Chapter 11. **Biomass and Utilization of Trees**

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Biomass is a measure of biological matter, customarily expressed in weight. The biomass of a forest is a complex topic that includes all organisms, trees, fungi, insects, and so forth, and is beyond the scope of this book. This chapter focuses on biomass of trees. Tree biomass may be that of a single individual or all individuals occupying a unit of area. Since trees have a substantial moisture content (Chapter 1), weights may be either with (i.e., green) or without (i.e., oven-dry) moisture. The remainder of this chapter is concerned with oven-dry biomass of individual trees and the relation between biomass and utilization.

Components of Tree Biomass

The biomass of trees is often subdivided into above- and below-ground components with further subdivisions of each. For example, above-ground biomass includes foliage, branches, stem, and bark. Various researchers may define components somewhat differently. Table 11-1 presents equations for estimating oven-dry biomass components of many commercial tree species found in the Pacific Northwest (Gholz et al. 1979).

Figure 11-1 shows an example of biomass distribution of a 16 inch (40.64 cm) dbh Douglas-fir tree as calculated from the equations in Table 11-1. About 83% of the biomass of this tree is above-ground and 17% is below-ground. The stem, including bark, is about 72% of the total biomass.

Care must be exercised in interpreting biomass data. Some researchers report only the above-ground portions; the stem (with bark) of the 16 inch Douglas-fir represents 87% of its above-ground biomass. Some may consider the stump as part of the stem, while others include it with the roots. The stem biomass may be the entire stem to the tip of the tree or it may be measured to a minimum top diameter with the remainder considered part of the crown. The original researchers' report must be examined to be certain that definitions of components are clearly understood. The reference for Table 11-1 is a compilation from many sources and lists the original sources.

Biomass Utilization

Harvesting systems are involved in removing portions of the above-ground biomass. Whole-tree harvesting converts most of the above-ground biomass into logs and chips. Whole-tree harvesting is relatively uncommon because markets for chips that contain bark and foliage are often weak. The more common harvesting practice converts just the stem into logs of specific sizes that are later converted to poles, lumber, veneer, and other products. Each of these processes has a minimum size of log that can be used. This generally means that the portion of the stem less than about 4 inches in diameter is not made into logs and is left in the forest along with the crown and below-ground biomass. In some trees, a portion of the stem may also be unusable because it is too crooked, rotten, or broken. Generally these losses, termed *defect percent*, are low in young-growth trees but can be as high as 70% or more in old-growth trees with advanced decay.

Figure 11-2 presents a material balance for the 16 inch Douglas-fir tree with the following assumptions: (1) The minimum top diameter is 4 inches (10.16 cm). The weight of wood and bark in the stem above this point was estimated by substituting this diameter into the stem wood and stem bark biomass equations. Thus 19.6 kg of stem wood and 3.8 kg of stem bark were left in the forest in the form of an unused top. (2) The defect percentage to account for other stem losses, perhaps a region of rot or crookedness, is 2%. (3) Five logs, 16 feet in length and having small end diameters (inside bark) from 4 to 12 inches, were obtained from the stem. The material balance in Figure 4-1 for processing logs into dimension lumber was applied to each log. The combined results are:

40%	becomes surfaced-dry lumber
43%	becomes chips
7%	becomes sawdust
10%	becomes planer shavings/dry trim
100%	total

Table 11-1. *Equations for predicting tree biomass (in kilograms) of Pacific Northwest species.*

