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ESTIMATING MERCHANTABLE VOLUMES OF SECOND GROWTH DOUGLAS-FIR STANDS FROM TOTAL CUBIC VOLUME AND ASSOCIATED STAND CHARACTERISTICS

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ABSTRACT

Equations are given for estimating merchantable volumes of second-growth Douglas-fir stands to specified breast high and top diameter limits, in cubic feet or board feet, from total volume in cubic feet and certain associated stand characteristics.

KEYWORDS: Volume (merchantable), second-growth stands, cubic volume measure, conversion factors, Douglas-fir, *Pseudotsuga menziesii*

METRIC EQUIVALENTS

1 cubic foot per acre = .06998 cubic meter per hectare
1 square foot per acre = .22955 square meter per hectare
1 acre = .40469 hectare

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Introduction

Research reports and data summaries concerned with growth of forest stands often present total stem cubic volumes, including volume of tops and stumps, and associated statistics for all trees. Land managers usually want to know merchantable volumes to specified breast high and top diameter limits, in both board and cubic feet. A method is needed to estimate merchantable volumes and associated merchantable stand statistics from total stand statistics.

This note gives estimation equations applicable to second-growth Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) stands, using customary measurement units. These equations were developed to provide conversions in a Douglas-fir stand simulator (DPSIM) now being developed as part of a cooperative effort by the USDA Forest Service's Pacific Northwest Forest and Range Experiment Station and by Weyerhaeuser Company, using permanent plot data contributed by a number of organizations.[1] These equations should also be useful to others with similar estimation problems concerning Douglas-fir.

[1]Cooperators are listed in an appendix.

The Data

Tne plot data used[2] were from even-aged second-growth stands of coastal Doaglas-fir in western Washington, Oregon, and British Columbia. Stands included were at least 80-percent Douglas-fir by basal area, under 100 years of age, both thinned and unthmned, and of both natural and plantation origin. Plot sizes ranged from .1 to l.C acre.

Plot volumes in total cubic feet per acre for all stems over 1.5-inch d.b.h. were Calcu ated using height-diameter functions and the Bruce-DeMars (1974; volume equation. Corresponding merchantable volumes were obtained by tree-by-tree conversion and summation, using the Washington Department of Natural Resources tarif system equations as given by Brackett (1973). For stems over 5.5-inch d.b.h., we calculated volume in cubic feet to a 4-inch top d.i.b. For stems over 7.5-inch d.b.h., we calculated cubic volume t, 4- and 6-inch tops d.i.b., and also board-foot volumes in Scribner and International 1/4-inch Rules to a 6-inch d.i.b. top.

Separate analyses were made for (1) live stand—trees alive at a given measurement date, (2) the "cut component"--those trees removed in thinning, and (3) the "mortality component"—those trees dying between two successive measurements on a plot.

There were 3,299 plot measurements for the live stand, after omitting incomplete or unsuitable data and stands with quadratic mean d.b.h. (D) less than 5.6 inches. Included were 585 plot measurements for trees cut in thinnings, after omitting plots where less than 15 percent of the stand by basal area was cut. Included also were 1,407 plot measurements for trees lost as mortality, obtained as differences between successive plot measurements while omitting cases with zero mortality. No minimum diameter was specified for mortality. Some of these observations were serial in time.

[2]This is the same data used as the basis for the stand simulation program DFSTM and will be described in more detail in a manuscript now in preparation.

Analysis

We considered three approaches to the estimation problem:

1. Diameter frequency functions in conjunction with individual tree merchantable volume tables or equations.
2. Individual tree merchantable volume tables or equations applied to mean trees.
3. Conversion ratios fitted as functions of available stand variables.

We adopted method 3, which requires no explicit assumptions about the d.b.h. frequency distributions in the "live," "cut," and "mortality" stand components (which are probably different). Estimation equations were derived for each of these three components.

Merchantability classes derived included:

1. Cubic volume, total stem, for stands with D greater than 5.5 inches ($CVTS_{5.6}$).
2. Cubic volume to 4-inch tops for stands with D greater than 5.5 inches ($CV4_{5.6}$).
3. Cubic volume, total stem, for stands with D greater than 7.5 inches ($CVTS_{7.6}$).
4. Cubic volume to 4-inch tops for stands with D greater than 7.5 inches ($CV4_{7.6}$).
5. Cubic volume to 6-inch tops for stands with D greater than 7.5 inches ($CV6_{7.6}$) .
6. Scribner volume to 6-inch tops for stands with D greater than 7.5 inches ($SV6_{7.6}$).
7. International 1/4-inch volume to 6-inch tops with D greater than 7.5 inches ($IV6_{7.6}$).

