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Estimating past diameters of mixed-conifer species in the central Sierra Nevada

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Tree diameter outside bark at an earlier period of growth can be estimated from the linear relationship of present inside bark and outside bark diameters at breast height. This note presents equations for estimating inside bark diameters, outside bark diameters, and past outside bark diameters for each of the mixed-conifer species in the central Sierra Nevada.

Retrieval Terms: Libocedrus decurrens, Pseudotsuga menziesii, Pinus ponderosa, Abies concolor, Pinus lambertiana, past diameters, bark measurement, Sierra Nevada

Estimating future growth and yield of forest stands by individual tree simulation methods requires prediction of basal area increments during specified growth periods. Basal area increments for past growth periods provide a basis for developing these predictions. Since the total diameter growth for a period is the sum of wood growth and bark growth, basal area increment may be calculated from the difference in diameter outside bark (d.o.b.) between the beginning and the end of the growth period. Present diameter (d.o.b. at the end of the growth period) can be measured directly; past diameter (d.o.b. at the start of the growth period) must be determined by some indirect method.

This note reports a method for estimating past outside bark diameters at breast height and presents equations for estimating these past diameters for young-growth mixed-conifer species of the west side Sierra Nevada. Past diameters have been estimated for conifers of the Pacific Northwest[1,2] and for young-growth ponderosa pine of northern California[3] by similar procedures.

The equations presented here apply to young-growth mixed-conifer species in the central Sierra Nevada. Regression coefficients may be slightly different in other areas of the Sierra Nevada; applicable coefficients for these areas will be determined as additional data are collected.

DATA

Prediction equations for past diameter were developed from data obtained for predicting growth of young-growth mixed-conifer stands in the Sierra Nevada.[4] The equations are based on stem analyses of 339 felled and sectioned trees growing in mixed stands throughout the Eldorado National Forest in eastern California.

The five mixed-conifer species sampled include: Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), ponderosa pine (*Pinus ponderosa* Laws.), sugar pine (*P. lambertiana* Dougl.) white fir (*Abies concolor* [Gord. & Glend.] Lindl.), and incense-cedar (*Libocedrus decurrens* Torr.). Species were sampled in proportion to their abundance at each sample site. Individual trees of each species were selected randomly. The total sample covered the range of diameters and crown classes typical of young-growth stands (*table 1*).

Diameter outside bark at breast height was measured on each tree to the nearest 0.1 inch using a diameter tape. Effective

Table 1—*Number and diameter range of sample trees*

Species	Sample size	D.b.h. (outside bark) range	Mean d.b.h.	Standard error
			— inches —	
Douglas-fir	17	4.2 to 19.6	11.4	4.55
Ponderosa pine	49	4.0 to 31.7	14.7	6.61
Sugar pine	19	4.8 to 23.6	14.4	6.49
White fir	155	2.9 to 33.7	13.9	5.77
Incense-cedar	99	3.5 to 23.1	10.3	4.71

bark thickness was determined by averaging eight uniformly spaced measurements of bark thickness, each taken to the nearest 0.05 inch, by the "wood to tape" method.[5] Diameter inside bark (d.i.b.) was then calculated by subtracting twice the average bark thickness from the d.o.b. measurement.

METHODS

If a linear relationship between d.o.b. and d.i.b. exists, and if current d.i.b. (d_c) is known, current d.o.b. (D_c) can be estimated by an equation of the form

$$D_c = b_0 + b_1 d_c \qquad (1)$$

where b_0 and b_1 are regression parameters that can be estimated by least squares.

Assuming these parameters are constant over a short period of time, such as a 10-year growth period, d.o.b. at the beginning of the period (D_p) could also be estimated from the d.i.b. at the beginning of the period (d_p) using the relationship

$$D_p = b_0 + b_1 d_p \qquad (2)$$

The change in d.o.b. during a growth period (D_Δ) is

$$D_\Delta = D_c - D_p$$

and the combined equation of (1) and (2) above may be expressed

$$D_c - D_p = (b_0 + b_1 d_c) - (b_0 + b_1 d_p)$$

and

$$D_c - D_p = b_1 (d_c - d_p) \qquad (3)$$

The change in d.i.b. during the growth period (d_Δ) is

$$d_\Delta = d_c - d_p$$

which is equal to twice the average radial growth during the period. Radial wood growth for any desired period may be easily measured from increment cores. Two or more cores per tree should be measured[6] and the average radial growth calculated. If we let R equal this average growth for a specified period, then

$$d_\Delta = d_c - d_p = 2R$$

By substituting this value (2R) into equation (3) and rearranging terms, we obtain

$$D_p = D_c - b_1 2R \qquad (4)$$

This equation, which accounts for the growth of both wood and bark, expresses past outside bark diameter in terms of present outside bark diameter and radial growth.