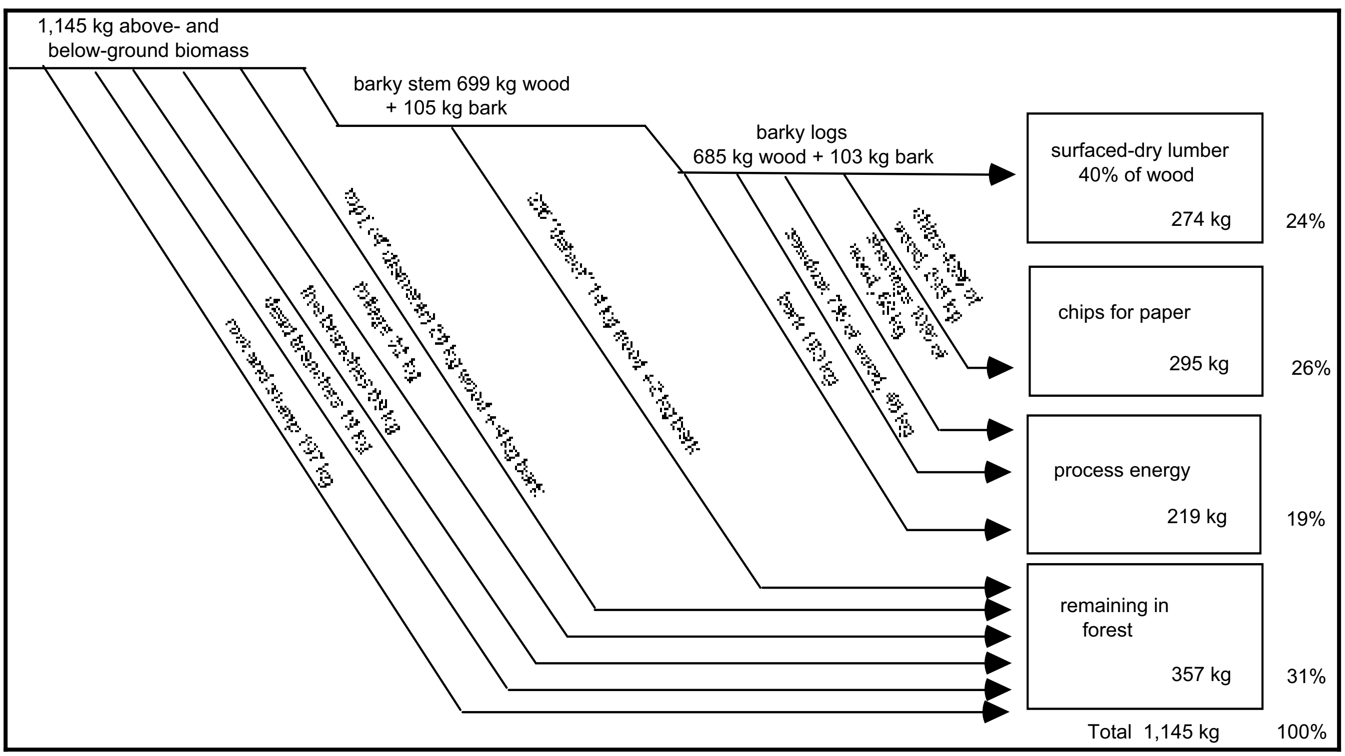
Species	Y	X	Equation
Abies, species	Total foliage	dbh	ln Y = – 3.4662 + 1.9278 ln X
True fir	Live branches	"	ln Y = – 4.8287 + 2.5585 ln X
(pooled)	Stem wood	"	ln Y = – 3.7389 + 2.6825 ln X
	Stem bark	"	ln Y = – 6.1918 + 2.8796 ln X
Abies amabilis	Total foliage	"	ln Y = – 4.5487 + 2.1926 ln X
Pacific silver fir	Live branches	"	ln Y = – 5.2370 + 2.6261 ln X
	Stem wood	"	ln Y = – 3.5057 + 2.5744 ln X
	Stem bark	"	ln Y = – 6.1166 + 2.8421 ln X
Abies procera	Total foliage	"	ln Y = – 4.8728 + 2.1683 ln X
Noble fir	Live branches	"	ln Y = – 4.1817 + 2.3324 ln X
	Stem wood	"	ln Y = – 3.7158 + 2.7592 ln X
	Stem bark	"	ln Y = – 6.1000 + 2.8943 ln X
Acer macrophyllum	Total foliage	"	ln Y = – 3.765 + 1.617 ln X
Bigleaf maple	Live branches	"	ln Y = – 4.236 + 2.430 ln X
	Dead branches	"	ln Y = – 2.116 + 1.092 ln X
	Stem wood	"	ln Y = – 3.493 + 2.723 ln X
	Stem bark	"	ln Y = – 4.574 + 2.574 ln X
Alnus rubra	Total foliage	dbh^2 + H/100	Y = – 0.5124 + 0.1298X
Red alder	Total wood and bark above ground	"	Y = 0.02 + 2.09 X – $0.0015X^2$
	Stem wood plus bark	"	Y = 0.02 + 1.60 X – $0.0005X^2$
	Root	"	Y = 0.1 + 0.48 X – $0.0005X^2$
Castanopsis chrysophylla	Foliage	dbh	ln Y = – 3.123 + 1.693 ln X
	Live branches	"	ln Y = – 4.579 + 2.576 ln X
Golden chinquapin	Dead branches	"	ln Y = – 7.124 + 2.883 ln X
	Stem wood	"	ln Y = – 3.708 + 2.658 ln X
	Stem bark	"	ln Y = – 5.923 + 2.989 ln X
Chamaecyparis nootkatensis	Foliage	"	ln Y = – 2.617 + 1.7824 ln X
	Live branches	"	ln Y = – 3.2661 + 2.0877 ln X
+ *Thuja plicata*	Stem wood	"	ln Y = – 2.0927 + 2.1863 ln X
Cedar (pooled)	Stem bark	"	ln Y = – 4.1934 + 2.1101 ln X
