9.0 Trees are More Than Timber (non-Timber Stand Attributes)

Forests are not just sources of solid wood products

- Dead tree parameters (snags, woody detritus, etc.)
- Non-tree vegetation (lichens, mosses, shrubs, ferns, forbs, etc.)
- Water (quality, depth, flow, extent, etc.)
- Forest residues for bio-fuels
- Biomass and carbon content / sequestration
- Soil (depth of litter, A horizon, carbon distribution through soil profile, texture, etc.)
- Wildlife (mammals – small & large, birds, other vertebrates, insects, etc.)

9.1 Tree Weight Determination

Tree weight is being used more and more to measure forest products (e.g., weight scaling, tree & stand biomass, etc.) Total (gross) tree weight is "easy" to determine, but dry weight (actual fiber content) is relatively more difficult – affected by density and moisture content

Wood is a porous material, so it shrinks and swells when it dries and when it absorbs moisture

Density is mass per unit volume and can be expressed in three ways, depending on purpose (D = density lbs / ft^3; W_d = dry weight of wood, lbs; V_g = "green" volume, ft^3):

[1] "Current-volume" density = $D = \frac{W_d}{V_g}$ (the norm, for most U.S. uses)

[2] "Actual Weight" density = $D_g = \frac{W_g}{V_g}$ (in many parts of the world)

[3] "Specific MC" density = $D_{MC\%} = \frac{W_d}{V_{MC\%}}$ (for specific purposes)

Alternatively, the density of wood can be referenced to the weight of an equal volume of water, by dividing its density by the weight of the water resulting in a unitless quantity called Specific Gravity (SG). There are also three (3) "flavors" of SG, but all use dry weight in the numerator (W_w = 62.4 lbs / ft^3):

[1] "Current-volume" SG = $SG = \frac{W_d}{V_g} \frac{1}{W_w}$

[2] "Dry-volume" SG = $SG_d = \frac{W_d}{V_d} \frac{1}{W_w}$

[3] "Specific MC" SG = $SG_{MC\%} = \frac{W_d}{V_{MC\%}} \frac{1}{W_w}$

Unless otherwise specified, *specific gravity* refers to current-volume specific gravity

For most species, SG decreases from the base of the tree to the tip, but this variation is small compared to between trees within the same species.

Density of the wood also tends to increase from pith to cambium

Moisture Content (MC) of wood varies by species, location in the tree, and time since cutting - causes major problems for using weight as a measure of wood quantity

Moisture occurs in wood as free water in cell cavities and as absorbed water in the cell wall. The condition where the cell wall is saturated with bound water and the cell cavity contains no free water is known as *fiber saturation point*.

By custom, the moisture content of wood is expressed as a percentage of dry weight.

Dry weight is obtained by drying a sample of wood at 103 +/- 2° C until a stable weight is obtained. Then, moisture content is calculated by:

$$MC_d = 100\left(\frac{W_g - W_d}{W_d}\right)$$

However, in the pulp and paper industry, MC is based on wet weight:

$$MC_g = 100\left(\frac{W_g - W_d}{W_g}\right)$$

In conifers heartwood generally contains less moisture than sapwood, moisture content generally increases as you go higher in the tree

Moisture content can vary by season, as well, some studies indicate higher MC in winter and spring than in summer and fall

9.2 Tree and Forest Biomass Estimation / Forest Carbon

Traditionally only the merchantable portion of tree boles has been utilized – nowadays other components (branches, top wood, foliage) are used for a multitude of purposes (e.g., see Cross, et al. 2013).

Tree stem biomass can be estimated directly from measured tree dimensions, such as DBH and total Height, in much the same way as in standard volume equations. Biomass of tree components, such as roots, branches and leaves, bark, etc., can also be estimated from such equations.

Many existing biomass equations rely on allometric relationships between plant parts. An allometric relationship describes how different parts of a body (in biology) or plant (in botany) grow at rates proportional to one another resulting in a change in body / plant part proportions. The relationship at any given point in time is expressed as

$$B_{part2} = aB_{part1}^{b},$$

where B represents biomass, and parameters a and b represent species-specific constants. This allometric equation can be linearized by taking natural logarithms:

$$\ln\left(B_{part2}\right) = \ln(a) + b\ln\left(B_{part1}\right)$$

A source of biomass equations used frequently is authored by Gholz, and others (1979).

