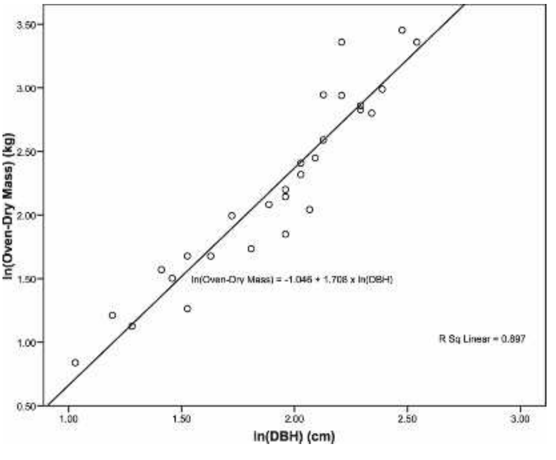

FIGURE 1. Plot of the natural log of oven-dry mass vs the natural log of diameter at breast height (DBH) for sub-merchantable ponderosa pine trees.

Oven-dry tree mass was measured in kg and DBH in cm. The adjusted R-squared value for this regression line was 0.897.

Oven-dry mass estimates were generated using Eq (1) and compared with actual tree data collected. These are presented in Table 3 along with estimates that were generated using equations derived by Gholz et al (1979). Differences between actual and oven-dry mass estimated using Eq (1) range up to 57.8%, averaging 2.9%, which indicates that on average the equation slightly over-estimates oven-dry tree mass.

Similar comparisons with oven-dry mass estimated using Gholz et al equations reveal that they differed from actual oven-dry mass by as much as 63.2%, averaging 33.0% less. Comparisons clearly show that differences for mass estimates derived using the Gholz et al equations increased as stem size decreased, which emphasizes the errors that can occur when extrapolating outside the data range. To further illustrate this point, Table 4 gives estimates of oven-dry mass for ponderosa pine trees with DBH of 5.1 and 10.2 cm, comparing oven-dry tree mass estimated using Eq (1), Gholz et al equations, and mass values converted from weights reported by Van Hooser and Chojnacky (1983). Mass estimates derived using Gholz et al equations are 14.0% less at 10.2-cm DBH and 44.1% less at a DBH of 5.1 cm, than estimates generated with Eq (1). Oven-dry mass estimates based oven-dry tree weights reported by Van Hooser and Chojnacky are more comparable to Eq (1) estimates, being 1.5% less for a 10.2-cm DBH tree and 19.6% less for a 5.1-cm DBH tree.

It is not known whether regional differences in ponderosa pine tree form contributed to oven-dry mass differences. However, crown vigor class and tree height were not significant predictors of oven-dry tree mass for sub-merchantable ponderosa pine trees evaluated in this study; therefore, findings would suggest that any differences in tree form should not have contributed significantly to differences.

TABLE 3. *Comparison of measured to estimated oven-dry mass for sub-merchantable ponderosa pine trees from north-central Colorado.*