Pines (pooled)	Foliage	"	ln Y = – 3.9739 + 2.0039 ln X
	Live branches	"	ln Y = – 5.2900 + 2.6524 ln X
	Dead branches	"	ln Y = – 3.7969 + 1.7426 ln X
	Stem wood	"	ln Y = – 4.2847 + 2.7180 ln X
	Stem bark	"	ln Y = – 4.2062 + 2.2475 ln X
Pinus contorta	Foliage	"	ln Y = – 3.6187 + 1.8362 ln X
Lodgepole pine	Live branches	"	ln Y = – 4.6004 + 2.3533 ln X
	Stem wood plus bark	"	ln Y = – 2.9849 + 2.4287 ln X
Pinus lambertiana	Foliage	"	ln Y = – 4.0230 + 2.0327 ln X
Sugar pine	Live branches	"	ln Y = – 7.637 + 3.3648 ln X
	Stem wood	"	ln Y = – 3.984 + 2.6667 ln X
	Stem bark	"	ln Y = – 5.295 + 2.6184 ln X
Pinus ponderosa	Foliage	"	ln Y = – 4.2612 + 2.0967 ln X
Ponderosa pine	Live branches	"	ln Y = – 5.3855 + 2.7185 ln X
	Dead branches	"	ln Y = – 2.5766 + 1.444 ln X
	Stem wood	"	ln Y = – 4.4907 + 2.7587 ln X
	Stem bark	"	ln Y = – 4.2063 + 2.2312 ln X
Pseudotsuga menziesii	Foliage	"	ln Y = – 2.8462 + 1.7009 ln X
Douglas-fir	Live branches	"	ln Y = – 3.6941 + 2.1382 ln X
	Dead branches	"	ln Y = – 3.529 + 1.7503 ln X
	Stem wood	"	ln Y = – 3.0396 + 2.5951 ln X
	Stem bark	"	ln Y = – 4.3103 + 2.4300 ln X
	Roots	"	ln Y = – 4.6961 + 2.6929 ln X
Tsuga heterophylla	Foliage	"	ln Y = – 4.130 + 2.128 ln X
Western hemlock	Live branches	"	ln Y = – 5.149 + 2.778 ln X
	Dead branches	"	ln Y = – 2.409 + 1.312 ln X
	Stem wood	"	ln Y = – 2.172 + 2.257 ln X
	Stem bark	"	ln Y = – 4.373 + 2.258 ln X
Tsuga mertensiana	Foliage	"	ln Y = – 3.8169 + 1.9756 ln X
Mountain hemlock	Live branches	"	ln Y = – 5.2581 + 2.6045 ln X
	Dead branches	"	ln Y = – 9.9449 + 3.2845 ln X
	Stem wood	"	ln Y = – 4.8164 + 2.9308 ln X
	Stem bark	"	ln Y = – 5.5868 + 2.7654 ln X

