Fixed Area Plot Summary, and beyond – Upper Canopy module

Eight steps to process standard upper canopy inventory data:

1. Compute mean DBH, mean height, mean crown ratio
2. Calculate trees per acre represented by each plot and mean TPA
3. Calculate basal area and estimate tree volume for every tree on each plot
4. Calculate basal area and estimate volume per acre for each plot
5. Summarize per acre statistics (with confidence interval)
6. Estimate tree species composition using basal area as basis
7. Estimate Site Index (measure of site quality)
8. Estimate Sample Size for a survey with specified reliability

Example:

We would like to summarize data collected from a recent upper canopy survey in a 30-acre, second-growth, Douglas-fir stand growing in the Pacific Northwest to obtain stand attributes, such as volume per acre (cubic-foot basis) including confidence interval, stand, and stock tables. Plot size used was 1/20 = 0.05 acre.

Partial listing of the data (n = 3 plots):

Plot 1		Plot 2		Plot 3	
DBH	Ht	DBH	Ht	DBH	Ht
15.1		15.0	77.7	18.9	94.8
14.5		13.7	79.3	15.3	83.8
12.8		12.7		15.2	
12.7	70.4	12.6	82.4	15.2	
12.6	75.8	11.1		13.8	
12.3		11.4		13.5	
11.3	72.2			10.4	
9.6				8.8	64.0
9.1					
(9 trees)		(6 trees)		(8 trees)	

Step 1. Compute mean DBH. First, compute mean DBH for each plot, then find the mean of those means.

Plot 1: 12.2 in.

Plot 2: 12.8 in.

Plot 3: 13.9 in. $\overline{DBH}$ = (12.2 + 12.8 + 13.9) / 3 = 13.0 in.

Compute Mean Height. Since we did not measure height on every tree, we need to use a ratio estimator for mean height. First, add up all the heights, then add up all the DBHs corresponding to those heights, then form the ratio of summed heights to summed DBHs, calling it R. Finally, calculate mean Height from the product of R and Mean DBH.

Sum of Heights: (70.4 + 75.8 + 72.2 + 77.7 + 79.3 + ... + 64.0) = 700.4 ft.

Sum of DBHs: (12.7 + 12.6 + 11.3 + 15.0 + 13.7 + ... + 8.8) = 120.9 in.

Ratio of summed Heights to DBHs, R = 700.4 / 120.9 = 5.7932 ft. / in.

Thus, $\bar{H}$ = R ($\overline{DBH}$) = 5.7932 (13.0) = 75.3 ft.

Compute mean Crown Ratio. Compute crown lengths for measured height trees as CL = $H_{Tot} - H_c$. Mean Crown Ratio is just the computed ratio of summed Crown Lengths to summed total Heights; $\overline{CR} = \sum CL \big/ \sum H_{Tot}$.

Step 2. First, compute a Tree Factor (TF) for each tree, which is the number per acre each tree represents. For fixed area plots,

TF = $\frac{1}{a}$, where a = plot size in decimal fraction of an acre. For the example,

TF = $\frac{1}{a} = \frac{1}{0.05} = 20$, which is the same for every tree.

Next, Compute number of trees per acre for each plot. On plot 1 in this example, there are 9 trees total, and each tree represents 20 per acre, so $9 \times 20 = 180$ trees per acre (TPA). As it happens, $\overline{TPA}$ = 153.3

Step 3. Calculate basal area and estimate tree volume for trees on the plot. Begin by calculating basal area (ba) for each tree, given by

$$ba = 0.005454 \bullet DBH^2$$

For the first tree on plot 1,

$ba = 0.005454 \bullet 15.1^2 = 1.24\ sq.ft.$ (repeat for all other trees on plot …)

Then, for trees having both a measured DBH & Ht, use a standard volume equation (e.g., Table 1, APPENDIX) to compute total cubic-foot volume, denoted by CVTS. The general equation form for the species listed in Table 1 is: $CVTS = 10^A DBH^B HT^C$

For coastal immature Douglas-fir (using A, B, C coefficients from Table 1)

$CVTS = 10^{-2.658025} DBH^{1.739925} HT^{1.133187}$,

where CVTS denotes Cubic-foot Volume including Top and Stump.

The fourth tree on plot 1, DBH = 12.7 in.; HT = 70.4 ft.:

$CVTS = 10^{-2.658025}(12.7)^{1.739925}(70.4)^{1.133187} = 22.7\ ft^3$

Compute an average Volume:Basal Area Ratio (VBAR):

VBAR = (sum of tree volumes) / (sum of basal areas)

For plot 1: VBAR = (22.7 +24.4 +19.1) / (0.88 +0.86 +0.70) = 27.13 ft^3/ft^2

Average DF VBAR = 28.98 ft^3/ft^2

Estimate volumes for all trees measured solely for DBH using the average VBAR. The first tree on plot 1, DBH = 15.1 in., BA = 1.24

CVTS = *VBAR* x *BA* = 28.98 x 1.24 = 35.9 ft^3

Step 4. Compute basal area and estimate volume per acre for each plot. Find the products (BA x TF) and (CVTS x TF) for each tree and add them up.