Their equation for Douglas-fir is:

$$\ln\left(B_{stemwood}\right) = -3.0396 + 2.5951\ \ln(DBH)$$

where, $B_{stemwood}$ represents biomass (kg) of stemwood, excluding bark, and DBH is Diameter Breast Height (cm). (Note that this estimates biomass from a single measured tree variable, DBH – akin to what type of volume equation?)

In original scale, the equation is:

$$B_{stemwood} = 0.04785 DBH^{2.5951}$$

In the following Exhibit, the relationship is expressed graphically.

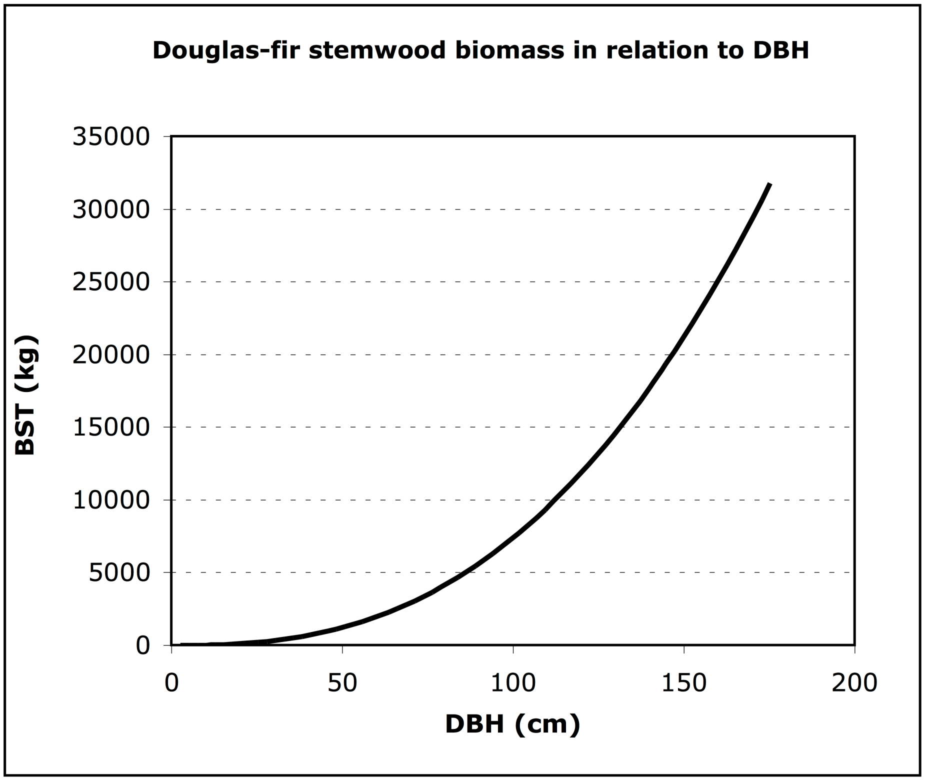

Exhibit 1. Relationship between Douglas-fir stemwood biomass (BST) and DBH (Gholz 1979).

Deriving Biomass / Weight Tables from Volume Tables

To estimate biomass (weight) for a tree from a volume table reporting total stem volumes, the following procedure can be used, which is based on a thorough analysis by Jenkins and others (2003).

Let total stem volume be denoted by $V_{stemwood}$, as estimated from a standard volume equation.

Use tables (Table 1 or 3 and 6, from the Jenkins publication, included below) to obtain two things:

i) specific gravity (dry wood weight as a ratio to weight of equal volume of water) for your species of interest (Table 1 or 3), and

ii) the ratio (proportion) of total above-ground biomass represented by stem biomass (from Table 6).

Using the information from step (i) above, find biomass (in lbs.) for the stem wood by solving the following equation for stemwood biomass, $B_{stemwood}$:

$$B_{stemwood} = 62.4 \times SG_{species} \times V_{stemwood},$$ where,

SG denotes Specific Gravity, and 62.4 is the weight of a cubic foot of water (lbs).

Given $B_{stemwood}$ and the ratio from step ii) above, i.e., $R_{stemwood} = \frac{B_{stemwood}}{B_{TotAboveGround}}$, it should be easy to see that total aboveground biomass is obtained with:

$$B_{TotAboveGround} = \frac{B_{stemwood}}{R_{stemwood}}$$

Once total aboveground biomass is known, use the other ratios from Table 6 to compute the biomass of the other tree components of interest.