Source: Gholz et al. (1979). dbh = diameter at breast height (4.5 feet or 1.3 m), in centimeters. H = total height in meters.

Figure 11-1. *Biomass distribution of a 16 inch dbh Douglas-fir tree.*

Crown	**Oven-dry weight**	**Percent**
foliage	32 kg	2.8
barky live branches	62 kg	6.0
barky dead branches	19 kg	1.7
Total	*120 kg*	*10.5*
Stem or Bole		
wood	719 kg	62.8
bark	109 kg	9.5
Total	*828 kg*	*72.3*
Total Above Ground	*948 kg*	*82.8*
Below Ground		
roots and stump	*197 kg*	*17.2*
TOTAL TREE:	*1,145 kg*	*100.00*

Figure 11-2. *Biomass distribution of a 16 inch Douglas-fir tree when processed into dimension lumber.*



It is assumed that the material balance values, developed for cubic log volume, can also be applied to log weight.

The material balance shows that 33% of the total tree remains in the forest, serving useful ecosystem and soil stability functions. About 48% of the tree was converted to lumber and chips for paper, and 19% was converted by industrial boilers into energy for manufacturing the products. In many cases, the logs from the stem may be allocated to different processes; the first 17 feet may be allocated to plywood and the remainder to one or more sawmills. The material balance method can be easily expanded to show this allocation and the multiproduct conversions.

Volume of Standing Trees

Individual Tree Volume

Standing trees are usually measured in terms of volume rather than biomass components. Volume may be estimated in cubic feet, cubic meters, or one of the board foot log scaling systems discussed in Chapter 2. Volume may represent the entire stem or the merchantable stem. Merchantable volume may be the volume between an assumed stump height and a minimum top diameter or the total volume of a series of fixed-length logs that must exceed a minimum diameter. There are several methods for developing volume estimates, and results are commonly presented in volume tables. The reader is referred to Avery (1975) for elaboration on methods and to Bell and Dilworth (1990) for volume tables for a number of Pacific Northwest species.

Although the methods for obtaining tree volumes have some features in common with scaling actual logs after felling and bucking, some discrepancy can be expected between the estimated volume in the standing tree and the actual volume of logs obtained. Conversion factors between log scaling systems presented in Chapter 2 should not be assumed to be applicable to standing timber. Forest inventory reports of the U.S. Forest Service should be consulted for explanation of how tree measurements are taken, how volumes are estimated, and appropriate conversion factors between different volumes of standing trees.

Conversion between tree volume and biomass, while seemingly straightforward, requires knowledge of average wood specific gravity of standing trees of the species in question. Specific gravity varies internally in a tree, with its age and genetics, and geographically, hence obtaining an accurate local specific gravity value is not easy. Conversions between volume and biomass may also be complicated by lack of consistency in the measurements and definitions used by volume table developers and biomass researchers.

Forest Inventory

Inventories of standing timber are generally given in terms of volume stratified by species and stem diameter, which is taken outside bark at a height of 4.5 feet. This stem diameter is called *diameter at breast height* (dbh). Volume may be gross or, more commonly, net volume after taking into account unusable portions such as rot and poor form (sweep, crook, forks, etc.). The U.S. Forest Service conducts and publishes periodic forest inventories as "resource bulletins" for all states and subregions thereof, and provides information for various landowner categories. These bulletins also provide full descriptions of terminology, measurement standards, and conversion factors used.

Volume may be expressed in cubic feet or in board feet, according to regionally preferred board foot log rules. Often this means Scribner in the West and the International 1/4 inch rule in much of the rest of the United States. Chapter 2 explains these log rules. It should be pointed out that the actual volume realized, when a tree is harvested and logs are measured, is likely to differ from the volume estimated by inventory methods. Volumes are commonly segregated according to

Growing stock: Live trees of commercial species meeting certain standards of quality and vigor. When growing stock volume is reported, only growing stock trees 5.0 inches dbh and larger are included.

Sawtimber: Live trees of commercial species that contain at least one 12 foot sawlog or two noncontiguous 8 foot logs that meet regional specifications for freedom from defect. Softwood sawtimber trees must be at least 9.0 inches dbh, while hardwood sawtimber trees must be at least 11 inches dbh.

In addition, volumes may be presented according to more than one merchantability standard, such as cubic feet for the whole tree, cubic feet from the stump to a 4 inch diameter top, and so on.