Prediction equations were fitted using forward stepwise regression. The dependent variable used was either (1) the ratio of the specified merchantable volume to total cubic volume, or (2) merchantable volume (with total cubic volume as one of the predictor variables). Independent variables included D of live stand and of the cut component; mean height of the largest 40 stems per acre, live stand (H40); relative stand density-[3] of live stand; whether the stand was of natural or planted origin; and whether or not the stand had been thinned prior to the date of measurement.

We list below our equations for estimating merchantable stand volume and associated stand statistics from stand volumes in total cubic feet in stems over 1.5-inches first, for live stand; next, for the cut portions of thinned stands; and last, for natural mortality. As would be expected, D was consistently, and by far, the most important predictor. Other variables, though significant and presumably representing differences in the underlying distributions, made much smaller contributions.

Some of these equations may be unreliable if extrapolated beyond the data. To avoid unreasonable estimates and inconsistencies between estimates to alternative merchantability limits, users should observe the stated restrictions.

The form of the dependent variable used in actual fitting was not the same in all cases and variances were usually not uniform across the range of stand diameters. As a result, multiple correlation coefficients and standard errors of estimate associated with these equations are not readily interpretable other than as an indication that quite close fits to the data were achieved in most cases. Multiple correlation coefficients were greater than 0.9 for most equations and greater than 0.95 for many. As would be expected from the erratic nature of mortality, the equations for the mortality component were much poorer in fit; and we give only those for total cubic volume in trees over 5.5- and over 7.5-inch d.b.h.

When comparing equations fitted with different forms of the dependent variable, we based our choices on Furnival's (1961) index of fit and on apparent reasonableness of behavior within and at the margins of the data.

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[3]Here expressed by the ratio of basal area to the square root of D, ($G/D^{1/2}$); which is nearly proportional to the ratio of observed basal area to the "normal" given by equation 1-0 in Bruce et al. (1977), as well as to other diameter-based stand density measures (Curtis 1971).

Variables appearing in these equations are as defined in table 1.

Table 1--Glossary of variables used for converting statistics for stands over 1.5-inch d.b.h. to statistics for stands over 5.5- and 7.5-inch d.b.h.

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1. CVTS = Cubic-foot volume of total stem, tops and stumps included, all trees over 1.5-inch d.b.h.
2. H = H40 before cut, where H40 is average height of the 40 trees per acre of largest d.b.h.
3. D = Quadratic mean diameter of trees over 1.5-inch d.b.h.
4. $D_{5.6}$ = Quadratic mean diameter of trees over 5.5-inch d.b.h.
5. $D_{7.6}$ = Quadratic mean diameter of trees over 7.5-inch d.b.h.
6. G = Basal area of trees over 1.5-inch d.b.h.
7. $G_{5.6}$ = Basal area of trees over 5.5-inch d.b.h.
8. $G_{7.6}$ = Basal area of trees over 7.5-inch d.b.h.
9. RD = Relative density = $G_{1.6} / (D_{1.6})^{1/2}$.
10. P = 1 if a plantation, otherwise 0.
11. T = 1 if stand had been thinned previous to measurement, any other = 0.
12. Unsubscripted variables refer to live stand. A variable with a "c" or "m" subscript refers to the "cut" or "mortality" component, respectively.

Equations for estimating statistics for stands over 5.5- and 7.5-inch d.b.h. from statistics for total stand over 1.5-inch d.b.h.

A. <u>Live Stand Before Cut</u>:

1. $$D_{5.6}/D = .984357 - .583464\ (P/D) + 1.89968\ (H/D^3) - 12.3567\ (H/D^5) - 30.8412\ (T/D^3) + 662.059\ (T/D^5) - .0115069\ (RD/D).$$

Restrictions:

If $\hat{y}$[4] < 1.0 or D >16.0, $\hat{y}$ = 1.0.

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[4]Here and later, $\hat{y}$ refers to the dependent variable in the equation in question.

2. $G_{5.6}/G = .893313 + 1.47633\ (1/D) - 3055.41\ (1/D^5)$
$+ .00983207\ (H/D) - 2,03654\ (H/D^3) + 63.6836\ (H/D^5)$
$+ 37.5119\ (P/D^3) - 1412.33\ (P/D^5)$.

Restrictions:

If y >1.0 or D ->16.0, y = 1.0.

3. $CVTS_{5.6}/CVTS = .975949 + .255308\ (P/D)$
$+ .106148\ (H/D^2) - 2288.48\ (1/D^5)$
$- 21.9646\ (H/D^4) + 121.832\ (H/D^5)$
$+ 2685.35\ (1/HD^3) - 81974.7\ (1/HD^5)$
$- 435.843\ (P/D^5)$.

Restrictions:

If y > 1 . 0 or D 16.0, y - 1.0.