Example.
An estimate of biomass is needed for a Douglas-fir tree having DBH = 21.2 in. and Total height = 133 ft. A std. vol. equation yields $V_{stemwood} = 113.9$ ft^3. From Table 3 (below), 0.45 is the specific Gravity of Douglas-fir. Thus,

$$B_{stemwood} = 62.4 \times 0.45 \times 113.9 = 3198.3 \text{ lb.}$$

For a softwood with DBH = 21.2 in., $R_{stemwood} = e^{\left(-0.3737 - \frac{1.8055}{(2.54 \cdot 21.2)}\right)} = 0.6655$. Thus, total above-ground biomass is

$$B_{TotAboveGround} = \frac{B_{stemwood}}{R_{stemwood}} = \frac{3198.3}{0.6655} = 4805.9 \text{ lb.}$$

For softwood foliage, $R_{foliage} = e^{\left(-2.9584 + \frac{4.4766}{(2.54 \cdot 21.2)}\right)} = 0.0564$, so foliage biomass is

$$B_{foliage} = R_{foliage} \cdot B_{TotAboveGround} = 0.0564 \times 4805.9 = 271.0 \text{ lb.}$$

For softwood coarse roots,

$$B_{coarseroots} = e^{\left(-1.5619 + \frac{0.6614}{(2.54 \cdot 21.2)}\right)} \cdot B_{TotAboveGround} = 0.2123 \times 4805.9 = 1020.4 \text{ lb.}$$

For softwood stem bark,

$$B_{stembark} = e^{\left(-2.0980 - \frac{1.1432}{(2.54 \cdot 21.2)}\right)} \cdot B_{TotAboveGround} = 0.1201 \times 4805.9 = 577.3 \text{ lb.}$$

Branch biomass, including bark is found by subtracting *above*-ground components from total above-ground biomass, thus

$$B_{branches} = 4805.9 - 3198.3 - 271.0 - 577.3 = 759.3 \text{ lb.}$$

Table 1. Hardwood species groups for the diameter-based aboveground biomass equations.

Species group	No. of eqs.	Genus	Species	Wood-specific gravity*	Literature reference†
Aspen/alder/ cottonwood/ willow	36	*Alnus*	*rubra*	0.37	7,8,44,55
			sinuata		7
			spp.	0.37	71,83,101
		Populus	*balsamifera*	0.31	90
			deltoides	0.37	2,3,19,59
			grandidentata	0.36	32,54,100
			spp.	0.37	45,65,101
			tremuloides	0.35	16,32,47,51,58,61,72,74,76,78,83,85,90,96
		Salix	spp.	0.36	83,101
Soft maple/ birch	47	*Acer*	*macrophyllum*	0.44	33
			pensylvanicum	0.44	101
			rubrum	0.49	12,22,23,25,26,32,45,51,53,61,63,65,77,81,83,100,101
			spicatum	0.44	14,60,79,101
		Betula	*alleghaniensis*	0.55	32,65,67,81,83,89,101
			lenta	0.60	15,45,63
			papyrifera	0.48	6,25,45,48,51,61,81,83,101
			populifolia	0.45	32,45,51,83,101
Mixed hardwood	40	*Aesculus*	*octandra*	0.33	15
		Castanopsis	*chrysophylla*	0.42	33
		Cornus	*florida*	0.64	10,63,77
		Fraxinus	*americana*	0.55	65,100,101
			nigra	0.45	71,81,101
			pennsylvanica	0.53	22
		Liquidambar	*styraciflua*	0.46	22,23,77
		Liriodendron	*tulipifera*	0.40	15,22,23,63,77,100
		Nyssa	*aquatica*	0.46	22
			sylvatica	0.46	22,77,100
		Oxydendrum	*arboreum*	0.50	63,77
		Platanus	*occidentalis*	0.46	23
		Prunus	*pensylvanica*	0.36	15,61,83,101
			serotina	0.47	100
			virginiana	0.36	83,101
		Sassafras	*albidum*	0.42	100
		Tilia	*americana*	0.32	45,101
			heterophylla	0.32	15
		Ulmus	*americana*	0.46	81
			spp.	0.50	23
Hard maple/ oak/hickory beech	49	*Acer*	*saccharum*	0.56	15,20,25,32,45,65,67,72,83,89,100,101
		Carya	spp.	0.62	22,23,63,77
		Fagus	*grandifolia*	0.56	15,45,65,83,89,101
		Quercus	*alba*	0.60	22,23,63,77,81,98
			coccinea	0.60	23,63,98
			ellipsoidalis	0.56	81
			falcata	0.52	23,77
			laurifolia	0.56	22
			nigra	0.56	22
			prinus	0.57	23,63,77
			rubra	0.56	15,20,36,45,53,63,65,101
			stellata	0.60	23,77
			velutina	0.56	100

* US Forest Products Laboratory. 1974. Wood handbook: Wood as an engineering material. USDA Agric. Handb. 72, rev.