Summary statistics for the entire United States are periodically prepared from the individual state reports giving both cubic foot and board foot (International 1/4 inch rule) volumes (Waddell et al. 1989).

Table 11-2 presents regional conversion factors based on these national statistics (Waddell et al. 1989). Ratios are presented separately for hardwoods and softwoods because (1) the average sizes of hardwood and softwood trees are normally different and (2) the lower limit for including a hardwood tree in the sawtimber category is 11 inches dbh rather than the 9 inch dbh for softwoods.

Columns 1 and 2 of Table 11-2 are ratios of cubic feet of growing stock and board feet of sawtimber. From the preceding definitions, note that all sawtimber size trees are included in the growing stock volumes. The percentage of total growing stock that is also sawtimber is given in column 3. The ratio of growing stock and sawtimber is a general index of tree size. It is also a rough index of quality since larger trees tend to be of better quality. Looking at column 1, as the ratio of growing stock volume (cubic feet) to sawtimber volume (board feet) decreases, more standing timber is in larger, higher quality sawtimber. This is also easily seen in column 3.

Column 4 applies only to the sawtimber category and represents the conversion from 1,000 BF International 1/4 inch scale to cubic feet. Column 5 is the reciprocal of column 4, added by the author, and is the number of International 1/4 inch board feet per cubic foot. Since these ratios are averages for whole trees based on standardized forest inventory procedures, they are likely to be different from counterpart ratios obtainable when logs are actually measured and scaled.

Table 11-2. *Growing stock/sawtimber inventory ratios in the United States, by softwoods and hardwoods, region and subregion, 1987.*

Region and Subregion	(1) Cubic feet growing stock per board foot sawtimber	(2) Board feet saw-timber per cubic foot growing stock	(3) Percent of growing stock in sawtimber	(4) Cubic feet per 1,000 board feet sawtimber	(5) Board feet sawtimber per cubic foot
SOFTWOODS					
North					
Northeast	0.3901	2.563	64.72	252.5	3.96
North Central	0.3538	2.827	54.75	193.7	5.16
Total	0.3720	2.695	59.73	223.1	4.48
South					
Southeast	0.3004	3.329	69.78	209.6	4.77
South Central	0.2511	3.982	76.82	192.9	5.18
Total	0.2758	3.656	73.30	201.3	4.97
Rockies					
Great Plains	0.2808	3.561	77.00	216.2	4.63
Rocky Mountains	0.2543	3.932	78.70	200.2	5.00
Total	0.2676	3.746	77.85	208.2	4.80
Pacific Coast					
Pacific Southwest	0.1601	6.244	95.02	152.2	6.57
Pacific Northwest	0.1725	5.798	88.56	152.7	6.55
Pacific Northwest-West	0.1714	5.835	93.06	159.5	6.27
Pacific Northwest-East	0.1736	5.762	84.07	145.9	6.85
Alaska	0.2201	4.543	92.20	202.9	4.93
Total	0.1842	5.529	91.93	169.3	5.91
United States	0.2749	3.953	75.91	198.4	5.04
HARDWOODS					
North					
Northeast	0.4529	2.208	54.19	245.4	4.07
North Central	0.3825	2.614	53.59	205.0	4.89
Total	0.4177	2.411	53.89	225.2	4.44
South					
Southeast	0.3454	2.896	65.26	225.4	4.44
South Central	0.3661	2.731	59.59	218.2	4.58
Total	0.3557	2.813	62.43	221.8	4.51
Rockies					
Great Plains	0.3000	3.333	65.86	197.6	5.06
Rocky Mountains	0.5059	1.977	36.74	185.8	5.38
Total	0.4029	2.655	51.30	191.7	5.22
Pacific Coast					
Pacific Southwest	0.3231	3.095	71.95	232.5	4.30
Pacific Northwest	0.3081	3.247	63.69	196.1	5.10
Pacific Northwest-West	0.3032	3.299	65.42	198.3	5.04
Pacific Northwest-East	0.3130	3.195	61.95	193.9	5.16
Alaska	0.5377	1.860	43.74	235.2	4.25
Total	0.3896	2.734	59.79	221.3	4.52
United States	0.3915	2.653	56.85	215.0	4.65

Source: Waddell et al. (1989). Column 5 added by the author.