Plot	Basal area (sq. ft.)	Volume (cu. ft.)
1:	150.1	4350
2:	107.5	3117
3:	175.8	5095

Step 5. Summarize per acre statistics (with confidence interval)

For basal area: Avg. BA per acre = 144.5 sq. ft. / acre

Variance (s^2) = 1,188.56 (ft^2 / acre)^2

Std. Dev. = 34.48 ft^2 / acre

Std. Err. = 19.90 ft^2 / acre

Desiring an 80% CI, let's say, $t_{0.20, 2}$ = 1.886 (see Table 2, APPENDIX),

80%CI = 144.5 $\pm$ 1.886 (19.9)

The population mean CVTS per acre for the sampled forest stand lies somewhere in the interval (107.0, 182.0) ft^3 / acre, unless a 20% chance occurred.

Step 6. Estimate tree species composition. Using the basal area calculations from Step 3, compute the proportion of plot basal area that each species represents. Let's say that on plot 1, the first tree was a hemlock, and the rest were Douglas-fir. The sum of tree basal areas for plot 1 is 7.50 sq. ft.

Proportion of hemlock = 1.24 / 7.50 = 0.205; therefore,

Plot 1 is ~ 21% hemlock, and ~ 79% Douglas-fir.

Perform similar calculations for each plot, then average the resulting proportions for each species.

Step 7. Estimate Site Index. (See Figure 1 below.) Calculate a Site Index for each "site" tree, then average.