If radial wood growth can be predicted for future growth periods, the relationship

$$D_\Delta = b_1 d_\Delta$$

can also be used for estimating future d.o.b. (D_f). In this case,

$$D_f = D_c + b_1 2R$$

ANALYSIS

Plotting of d.o.b. over d.i.b. yielded a linear relationship for each of the mixed-conifer species. Linear regression was used to predict (1) d.o.b. as a function of d.i.b. and (2) d.i.b. as a function of d.o.b. Examination of residual plots showed the variance was not constant but increased with larger tree diameters. Parameter estimates were obtained using weighted least squares analysis.

RESULTS AND DISCUSSION

Regression equations which express the linear relationships of d.o.b. and d.i.b., coefficients of determination (r^2), standard errors of estimate, and the past d.o.b. prediction equation are shown for each of the mixed-conifer species:

Douglas-fir

d.i.b. = 0.8497 (d.o.b.) + 0.2394
($r^2 = 0.999$, $S_{yx} = 0.114$)
d.o.b. = 1.1759 (d.i.b.) − 0.2721
($r^2 = 0.999$, $S_{yx} = 0.134$)
Past d.o.b. =
present d.o.b. − 2.3518(R)

Ponderosa pine

d.i.b. = 0.9040 (d.o.b.) − 0.6103
($r^2 = 0.997$, $S_{yx} = 0.328$)
d.o.b. = 1.1029 (d.i.b.) + 0.7162
($r^2 = 0.997$, $S_{yx} = 0.362$)
Past d.o.b. =
present d.o.b. − 2.2058(R)

Sugar pine

d.i.b. = 0.8859 (d.o.b.) − 0.1813
($r^2 = 0.997$, $S_{yx} = 0.345$)
d.o.b. = 1.1252 (d.i.b.) + 0.2488
($r^2 = 0.997$, $S_{yx} = 0.389$)
Past d.o.b. =
present d.o.b. − 2.2504(R)

White fir

d.i.b. = 0.8878 (d.o.b.) − 0.1451
($r^2 = 0.998$, $S_{yx} = 0.241$)
d.o.b. = 1.1238 (d.i.b.) + 0.1952
($r^2 = 0.998$, $S_{yx} = 0.271$)
Past d.o.b. =
present d.o.b. − 2.2476(R)

Incense-cedar

d.i.b. = 0.8300 (d.o.b.) + 0.0887
($r^2 = 0.993$, $S_{yx} = 0.299$)
d.o.b. = 1.1975 (d.i.b.) − 0.0427
($r^2 = 0.993$, $S_{yx} = 0.359$)
Past d.o.b. =
present d.o.b. − 2.3950(R)

The method given here for estimating past outside bark diameters is a refinement of the method given by Myers and Alexander.[7] Using the relationship $D_\Delta = b_1 d_\Delta$ eliminates the need of using cross-products of regression coefficients and intercept terms as shown in their prediction equation.

The estimate of b_1 can be considered an indirect estimate of wood and bark growth since it indicates the change in outside bark diameter per unit change in inside bark diameter (D_Δ/d_Δ).

The coefficient estimate for a given species, though useful in one area, may not apply in another, largely due to genetic variation, differences in site condi-

Table 2—*Coefficient estimates of D_Δ/d_Δ for three west coast conifer species*

Area and source	Species		
	Douglas-fir	Ponderosa pine	White fir
		D_Δ/d_Δ	
Pacific Northwest			
Johnson[1]	1.104	1.245	
Spada[2]	1.133	1.108	1.117
Central Sierra			
Dolph	1.176	1.103	1.124
Northern California			
Powers[3]		1.214	

tions, and differences in stand ages. *Table 2* gives a comparison of coefficient estimates found by different investigators for three west coast conifer species.

The estimate of the coefficients for each species in a given area is also an indication of relative bark thickness. Among trees of equal age and outside bark diameter, those which have larger estimates of coefficient values will, on the average, have thicker bark.

Equations for predicting inside bark diameters from measurements of outside bark diameters have been shown for each species. These estimates are useful for determining the peeled wood volume of a tree. The relation between d.i.b. and d.o.b. for each species is apparently linear for the range of diameters sampled. The relationship should logically show zero d.i.b. for zero d.o.b. When the intercept term in the regression equation is some value other than zero, it suggests that curvilinear regression would be required beyond the lower range of the data. If an estimate of d.i.b. is needed below the range of diameters shown in *table 1*, an approximate value may be obtained by drawing a line from the lower end of each regression to the origin.

Analysis of variance of the regression coefficients was used to test for species differences. Controlling the overall α level at 0.05 by using the Bonferroni multiple comparison technique,[8] showed the following:

- The regression lines for Douglas-fir, white fir, and sugar pine were not significantly different.
- There was not enough evidence to show the regression lines of sugar pine and ponderosa pine to be significantly different.
- The regression line for incense-cedar was significantly different from those of the other species.

NOTES

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