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# Biomass Estimators For Thinned Second-Growth Ponderosa Pine Trees

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## Abstract

Usable estimates of the mass of live foliage and limbs of sapling and pole-sized ponderosa pine in managed stands in central Oregon can be obtained with equations using the logarithm of diameter as the only independent variable. These equations produce only slightly higher root mean square deviations than equations that include additional independent variables. A better estimate of live foliage mass is produced when distance from breast height to live crown is added. A better estimate of live limb mass is produced with the addition of height. For other components investigated (bole wood volume, bole wood mass, bark volume and mass, and total aboveground mass) equations that include height, as well as diameter, greatly reduce the root mean square deviations, compared with equations based on diameter alone.

Keywords: Biomass, estimates, second-growth stands, ponderosa pine.

## Introduction

Intensive logging of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands in south central Oregon since the early 1900's has resulted in large acreages of second growth. Most of these stands are being managed on an even-aged basis with precommercial and commercial thinnings to control stocking levels. No equations for estimating biomass components of young ponderosa pine trees have previously been developed from data collected in central Oregon. We report some equations based on biomass data obtained by destructively sampling 23 ponderosa pine trees growing in precommercially thinned stands in central Oregon.

These equations allow managers to estimate biomass components for trees in similar stands that have been precommercially thinned. Researchers need these estimators to study nutrient cycling and productivity.

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## Methods

Two study sites were chosen to represent the range of tree sizes in most of the precommercially thinned, second-growth stands in central Oregon. The six largest trees in the 23-tree sample were selected from a stand 18 kilometers (km) south of Bend, Oregon. The stand originated from seed after clearcutting and had been precommercially thinned 14 years previously. Seventeen other trees were sampled in a second natural stand 40 km southwest of Bend. This stand had been thinned precommercially following overstory removal 18 years before sampling. Site index (Barrett 1978) was 33.5 meters (m) at both locations. Both stands are on soils developing from Mazama pumice and ash and are ashy over loamy, mixed Typic Cryorthents. Tree sizes were smaller at the second location because an overstory was present before thinning. Diameters of the 23 trees ranged from 5.3 to 38.7 centimeters (cm) and heights ranged from 3.11 to 20.63 m.

Healthy appearing trees with intermediate to dominant crowns were selected subjectively to represent the range of diameters, heights, and crown ratios in the two stands. Diameters (D) of selected trees were measured at breast height (bh) to the nearest 0.1 cm, and total heights (H), and crown lengths (C) were determined to the nearest 0.01 m after felling. Crown lengths were divided into thirds and referred to as upper, middle, and lower crown. All live needles including fascicles were separated from branches by crown position. Boles of 17 trees, which ranged from 5.3 to 29.5 cm dbh, were sectioned at 46-cm intervals. For six trees 32.3 to 38.7 cm dbh, disks were removed from the bole at 0.3, 1.37, and 3 m and then 3-m intervals up the stem. Inside and outside bark measurements were taken at each position of sectioning to determine total bole volume inside and outside bark. All needles, limbs, and either entire boles or disks from boles of the larger trees were taken to the laboratory.

For trees greater than 32-cm dbh, foliage and limbs were weighed fresh and then subsampled to determine dry weights. For trees less than 32-cm dbh, bark was stripped from the bole, and all needles, limbs, bole wood, and bole bark were dried and weighed. Bark was stripped from the disks of the six larger trees, dried, and weighed after thickness of the disk was determined at four points. Samples were taken from each disk to determine wood density. Volume of these green wood samples was determined by water displacement, and density was calculated by dividing the dry weight by the green volume. Density of the bole bark was calculated for the larger trees by dividing dry weight of the bark removed from each disk by the volume calculated from the disk thickness and the diameters inside and outside bark for that disk. Bark and wood densities were then applied to volume of bole wood and bark from corresponding segments of the trees greater than 32-cm dbh to estimate weight of bole wood and bark.

Needles were dried at 75 °C for at least 48 hours. Bark and wood were dried at 90 °C for at least 96 hours. Volume of the bole, both inside and outside bark, above the stump to the tip segment was determined using Smalian's formula. The stumps were considered cylinders with diameters at the 0.3-m height, and all tip segments were considered cone shaped.

Snell (1979) described total tree weights of tanoak, black oak, and Pacific madrone using equations of the form

$ln$ (total tree weight) $= a + b\ (ln\ D)$; where *ln* refers to the natural logarithm.

Gholz and others (1979) used an equation of this form to describe biomass components for several plants, including ponderosa pine. For nine ponderosa pine trees sampled in Arizona, ranging in size from 15.5 to 79.5 cm in diameter, they present the following estimates for mass in kilograms (kg):

*ln* (live foliage mass) = -4.2612 + 2.0967 (*ln D*);
*ln* (live limb mass) = -5.3855 + 2.7185 (*ln D*).

Taras and Clark (1977) related several biomass components, M, of longleaf pine, including limb and foliage mass, to diameter squared times total height ($D^2H$). Their equations were of the form $\log_{10} M = a + b \log_{10} (D^2H)$.