† Reference numbers are matched to authors in Table 2. Reference number 32 for Freedman's combined species equation is also included in each species group.

Table 3. Softwood and woodland species groups for the diameter-based aboveground biomass equations.

Species group	No. of eqs	Genus	Species	Wood-specific gravity	Literature reference*
Cedar/larch	21	*Calocedrus*	*decurrens*	0.37	42
		Chamaecyparis	*nootkatensis*	0.42	42,56
		Chamaecyparis/ Thuja	spp.		33
		Juniperus	*virginiana*	0.44	87
		Larix	*laricina*	0.49	18,51,90,101
			occidentalis	0.48	13,34
			spp.	0.44	36
		Sequoiadendron	*giganteum*	0.34	42
		Thuja	*occidentalis*	0.29	50,75,81,101
			plicata	0.31	1,13,30,42
Douglas-fir	11	*Pseudotsuga*	*menziesii*	0.45	4,13,30,33,34,35,38,42,44,62,91
True fir/ hemlock	32	*Abies*	*amabilis*	0.40	33,42,56
			balsamea	0.34	6,32,46,51,61,101
			concolor	0.37	42,97
			grandis	0.35	13
			lasiocarpa	0.31	13,42
			magnifica	0.36	42,97
			procera	0.37	33,42
			spp.	0.34	33
		Tsuga	*canadensis*	0.38	15,45,65,101
			heterophylla	0.42	1,13,33,42,56,86
			mertensiana	0.42	33,42,56
Pine	43	*Pinus*	*albicaulis*	0.37	13
			banksiana	0.40	37,43,51,61,90
			contorta	0.38	13,17,33,34,42,73,84
			discolor	0.50	99
			edulis	0.50	27,39
			jeffreyi	0.37	42
			lambertiana	0.34	33,42
			monophylla	0.50	64
			monticola	0.35	13
			ponderosa	0.38	13,33,36,42,84
			resinosa	0.41	9,36,51,101
			rigida	0.47	98
			strobus	0.34	36,45,53,61,65,92,101
			taeda	0.47	68,69,80,94
Spruce	28	*Picea*	*abies*	0.38	36,49,93
			engelmannii	0.33	13,42,57
			glauca	0.37	6,32,41,51,52,90
			mariana	0.38	5,32,40,51,66,70,82,90
			rubens	0.38	32,61,89
			sitchensis	0.37	11,42
			spp.	0.38	65,101
Woodland	11	*Acacia*	spp.	0.60	28,60,88
		Cercocarpus	*ledifolius*	0.81	21
		Juniperus	*monosperma*	0.45	39
			osteosperma	0.44	27,64
		Prosopis	spp.	0.58	29,95
		Quercus	*gambelii*	0.64	24
			hypoleucoides	0.70	99

* Reference numbers are matched to authors in Table 2.

Table 6. Parameters and equations* for estimating component ratios of total aboveground biomass for all hardwood and softwood species in the United States.

Species class	Biomass component	Parameters β_0	β_1	Data points†	R^2
Hardwood	Foliage	–4.0813	5.8816	632	0.256
	Coarse roots	–1.6911	0.8160	121	0.029
	Stem bark	–2.0129	–1.6805	63	0.017
	Stem wood	–0.3065	–5.4240	264	0.247
Softwood	Foliage	–2.9584	4.4766	777	0.133
	Coarse roots	–1.5619	0.6614	137	0.018
	Stem bark	–2.0980	–1.1432	799	0.006
	Stem wood	–0.3737	–1.8055	781	0.155

* Biomass ratio equation:

$$ratio = \text{Exp}\left(\beta_0 + \frac{\beta_1}{dbh}\right)$$

where

ratio = ratio of component to total aboveground biomass for trees 2.5 cm dbh and larger

dbh = diameter at breast height (cm)

Exp = exponential function

ln = log base e (2.718282)

† Number of data points generated from published equations (generally at 5 cm dbh intervals) for parameter estimation.

Deriving Weight / Biomass Directly from Upper-stem Diameters

To estimate biomass (weight) for a tree when armed with a series of outside bark diameter measurements taken at various points along a tree stem, such as with a Relaskop, first convert outside bark diameter measurements to inside bark either by using bark thickness samples directly measured on the tree, or by using the mean Bark Thickness Ratios (BTR) appearing in Table 21 below. NOTE: The figures in Table 21 below are the square of BTR.