4. $CV4_{5.6}/CVTS = .961397 - 768.661\ (1/D^4)$
$+ .138938\ (P/D) + .0330124\ (H/D^2) + 42.8285\ (1/D^3)$
$- 13.9873\ (H/D^4) + 99.8628\ (H/D^5) - 515.9\ (P/D^5)$
$- 1.09081\ (RD/D^4) - 34.8689\ (T/D^4)$.

Restrictions:

If $\dot{y}$ >0.97(CVTS), $\dot{y}$ = .97(CVTS).

5. $D_{7.6}/D = 1.07445 - .609012\ (P/D) + 3.86485\ (H/D^3)$
$- 124.037\ (H/D^5) - 2.48009\ (1/D) + 8786.25\ (1/D^5)$
$- 20.0203\ (T/D^3) + 8368.65\ (1/HD^3)$
$- 448096.0\ (1/HD^5) - .00821434\ (RD/D)$.

Restrictions:

If y < 6.0 or D .8.0, y = 1.0.

6 $G_{7.6}/G = 1.36153 - .0237196\ (H/D) + 1.11498\ (P/D)$
$- 79.8001\ (P/D^3) - 53.6643\ (1/H) + 23409.5\ (1/H^3)$
$+ 4116.87\ (1/D^5) + 639.163\ (1/HD) - 41771.5\ (1/HD^3)$
$+ 556335.0\ (1/HD^5) - 687.478\ (T/D^5)$
$- .428632\ (RD/D^3).$

Restrictions:
If $\hat{y} > 1.0$ or $D > 18.0$, $\hat{y} = 1.0$.

7. $CVTS_{7.6}/CVTS = .972557 + .37322\ (P/D) + 133.694\ (1/HD)$
$- 21229.9\ (1/HD^3) + 404110.0\ (1/HD^5)$
$- 1912.74\ (P/D^5) - .249844\ (RD/D^3).$

Restrictions:
If $\hat{y} > 1.0$, $\hat{y} = 1.0$;
If $CVTS_{7.6} > CVTS_{5.6}$, $C\hat{V}TS_{7.6} = CVTS_{5.6}$.

8. $CV4_{7.6}/CVTS = 1.23073 + 87.0257\ (1/D^3)$
$- 36.3249\ (1/H) - .0204814\ (H/D) + 501.03\ (1/HD)$
$- 38884.7\ (1/HD^3) + 595741.0\ (1/HD^5)$
$- 1060.09\ (P/D^5) - 11.7193\ (T/D^3) - .00805095\ (RD/D)$
$+ 22461400.0\ (1/H^5).$

Restrictions:
If $C\hat{V}4_{7.6} > C\hat{V}4_{5.6}$, $C\hat{V}4_{7.6} = CV4_{5.6}$.

9. $CV6_{7.6}/CVTS = .984543 + 6.55643\ (H/D^5)$
$- 19687.8\ (1/HD^3) + 393312.0\ (1/HD^5)$
$- 28.83\ (P/D^3) - 13.588\ (T/D^3) - .00890657\ (RD/D)$
$+ 16376.3\ (1/H^3).$

Restrictions:
If $C\hat{V}6_{7.6} > 0.96(CVTS)$, $C\hat{V}6_{7.6} = .96(CVTS)$.

10. $IV6_{7.6}/CVTS = 8.04286 - 1329.66\ (1/D^3)$
$- 192.389\ (1/H) + 20839.0\ (1/D^5) + 106.122\ (H/D^5)$
$- 139.485\ (P/D^3) - 66.0059\ (T/D^3) - .0556108\ (RD/D)$
$+ 98099100.0\ (1/H^5)$.

Restrictions:
None.

11. $SV6_{7.6}/CVTS = 8.34551 - 15.541\ (1/D) - 232.834\ (1/H)$
$- 5.55669\ (H/D^3) + 166.021\ (H/D^5) - 103.673\ (P/D^3)$
$- 53.4672\ (T/D^3) - .0471846\ (RD/D)$
$+ 118540000.0\ (1/H^5)$.

Restrictions:
None.

B. <u>Cut Component</u>:

1. $D_{5.6c}/D_c = .99778 - .150016\ (P/D_c)$
$+ 24.4189\ (H/D_c^5)$.

Restrictions:
If $\hat{y} < 1.0$ or $D_c > 15.0$, $y = 1.0$.

2. $G_{5.6}/G_c = .996566 - 40594.1\ (1/D_c^6)$
$+ 961584.0\ (1/D_c^8) - 1286970.0\ (1/HD_c^6)$
$+ 38406.5\ (1/HD_c^4)$.

Restrictions:
If y 1.0 or $D_c > 15.0$, $\hat{y} = 1.0$.

3. $CVTS_{5.6c} / CVTS_c = .99674 - 26160.8 \ (1/D_c^6)$
$+ 7979.08 \ (H/D_c^8) + 2020.83 \ (1/HD_c^3)$
$- 808.02 \ (RD/D_c^7)$.