Various models were tested to determine the estimators with the minimum root mean square deviations. Logarithmic equations were used to reduce heterogeneity of variances and eliminate the need for weighted regressions, because estimates of proper weights for some of the biomass components are unknown. Models tested related some biomass components (*M*) and bole volumes (*V*) to diameter (*D*), height (*H*), live crown length (*C*), and distance to the start of the live crown above breast height (*K*). Because only 23 observations were available, no more than three independent variables were used in fitting equations to the data. Further, interactions of the independent variables were restricted to $D^2H$ and $D^2C$ in the equation-fitting process. *D* is in centimeters while *H, C,* and *K* are in meters. *K* is negative when the crown length extends below 1.37 m. Biomass components are in kilograms, volumes are in cubic meters ($m^3$), and natural logarithms are symbolized by *ln*.

In addition to these models, the bole wood volume (*V*) was also estimated using a model incorporating form factor (*F*);

$V = a\, F\, (D-T)^2\, H$, where *T* is double bark thickness and *a* is a constant. Equations developed by DeMars[1/] were used for *T* and *F*.

Mass of bole wood was also estimated by multiplying the volume in cubic meters, as determined with DeMars' equation, by the average wood density for all the trees.

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[1/]Personal communication with Donald DeMars, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

$\log_{10} T = -0.883813 + 1.39767 \log_{10} D - 0.291682 (\log_{10} D)^2$.

For trees over 20 feet in height,

$F = 0.712868 + 6.64002/H - 0.760078/D - 1.61467\, D/H + 1.69747\, D^2/H^2$.

For trees under 20 feet in height,

$F/W^2 = -1.00602 + 0.566024\, (D)\, (W) + 0.00177039\, (H/D)\, W - 0.0597387\, D^2W + 31.5012/H - 117.132/H^2 - 12.0570\, (D/H)W + 41.6193\, (D/H^2)\, W + 1.17642\, (D^2/H)W - 2.66157\, (D^2/H^2)\, W$;

where $W$ = (height in feet − 2.25)/(height in feet − 4.5).

*D* and *T* are in inches, *H* is in feet, *a* is equal to 0.005454154, and *V* is cubic feet ($ft^3$). *V* can be converted to cubic meters by multiplying by 0.028316846592 $m^3/ft^3$.

Multiple linear regression methods were used to determine the coefficients of each model for each volume and biomass component measured. Corrections for logarithmic bias (Baskerville 1972) were made by dividing residual mean squares by two and adding the result to the constant term of the equation. The root mean square deviation (RMSD), RMSD = $(\Sigma(\text{actual value} - \text{estimated value})^2/\text{number of estimates})^{0.5}$, was determined for each equation, with and without the correction for bias. The equation with the lowest RMSD for each volume or biomass component was judged the best estimator for that volume or biomass component.

## Results and Discussion

Live foliage mass for the sample trees ranged from 0.56 to 48.3 kg. For these trees, 22 percent of the total needle mass is in the upper third of the crown, 45 percent in the mid third, and 33 percent in the lower third. Mass of live limbs ranged from 0.8 to 146 kg. Eleven percent of the live limb mass is in the upper third of the crown, 41 percent in the mid third, and 48 percent in the lower third. Live crown ratios (live crown length divided by total tree height) ranged from 0.44 to 0.82 and averaged 0.7. Wood and bark densities for the 23 trees averaged 0.38 grams per cubic centimeter ($g/cm^3$) for wood and 0.29 $g/cm^3$ for bark, with standard deviations of 0.03 and 0.05 $g/cm^3$, respectively.

The estimate with the lowest RMSD for live foliage mass, $N$, is

$$ln\,N = -3.6362 + 1.93\,(ln\,D) + 0.2234\,(ln\,C) - 0.07329\,K. \quad (1)$$

Dropping live crown length, $C$, produces

$$ln\,N = -3.8984 + 2.1607\,(ln\,D) - 0.07394\,K. \quad (2)$$

Omitting distance between breast height and crown, $K$, and adding total height, $H$, results in

$$ln\,N = -3.0669 + 2.0218\,(ln\,D) + 0.73665\,(ln\,C) - 0.8652\,(ln\,H). \quad (3)$$

Regression with diameter alone yields

$$ln\,N = -3.5328 + 1.992\,(ln\,D). \quad (4)$$

The $R^2$, residual mean squares, and RMSD's, with and without Baskerville's (1972) correction, are:

| Equation | $R^2$ | Residual mean square | RMSD: Corrected | RMSD: Not corrected |
|---|---|---|---|---|
| | | | *kilograms* | *kilograms* |
| (1) | 0.9799 | 0.03475 | 3.01 | 3.09 |
| (2) | .9792 | .03412 | 3.27 | 3.35 |
| (3) | .9803 | .03403 | 3.33 | 4.00 |
| (4) | .9721 | .04362 | 4.11 | 4.07 |

Equation (4) demonstrates a close relationship between diameter at breast height and foliage mass, while the next most important variable is the distance between breast height and crown. This is a reflection of the high correlation between sapwood area at the base of the live crown and needle mass (Waring and others 1982). The equation fitted using only *ln D* and *ln H* as independent variables had nearly the same residual mean square and RMSD as equation (4).