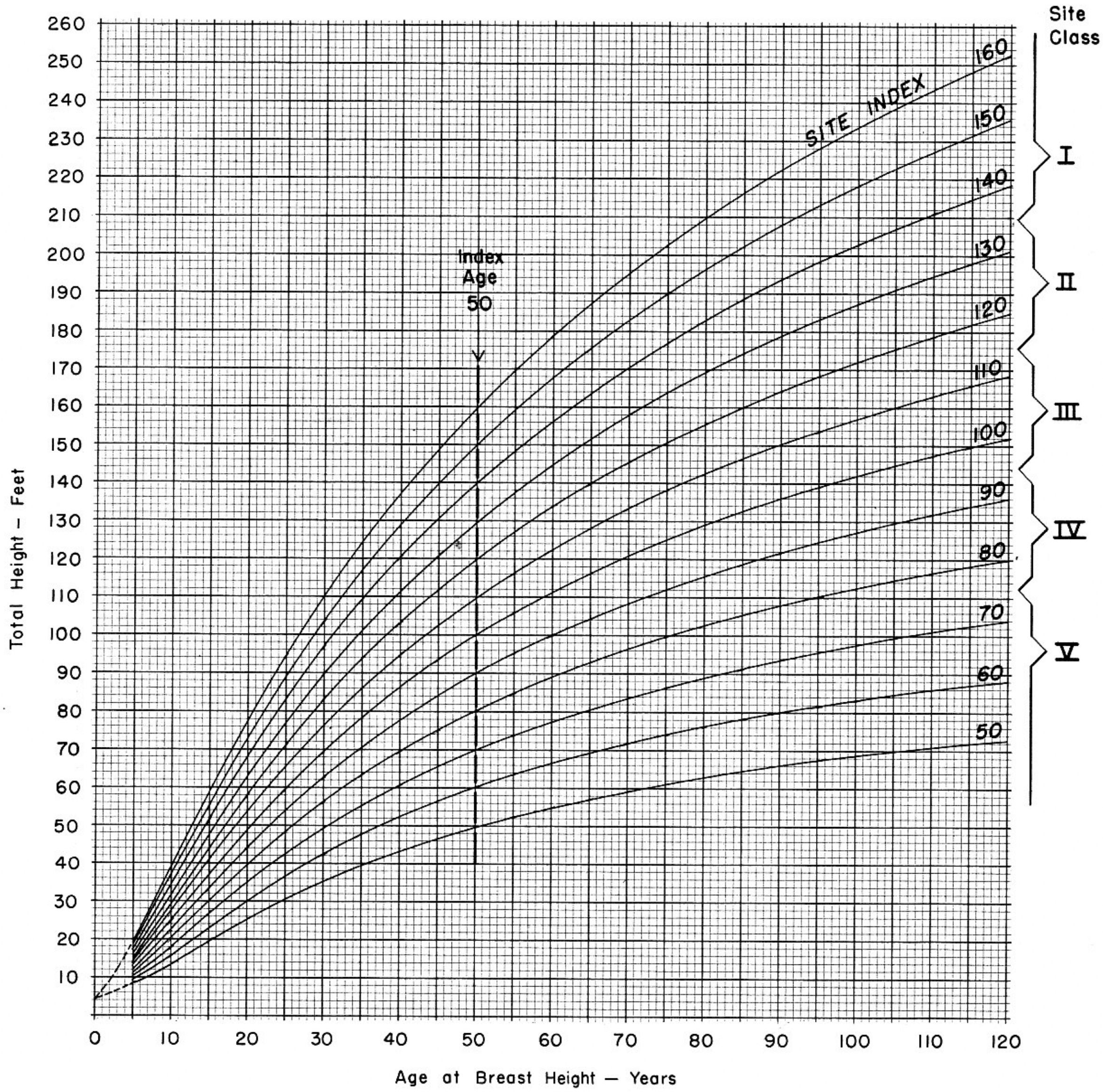

Figure 1. Site Index Curves for Douglas-fir. From King, J.E. 1966. Site Index Curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Paper No. 8.

$$S_{50} = 4.5 + \frac{274.3925 + 19.8059(A) + 0.494233(A^2)}{0.954038 - 0.0558178(A) + 0.000733819(A^2) + \dfrac{A^2}{H_D - 4.5}}$$

Step 8. Estimate Sample Size for a survey with specified reliability

Use of statistical formulas preferred

- For SRS infinite populations (or sampling with replacement)

  $$n = k + \frac{z^2 (CV)^2}{E^2}, \quad \text{where}$$

  n = number of sample units required for desired precision E, with confidence level implied by z, k

  k = correction term to avoid iterating between *t*-values

Confidence level	z-value	k
80%	1.282	1.31
90%	1.645	1.87
95%	1.960	2.44
99%	2.576	3.79

  z = standard normal deviate

  CV = coefficient of variation, standard deviation divided by mean (in percent), for forest to be sampled

  E = allowable error or desired precision (in percent) for average volume (or basal area, etc.).

- For SRS finite populations (or sampling without replacement)

  $$n = k + \frac{Nz^2 (CV)^2}{NE^2 + z^2 (CV)^2}, \quad \text{where}$$

  N = Total number of sampling units in population,

  and all other symbols are as before

– Rules of thumb:

  For ~ 1/10 acre plots in highly variable (i.e., CV > 45% populations:

Area (in acres)	number of samples
Up to 10	10
11 – 40	1 per acre
41 – 80	20 + 0.5 (area in acres)
81 – 200	40 + 0.25(area in acres)
200 +	Use sample size formulas

APPENDIX.

Table 1. Coefficients for Cubic Volume contents of various species.

A. CUBIC VOLUME INCLUDING TOP AND STUMP (CVTS)

Four methods are readily available to calculate cubic volume including top and stump.

1. British Columbia Equations

The British Columbia cubic volume equations (1) are presented in the form:

Log CVTS = A + B (Log DBH) + C (Log HT)

This has been changed for the computer to:

CVTS = 10. ** A * DBH ** B * HT ** C

$CVTS = (10^A)(DBH^B)(HT^C)$

Table 1. British Columbia Cubic Volume Equation Coefficients

SPECIES	A	B	C
DOUGLAS FIR:			
Coastal Immature Less Than 140 Years	−2.658025	1.739925	1.133187
Coastal Mature 80 Years +	−2.712153	1.659012	1.195715
Interior	−2.734532	1.739418	1.166033
WESTERN HEMLOCK:			
Coastal Immature Less Than 140 Years	−2.702922	1.842680	1.123661
Coastal Mature 80 Years +	−2.663834	1.790230	1.124873
Interior	−2.571619	1.969710	.977003
WESTERN RED CEDAR:			
Coastal Immature Less Than 140 Years	−2.441193	1.720761	1.049976
Coastal Mature 80 Years+	−2.379642	1.682300	1.039712
Interior	−2.464614	1.701993	1.067038
BALSAM:			
Coastal	−2.575642	1.806775	1.094665
Interior	−2.502332	1.864963	1.004903
SITKA SPRUCE:			
Immature Less Than 140 Years	−2.550299	1.835678	1.042599
Mature 140 Years +	−2.700574	1.754171	1.164531
Interior	−2.539944	1.841226	1.034051
PINE:			
Ponderosa	−2.729937	1.909478	1.085681
Lodgepole	−2.615591	1.847504	1.085772
Western White	−2.480145	1.867286	.994351
WESTERN LARCH:	−2.624325	1.847123	1.044007
YELLOW CEDAR:	−2.454348	1.741044	1.058437
HARDWOODS:			
Alder	−2.672775	1.920617	1.074024
Maple	−2.770324	1.885813	1.119043
Aspen	−2.635360	1.946034	1.024793
Birch	−2.757813	1.911681	1.105403
Cottonwood	−2.945047	1.803973	1.238853

Source: Browne, J.E. 1962. Standard cubic-foot volume tables for the commercial tree species of British Columbia, Vancouver, BC: British Columbia Forest Service. 107 p.