[Note: RD is before cut value]

Restrictions:

If y. 1.0 or D_c 15.0, y = 1.0.

4. $CV4_{5.6c} / CVTS_c = .967377 - 641.703 \ (1/D_c^4)$
$+ 878.217 \ (1/D_c^5) + .634701 \ (H/D_c^4)$.

Restrictions:

If $CV4_{5.6c}$ 0.97($CVTS_c$), $CV4_{5.6c}$ = .97($CVTS_c$).

5. $D_{7.6c}/D_c = 1.03177 + 53.8217 \ (1/D_c^2)$
$- .246223 \ (H/D_c^2) - 233.096 \ (1/HD_c)$.

Restrictions:

If Y / 1 - 0 or D_c 18.0, y = 1.0.

6. $G_{7.6c}/G_c = 1.00712 - 192.551 \ (1/D_c^3)$
$+ 3888.64 \ (1/D_c^5) + 70373.0 \ (1/HD_c^3)$
$+ 2931700.0 \ (1/HD_c^5) - 934558.0 \ (1/HD_c^4)$.

Restrictions:

If y 1.0 or D_c > 18.0, y = 1.0.

7. $CVTS_{7.6c}/CVTS_c = .993026 - 89.5832 \ (1/D_c^3)$
$+ 1306570.0 \ (1/D_c^8) - 9631.5 \ (H/D_c^8)$
$+ 2671.7 \ (1/HD_c^2) - 24941.7 \ (1/HD_c^3)$.

Restrictions:

If y > 1.0 or D_c 18.0, $\hat{y}$ = 1.0.

8. $CV4_{7.6c}/CVTS_c = .91505 - 83.8359\ (1/D_c^3)$
$+ 6240260.0\ (1/HD_c^6) - 1242810.0\ (1/HD_c^5)$
$+ 9.67241\ (1/H)$.

Restrictions:
If $CV4_{7.6c}$ $CV4_{5.6c}$, $CV4_{7.6c} = CV4_{5.6c}$.

9. $CV6_{7.6c}/CVTS = .708274 + 10.1904\ (1/D_c)$
$- 92.0439\ (1/D_c^2) + 1215.26\ (1/D_c^4)$
$- .0943753\ (H/D_c^2) - 125129.0\ (1/HD_c^4)$
$+ 549227.0\ (1/HD_c^5)$.

Restrictions:
If $CV6_{7.6c}$.0.99($CV4_{7.6c}$), $CV6_{7.6c}$
= 0.99($CV4_{7.6c}$).

10. $IV6_{7.6c}\ /CVTS_c = 6.95049 + 62.942\ (1/D_c)$
$- 671.623\ (1/D_c^2) - .113959\ (H/D_c)$
$+ 8156.0\ (1/D_c^4) - 171.945\ (1/H)$.

Restrictions:
None.

11. $SV6_{7.6c}/CVTS_c = 9.75211 - 32.992\ (1/D_c)$
$- .115131\ (H/D_c) + 365922.0\ (1/HD_c^5)$
$- 187.155\ (1/H)$.

Restrictions:
None.

C. Mortality:[5]

1. $CVTS_{5.6m}.CVTS_m = 5.0650 - .10790 (D_m) - 9.5417 (1/D^{1/2}) + 160.50 (1/D_m^4) - 271.93 (1/D_m^5)$.

Restrictions:

If $\hat{y} < 0.0$, $\hat{y} = 0.0$;

If $\hat{y} > 1.0$ or $D_m > 14.0$, $\hat{y} = 1.0$.

2. $CVTS_{7.6m}/CVTS_m = 8.8335 - .11872 (D_m) + 28.010 (1/D_m) - 30.638 (1/D_m^{1/2}) - 500.67 (1/D_m^8)$.

Restrictions:

If $\hat{y} < 0.0$, $\hat{y} = 0.0$;

If $\hat{y} > 1.0$ or $D_m > 18.0$, $\hat{y} = 1.0$.

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[5]We fit these equations by a "two-stage" procedure, using as predictor a regression estimate $\hat{D}_m$ = f(stand variables). This is consistent with intended use in a stand simulator, where the available D_m statistic is a stand mean, estimated from live stand characteristics.

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Appendix

List of Organizations Contributing Data

British Columbia Forest Service
Bureau of Land Management, U.S. Department of the Interior
Canadian Forestry Service
Crown Zellerbach Corp.
International Paper Co.
MacMillan Bloedel Ltd.
Oregon Department of Forestry
Oregon State University
Pacific Northwest Forest and Range Experiment Station, USDA
Forest Service
Roseburg Lumber Co.
University of Washington
Washington Department of Natural Resources
Weyerhaeuser Co.

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