DBH (cm)	Measured oven-dry mass (kg)	Oven-dry mass Mackes & Lozinski* (kg)	Difference from measured mass (%)	Oven-dry mass Gholz et al equations** (kg)	Difference from measured mass (%)
2.8	2.31	2.05	−11.3	0.87	−62.4
3.3	3.36	2.72	−18.9	1.23	−63.2
3.6	3.08	3.09	0.1	1.44	−53.2
4.1	4.81	3.87	−19.4	1.93	−59.9
4.3	4.49	4.30	−4.4	2.20	−51.0
4.6	5.35	4.73	−11.6	2.49	−53.4
4.6	3.54	4.73	33.8	2.49	−29.5
5.1	5.35	5.66	5.7	3.15	−41.1
5.6	7.35	6.65	−9.4	3.91	−46.8
6.1	5.67	7.71	36.0	4.77	−15.9
6.6	8.03	8.84	10.1	5.73	−28.6
7.1	9.03	10.02	11.0	6.80	−24.6
7.1	8.53	10.02	17.5	6.80	−20.2
7.1	6.35	10.02	57.8	6.80	7.1
7.6	10.16	11.27	10.9	7.99	−21.3
7.6	11.11	11.27	1.4	7.99	−28.1
7.9	7.71	11.91	54.5	8.63	11.9
8.1	11.57	12.57	8.7	9.30	−19.6
8.4	13.34	13.25	−0.7	10.00	−25.0
8.4	19.01	13.25	−30.3	10.00	−47.4
9.1	28.76	15.36	−46.6	12.30	−57.2
9.1	18.91	15.36	−18.8	12.30	−35.0
9.9	17.46	17.59	0.7	14.90	−14.7
9.9	16.92	17.59	4.0	14.90	−11.9
10.4	16.47	19.15	16.3	16.81	2.1
10.9	19.87	20.76	4.5	18.86	−5.0
11.9	31.62	24.15	−23.6	23.42	−25.9
12.7	28.76	26.82	−6.7	27.25	−5.2
Mean			2.9		−33.0

* Based on equation ln(Oven-Dry Mass) = −1.046 + 1.708 × ln(DBH) [Eq 1] .
** Based on research equations published by Gholz et al (1979).

TABLE 4. *Comparison of estimated oven-dry mass for sub-merchantable ponderosa pine trees.*

DBH (cm)	Oven-dry mass Mackes & Lozinski* (kg)	Oven-dry mass. Gholz et al equations** (kg)	Difference from Mackes & Lozinski* (%)	Oven-dry mass Van Hooser & Chojnacky*** (kg)	Difference from Mackes & Lozinski* (%)
5.1	5.64	3.15	−44.1	4.5	−19.6
10.2	18.43	15.84	−14.0	18.1	−1.5

* Based on equation, ln(dry mass) = −1.046 + 1.708 × ln(DBH) [Eq 1]
** Based on research equations published by Gholz et al (1979).
*** Weights reported for ponderosa pine by Van Hooser and Chojnacky converted to kg (1983)

CONCLUSIONS

In this study, DBH proved to be a significant predictor of oven-dry tree mass. Tree height and crown vigor class were not statistically significant. Biomass yield (oven-dry tree mass) estimates that were calculated based on a regression line fitted to ln(oven-dry mass) vs ln(DBH) data resulted in an average difference of 2.9% when compared with actual oven-dry mass measurements for sub-merchantable ponderosa pine trees. As DBH decreased from 10.2 cm, estimates based on prediction equations derived by Gholz et al (1979) were increasingly less precise, under-estimating oven-dry tree mass. Oven-dry mass estimates converted from oven-dry tree weights reported by Van Hooser and

Chojnacky (1983) were more comparable to findings in this study. Generally, the prediction equation derived as part of this research should be used to estimate the biomass yield for sub-merchantable ponderosa pine trees with a DBH < 10.2 cm because it is more accurate then other prediction equations in literature developed for merchantable size trees.

REFERENCES

GHOLZ HL, GRIER CC, CAMPBELL AG, BROWN AT (1979) Equations for estimating biomass and leaf area of plants in the Pacific Northwest. Oregon State Univ For Res Lab Res Paper 41.

LYNCH DL (2005) Foresters field handbook. Cooperative Extension, Colorado State University, Fort Collins, CO. 302 pp.

———, MACKES KH (2002) Opportunities for making wood products from small diameter trees in Colorado. USDA For Serv Rocky Mountain Research Station, Res Paper RMRS-RP-32.

———, ——— (2003) Cost for reducing fuels in Colorado forest restoration projects. Proc Fire, Fuel Treatments, and Ecological Restoration Conference. USDA For Serv Proc RMRS-P-29: 167–175.

VAN HOOSER DD, CHOJNACKY DC (1983) Whole tree volume estimates for the Rocky Mountain States. USDA For Serv Res Bull INT–29, Intermountain Forest and Range Experiment Station, Ogden, UT.