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Stem diameter and dry weight relationships in *Tsuga canadensis* (L.) Carr.[1]

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SANTEE, WILLIAM R. and CARL D. MONK. (Dept. Bot., Univ. Georgia, 30602). Stem diameter and dry weight relationships in *Tsuga canadensis* (L.) Carr. Bull. Torrey Bot. Club. 108: 320-323. 1981.—Stem diameters and dry weight for bole, branches, bark and needles are given for twenty hemlock trees from the southern Appalachians. Simple allometric equations relating dry weights to dbh are also presented. Nutrient concentrations for fifteen elements are included.

Key words: standing crop; biomass, nutrients; *Tsuga canadensis*; diameter—weight relationships

Estimates of standing crop biomass in inviolate areas must be obtained through some nondestructive sampling technique. A frequently employed method is the development of regression equations whereby weight of standing crops of different tree components can be estimated from field measurements such as diameter and/or height coupled with the distribution of these among the individuals within the community. Such regression relationships have been established for many individual tree species as well as for mixed species populations (Monk *et al.* 1970; Ovington *et al.* 1967; Satoo 1970; Whittaker 1966; Whittaker and Woodwell 1968; Young *et al.* 1964).

In a mineral cycling project in managed and unmanaged watersheds in the southern Appalachians, estimates of standing crop biomass, net primary production and seasonal dynamics of mineral uptake were determined (Day and Monk 1974; 1977a; 1977b). The data for the regressions to estimate standing crop biomass came from a variety of sources (Sollins and Anderson 1971; Monk *et al.* 1971; Whittaker and Woodwell 1968). The data used to estimate biomass of eastern hemlock (*Tsuga canadensis* (L.) Carr.) are presented in this paper.

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Methods. Twenty hemlock trees were harvested from a watershed in the Coweeta Hydrologic Laboratory near Franklin, N.C. Trees were selected to provide a continuous sample from 1.4 cm dbh to the maximum present on the site. The sample population was chosen to duplicate the tree size range of a hemlock population located on another watershed that was the subject of an intensive biomass study (Day and Monk 1974). Basal and breast height diameters and crown width were measured on the standard tree. Height was measured from the felled tree; then the tree was separated into bole and branch components and transported to a storage area. Wet bole weight was determined and the boughs were allowed to air dry prior to separation of needles from branches. Current year needles were separated from older needles on two trees. Air dried bole, branch and needle subsamples were dried at 80°C. Single-variable, logarithmic, least-squares regressions were determined for dbh versus bole, branch, needle and total dry weight.

Results. The dimensions of the 20 harvested hemlock trees are given in Table 1 along with the data for three larger trees from the Great Smoky Mountains (Clebsch 1971). The sampled population is representative of 95 percent of the hemlock on the study site (Day 1971) and covers a range of values up to 26 cm dbh, 20 m high and 300 kg in total weight.

Using log-log conversions all of the dry weight components are significantly corre-

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Table 1. Diameter, height and dry weights for a population of hemlock from the southern Appalachians.

dbh (cm)	basal diameter (cm)	height (m)	crown width (m)	dry wt. bole (kg)	dry wt. branch (kg)	dry wt. bark (kg)	dry wt. needles (kg)	total standing (kg)
1.40	2.60	2.74	1.53	0.21	0.25	0.034	0.14	0.60
1.40	3.30	2.95	2.13	0.34	0.36	0.025	0.26	0.97
1.47	2.97	3.00	2.74	0.37	0.27	0.028	0.21	0.85
2.06	3.99	3.99	2.74	0.60	0.45	0.057	0.36	1.41
2.08	3.62	3.05	3.35	0.48	0.49	0.042	0.32	1.29
2.54	4.06	4.06	2.44	0.55	0.74	0.046	0.64	1.94
3.05	5.08	3.28	2.44	0.83	0.59	0.123	0.56	1.98
4.32	6.86	4.27	3.66	1.59	2.85	0.167	0.86	5.30
4.57	6.35	6.12	4.27	2.10	3.19	0.130	0.80	6.08
6.55	8.89	7.49	3.35	4.63	2.76	0.497	1.35	8.75
6.73	9.53	8.41	4.88	6.82	2.04	0.510	0.75	9.62
8.13	10.80	8.84	3.96	8.42	4.68	0.147	1.81	14.90
8.64	11.43	8.66	3.35	9.00	5.97	0.782	2.25	17.21
9.02	12.19	12.12	5.49	15.05	5.04	1.122	1.42	21.51
12.70	15.75	10.16	4.27	23.63	18.41	2.236	3.77	45.81
14.99	19.94	13.11	5.79	41.60	16.55	3.347	5.54	63.69
14.99	19.81	13.11	3.96	44.39	16.87	4.500	4.00	65.26
17.86	23.37	12.14	6.40	66.72	26.89	7.699	10.00	103.61
18.54	24.38	11.71	6.71	74.55	42.81	5.600	11.46	128.82
26.16	32.00	20.32	9.14	194.57	87.78	22.700	13.91	299.26
68.60*	—	24.00	—	2017.7	730.68	—	37.71	2786.1
80.30*	—	32.60	—	3741.8	1589.9	—	49.02	5380.7
85.10*	—	26.50	—	3183.2	1654.7	—	57.08	4895.0