The estimate of live limb mass, L, with the lowest RMSD is

$$ln\ L = -3.6363 + 1.2426\ (ln\ D) + 0.7659\ (ln\ H) + 0.5127\ (ln\ C). \quad (5)$$

Two other estimates are

$$ln\ L = -4.1068 + 1.5177\ (ln\ D) + 1.0424\ (ln\ H), \quad (6)$$

and

$$ln\ L = -4.5745 + 2.4645\ (ln\ D). \quad (7)$$

The $R^2$, residual mean squares, and RMSD's are:

| Equation | $R^2$ | Residual mean square | RMSD Corrected | RMSD Not corrected |
|---|---|---|---|---|
| | | | ---------- *kilograms* | ------------ |
| (5) | 0.9525 | 0.1297 | 14.06 | 14.88 |
| (6) | .9510 | .1273 | 14.84 | 15.42 |
| (7) | .9411 | .1454 | 16.10 | 17.27 |

The model using a form factor to determine bole volume had a lower RMSD, 0.021 $m^3$, than any of the logarithmic equations. Further, multiplication of the estimated bole volume, as determined with the form factor equation, by the overall average density of bole wood, 380 kg/$m^3$, produced estimates of bole mass with a lower RMSD, 6.67 kg, than produced with the logarithmic equations.

Estimators with the lowest RMSD for bole bark volume, *BV,* and bole bark mass, *BW*, are

$$ln\ BV = -10.3786 + 2.0879\ (ln\ D) + 0.3799\ (ln\ H) \quad (8)$$

and

$$ln\ BW = -3.6263 + 1.34077\ (ln\ D) + 0.8567\ (\ln H) \quad (9)$$

Residual mean squares are 0.0215 for the bole bark volume equation and 0.0256 for the bole bark mass equation. $R^2$ is 0.99 for both equations. RMSD, with and without Baskerville's correction, is 0.01 $m^3$ and 0.01 $m^3$ for the bole bark volume equation and 2.7 and 2.6 kg for the bole bark mass equation.

The estimator for total aboveground mass, excluding dead limbs and needles, *TW*, with the lowest RMSD is:

$$ln\ TW = -2.3371 + 1.5812\ (ln\ D) + 0.9036\ (ln\ H) \quad (10)$$

$R^2$ is 0.9949, the residual mean square is 0.0119, and the RMSD, with and without Baskerville's correction, is 25.3 and 25.7 kg. Addition of the other independent variables does not reduce the residual mean square or the RMSD.

## Conclusions

Usable estimates of the mass of live foliage and limbs can be obtained with equations using diameter alone. Including distance from breast height to the live crown, along with diameter, as an independent variable produces a better estimate. The addition of height as an independent variable, along with diameter, produces a better estimate for mass of live limbs. The best estimate is considered here as the estimate with the lowest root mean square deviation. Equations using a form factor provided the best estimate of volume and mass of bole wood. The best estimates of volume and mass of bark, as well as total mass aboveground, were obtained by equations using diameter and height. For all estimates except foliage and limb mass, equations using height as well as diameter reduced the RMSD by a factor of at least two, compared with equations using diameter alone. Correction for logarithmic bias only slightly changes root mean square deviations and does not seem to be of practical importance.

The equations presented here are regarded as first approximations for sapling and pole-sized trees in managed stands in central Oregon. These equations should not be extended to larger trees or to other areas without validation.

## Literature Cited

**Barrett, James W.** Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-232. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1978.** 14 p.

**Baskerville, G. L.** Use of logarithmic regression in the estimation of plant biomass. Canadian Journal of Forest Research 2: 49-53; **1972.**

**Gholz, H. L.; Grier, C. C.; Campbell, A. G.; Brown, A. T.** Equations for estimating biomass and leaf area of plants in the Pacific Northwest. Res. Pap. 41. Corvallis, OR: Forest Research Laboratory, Oregon State University; **1979.** 39 p.

**Snell, J. A. Kendall.** Preliminary crown weight estimates for tanoak, black oak, and Pacific madrone. Res. Note PNW-340. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1979.** 4 p.

**Taras, Michael A.; Clark, III, Alexander.** Aboveground biomass of longleaf pine in a natural sawtimber stand in southern Alabama. Res. Pap. SE-162, Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest and Range Experiment Station; **1977.** 32 p.

**Waring, R. H.; Schroeder, P. E.; Oren, R.** Application of the pipe model theory to predict canopy leaf area. Canadian Journal of Forest Research 12: 556-560; **1982.**

## Conversion Factors

1 kilometer = 0.6214 miles
1 meter = 3.2808 feet
1 centimeter = 2.54 inches
1 kilogram = 2.2046 pounds
1 cubic meter = 35.3145 cubic feet
1 kilogram per cubic meter = 0.06243 pounds per cubic foot
1 gram per cubic centimeter = 62.428 pounds per cubic foot



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