Then, use the mathematical formula(s) (Huber's, or Smalian's, or etc.) for the volume of appropriate geometric solids (paraboloids, or neiloids, or etc.) to obtain the volume, $V_{stemwood}$, of the entire tree stem. Then, use Table 6 to continue estimating biomass for different tree components, as before.

If the tree data you have are species, DBH, and height only, you are constrained to using a standard volume equation to estimate tree stemwood volume instead, as in the previous section.

Table 21. Mean Squared Bark Thickness Ratios for Top of 16-Foot Logs.1/

Species	Bark Thickness Ratio Squared		
	Oregon	Western Washington	Alaska
Ponderosa pine	.820		
Western larch	.810		
Sugar pine	.780		
Concolor fir	.805		
Incense cedar	.699		
Douglas-fir			
25 to 50 years	.850		
over 50 years	.812		
Western hemlock	.891	.885	.86
Western red cedar	.903	.895	.88
Sitka spruce	.925	.937	.90
Lodgepole pine		.899	
White pine		.933	
Noble fir		.902	
Red alder		.890	
Alaska cedar			.90

1/ Ratios are merely guides since variation is found from area to area. Sources: Alaska, U.S.F.S.; Washington, Dept. of Nat. Res.; Oregon, Mason, Bruce & Girard, and Oregon State University.

2/ BTR = dib/dob

Source: Bell, J.F. and J.R. Dilworth. 2007 – Revised Ed. Log Scaling and Timber Cruising.

Forest Biomass

A useful definition for *forest biomass* is total amount of above-ground living organic matter expressed as oven-dry tons per unit area (*Necromass* is commonly used to refer to dead organic matter)

Knowing forest biomass is important for

- Deriving estimates of carbon pools
- Studying other biogeochemical cycles

Forest vegetation biomass would be that portion of forest biomass that excludes non-plant biomass

The distinction has been made between forest vegetation biomass and *timber biomass*, which is the biomass in merchantable trees, including their bark, branches, foliage, and coarse roots *and* cull trees *and* salvageable dead trees

The most economical way to estimate timber biomass is from forest inventory data, but problems arise, because:

The minimum DBH of trees in the inventory is often greater than 4 inches, sometimes as large as 20 inches (worldwide),

The maximum DBH class in stand tables generally lumps the very large trees into this single class,

Frequently, only commercial trees species are included in forest inventory info,

Definition of inventory volume is often not consistent (CVTS, CV4, SV6, etc.)

Using forest inventory data to estimate forest biomass begins with estimating *Aboveground biomass density* (aboveground biomass in trees per unit area)

Reduction factors to account for rot must then be developed (can range widely, say from 0.80 to 0.96 in certain forest types), as well as

Expansion factors to account for the biomass in the DBH classes below minimum tally threshold (ranging from 1.0 to 4.5 for types of forests in NE United States)

Expansion factors to account for [absent from inventory] non-commercial species

Forest Carbon

The Kyoto protocol and its follow-ups have established a mechanism by which the quantity of carbon captured or sequestered by a forestry project can be sold to companies or countries to count against reductions that they are obligated to effect to meet carbon emissions limits

Where studied, the weight of carbon in vegetation expressed as a proportion of biomass for most plant species is somewhere between 0.45 and 0.55 – in the absence of information for a particular species, a value of 0.50 is most often used

Factors to convert tree biomass to carbon (kg)

Region	Forest Type	Softwood	Hardwood
Rocky Mountain	Douglas-fir	0.512	0.496
and Pacific Coast	Ponderosa Pine	0.512	0.496
	Fir-Spruce	0.512	0.496
	Hemlock-Sitka Spruce	0.512	0.496
	Lodgepole pine	0.512	0.496
	Larch	0.512	0.496
	Redwoods	0.512	0.496
	Hardwoods	0.512	0.496

Source: Birdsey, R.A. 1992.

Establishing how much carbon is in the soil is quite difficult; it often accounts for upwards of 50% of the carbon stock in forest ecosystems

Summary

1. Knowledge of tree and tree component biomass provides valuable information for productivity, carbon storage and sequestration, etc.
2. Applying “local” biomass equations to a species regardless of age and geographic region is flawed; methods analogous to Volume Ratio Systems are preferred, such as Jenkins, et al.
3. Total stem volume can be estimated by direct measurement, using a relaskop to find upper stem diameters, or by using a standard vol. eqn.
4. Estimating forest biomass from forest inventory data is problematic, at best

Further Reading

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