*(Clebsch 1971).

lated with stem diameter. All of the coefficients of determination (r^2) are 0.94 or higher. The equations for the needles, branches and bole dry weights are:

(1) $\log Y = -0.9433 + 1.3926_{\log} x\ (0.0090)$[3]

(2) $\log Y = -1.0448 + 2.0811_{\log} x\ (0.0180)$

(3) $\log Y = -1.0891 + 2.3418_{\log} x\ (0.0094)$

The ratio of wet to dry weight for the boles is 0.444. This value was obtained by dividing total estimated bole weights for all 20 individuals by their total wet weight. This conversion factor is similar to a value of 0.440 derived from three smaller trees weighed wet then dried whole.

A subsample of 100 needles had dry and wet weights of 1.28 mg and 2.78 mg with an average needle surface area of 0.725 cm^2. Current year needles were separated from the older needles for two sample trees. One tree yielded a ratio of new to old needles of 0.332, the other a 0.194 ratio.

The concentrations of fifteen elements in different components of hemlock are presented in Table 2. Nitrogen is in the highest concentrations in leaves and cones and lowest in wood tissue. Phosphorus and K exhibit a similar pattern. Calcium is found in greater concentrations in the bark and leaves while Mg is found more abundantly in leaves.

Discussion. The regression equations developed for the 20 sample trees in this study accurately describe the relationship that exists between dbh of those trees and different weight components of hemlock (Table 1); however, the equations give very low estimates of branch and bole weights of trees larger than 26 cm dbh. The equations given in this paper underestimate the weights of larger trees (Clebsch 1971) by 25–50 percent. Starting with small sized individuals, branch and bole weights are similar in magnitude. As trees become larger, bole weight surpasses branch

[3] Values in parentheses are correction factors based on Baskerville (1972).

Table 2. Nutrient concentrations (% weight for N, P, K, Ca, Mg and ppm for all other) in different parts of hemlock.

	Needles	Branches	Bark	Wood	Cones
N	1.340	0.500	0.525	0.229	1.100
	0.027	0.015	0.122	0.022	
P	0.168	0.104	0.115	0.084	0.160
	0.0002	0.0001	0.0001	0.0001	
K	0.671	0.188	0.243	0.139	1.180
	0.016	0.001	0.006	0.006	
Ca	0.575	0.371	0.684	0.046	0.040
	0.038	0.005	0.032	0.0003	
Mg	0.126	0.002	0.014	0.003	0.020
	0.0007	0.00002	0.0003	0.00002	
Mn	734	381	472	105	218
Fe	124	91	55	83	43
B	35	12	6	12	2
Cu	8	13	10	11	11
Zn	19	26	14	27	11
Al	788	275	414	55	350
Mo	4	3	3	2	2
Sr	20	14	25	4	4
Ba	41	60	105	10	3
Na	<1	4	22	25	<1
Numbers	17	17	17	17	1

weight at about 5 cm dbh and remains larger thereafter. The decreased branch to bole ratio has been noted by other authors. Whittaker (1966) gives values ranging from 28 to 90 percent in trees. The branch to bole ratio in hemlock varies with tree size but eventually stabilizes around 40 to 50 percent.

Nicholson (1975) estimated dry leaf weight for a variety of tree species. Leaf weight for a standard type of 25.4 cm dbh is generally greater for gymnosperm than angiosperm species. The average dry weight of leaves for 26 species of angiosperms is 10.0 kg versus 19.2 kg for 18 conifer species. Hemlock, using the formula developed in this study, had a calculated needle weight of 10.3 kg, a value more similar to angiosperms than to most gymnosperms.

Young and Carpenter (1967) give the concentrations of twelve nutrients in hemlock from Maine. The concentrations of those elements in the hemlocks from the southern Appalachians are equal to or greater than the concentrations found in Maine with the exception of Ca in wood. No differences are evident in N, Mn, Fe, Zn or Mo in any of the plant tissue while K and Cu are higher in all plant tissues in the southern Appalachians. The Coweeta hemlocks had more P, Mg, and B in branches and wood; the needles and branches had more Al.

The nutrient concentrations within the plant tissue of hemlock from the southern Appalachians tended to be less than those generally found in the broadleaved trees of the area (Day and Monk 1977b; Boring, Monk and Swank, unpub. data). This is particularly true for N, K, Ca and Mg. In fact the nutrient characteristics of hemlock are very similar to other species of the sclerophyllous component of the southern Appalachian vegetation. Tissue concentrations may vary with carbon density even though the ratios of other elements with each other may not. Thus sclerophyllous leaves would tend to have high carbon densities and low elemental concentrations.

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