APPENDIX (concluded).

Table 2. Student's *t* table (two-sided).

Degrees of Freedom	Two-Tailed Probability of Obtaining a Larger Value								
	0.5	0.4	0.3	0.2	0.1	0.05	0.02	0.01	0.001
1	1.0000	1.3764	1.9626	3.0777	6.3137	12.7062	31.8210	63.6559	636.5776
2	0.8165	1.0607	1.3862	1.8856	2.9200	4.3027	6.9645	9.9250	31.5998
3	0.7649	0.9785	1.2498	1.6377	2.3534	3.1824	4.5407	5.8408	12.9244
4	0.7407	0.9410	1.1896	1.5332	2.1318	2.7765	3.7469	4.6041	8.6101
5	0.7267	0.9195	1.1558	1.4759	2.0150	2.5706	3.3649	4.0321	6.8685
6	0.7176	0.9057	1.1342	1.4398	1.9432	2.4469	3.1427	3.7074	5.9587
7	0.7111	0.8960	1.1192	1.4149	1.8946	2.3646	2.9979	3.4995	5.4081
8	0.7064	0.8889	1.1081	1.3968	1.8595	2.3060	2.8965	3.3554	5.0414
9	0.7027	0.8834	1.0997	1.3830	1.8331	2.2622	2.8214	3.2498	4.7809
10	0.6998	0.8791	1.0931	1.3722	1.8125	2.2281	2.7638	3.1693	4.5868
11	0.6974	0.8755	1.0877	1.3634	1.7959	2.2010	2.7181	3.1058	4.4369
12	0.6955	0.8726	1.0832	1.3562	1.7823	2.1788	2.6810	3.0545	4.3178
13	0.6938	0.8702	1.0795	1.3502	1.7709	2.1604	2.6503	3.0123	4.2209
14	0.6924	0.8681	1.0763	1.3450	1.7613	2.1448	2.6245	2.9768	4.1403
15	0.6912	0.8662	1.0735	1.3406	1.7531	2.1315	2.6025	2.9467	4.0728
16	0.6901	0.8647	1.0711	1.3368	1.7459	2.1199	2.5835	2.9208	4.0149
17	0.6892	0.8633	1.0690	1.3334	1.7396	2.1098	2.5669	2.8982	3.9651
18	0.6884	0.8620	1.0672	1.3304	1.7341	2.1009	2.5524	2.8784	3.9217
19	0.6876	0.8610	1.0655	1.3277	1.7291	2.0930	2.5395	2.8609	3.8833
20	0.6870	0.8600	1.0640	1.3253	1.7247	2.0860	2.5280	2.8453	3.8496
25	0.6844	0.8562	1.0584	1.3163	1.7081	2.0595	2.4851	2.7874	3.7251
30	0.6828	0.8538	1.0547	1.3104	1.6973	2.0423	2.4573	2.7500	3.6460
35	0.6816	0.8520	1.0520	1.3062	1.6896	2.0301	2.4377	2.7238	3.5911
40	0.6807	0.8507	1.0500	1.3031	1.6839	2.0211	2.4233	2.7045	3.5510
45	0.6800	0.8497	1.0485	1.3007	1.6794	2.0141	2.4121	2.6896	3.5203
50	0.6794	0.8489	1.0473	1.2987	1.6759	2.0086	2.4033	2.6778	3.4960
55	0.6790	0.8482	1.0463	1.2971	1.6730	2.0040	2.3961	2.6682	3.4765
60	0.6786	0.8477	1.0455	1.2958	1.6706	2.0003	2.3901	2.6603	3.4602
70	0.6780	0.8468	1.0442	1.2938	1.6669	1.9944	2.3808	2.6479	3.4350
80	0.6776	0.8461	1.0432	1.2922	1.6641	1.9901	2.3739	2.6387	3.4164
90	0.6772	0.8456	1.0424	1.2910	1.6620	1.9867	2.3685	2.6316	3.4019
100	0.6770	0.8452	1.0418	1.2901	1.6602	1.9840	2.3642	2.6259	3.3905
150	0.6761	0.8440	1.0400	1.2872	1.6551	1.9759	2.3515	2.6090	3.3565
200	0.6757	0.8434	1.0391	1.2858	1.6525	1.9719	2.3451	2.6006	3.3398
∞	0.6745	0.8416	1.0364	1.2816	1.6449	1.9600	2.3263	2.5758	3.2905

Source: Table was generated using the Splus Statistical Software Package (Insightful Corp., Seattle, WA).