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Dimension Relations of Branches in Hinoki (*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.)

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Abstract

All the 114 branches of a 26-year-old hinoki (*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.) tree were cut along the stem. The following measurements were obtained on each branch : total length, clear length (length to the first fork of the second-order branches), diameter at the base, diameter at the upper end of the clear length, and diameter at a distance of 10% of the total length from the base. The regression of branch dry weight, leaf dry weight or leaf area on diameter or diameter squared times length was examined on logarithmic coordinates. It was concluded that the diameter at the base d_0 was the most appropriate dimension for estimating the weight of a branch w_c, and the weight w_f and the area u of leaves on the branch, though the use of d_0 led to lessening accuracy of their estimates to some extent, especially in leaves. Regression equations showing the allometric relationships of w_c [g], w_f [g], and u [dm^2] to d_0 [cm] were as follows : $w_c = 10.8 d_0^{3.67} (r^2 = 0.93)$, $w_f = 33.6 d_0^{2.46} (r^2 = 0.85)$, and $u = 17.6 d_0^{2.47} (r^2 = 0.86)$.

Key words : allometric equation, branch diameter at the base, branch weight, leaf area, leaf weight.

I. Introduction

This paper is part of a study on the structure and functions of a hinoki (*Chamaecyparis obtusa* (Sieb et Zucc.) Endl.) plantation (MORI and HAGIHARA, 1991; HAGIHARA and YAMAJI, 1993). Such a study demands knowledge of the spatial distributions of branch and leaf biomasses, and leaf area. A resolution to overcome obvious difficulties in measuring the spatial distributions is to correlate the weight of a branch or the weight (or the area) of leaves on the branch with easily measurable characteristics, such as branch diameter (ROTHACHER *et al.*, 1954; ATTIWILL, 1962). Once the regression is established from destructive samples, it becomes possible to estimate the spatial distributions non-destructively by combing it with results of branch census.

The base of such correlation is reduced to the allometric relationship between different dimensions of a tree. KITTREDGE (1944) first showed that an allometric regression existed between the leaf weight or the leaf area of a tree and dbh. This principle

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was applied for estimating the amounts of stems and branches, and further elaborated by introducing stem diameter at the height just below the lowest living branch, as well as the combined use of tree height and dbh (or stem diameter at a height of one-tenth of the tree height) into the allometric regression (OGAWA and KIRA, 1977).

This paper deals with establishment of allometric relationships among dimensions of hinoki branches. Each case of the allometric correlations between the weight of a branch and branch diameter (or branch diameter squared times branch length), and between the weight (or the area) of leaves on the branch and branch diameter (or branch diameter squared times branch length) is examined.

II. Materials and Methods

1. *Site description*

This study was carried out in a hinoki (*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.) plantation on Aichi Prefectural Forest Research Institute, 70 km east of Nagoya. This forest is located on an 18.5° north-east facing slope at an altitude of 435 m. No artificial management has been applied to the plantation for the last 20 years. Stand age, tree density, mean tree height, mean stem diameter at breast height (dbh), and mean clear bole length were respectively 26 yr, 2281 trees ha^{-1}, 9.8±0.12(SE) m, 15.8±0.34 cm, and 4.7±0.13 m.

2. *Collection of data*

Measurement was performed on a representative tree, whose size was 10.7 m in total height, 5.3 m in clear bole length, 15.9 cm in dbh, 10.3 cm in stem diameter at the position of the clear bole length, and 15.0 cm in stem diameter at a height of 10% of the total height as of August 1988. All the branches were cut along the stem from the lowest branch upwards. Number of the branches was five between 5.3 and 6.3 m, 15 between 6.3 and 7.3 m, 25 between 7.3 and 8.3 m, 29 between 8.3 and 9.3 m, and 40 between 9.3 and 10.3 m above ground, yielding a total of 114 (Appendix 1).

As illustrated in Fig. 1, the following measurements were obtained on each branch ; total length l, clear length l_b, diameter at the base d_0, diameter at the upper end of the clear length d_b, and diameter at a distance of $l/10$ from the base $d_{0.1}$. Immediately after measuring the various diameters and lengths of a branch, leaves on the branch were clipped, and thereafter the branch and the leaves were separately weighed.

Branch and leaf samples were randomly taken from each stratum for dry weight determination. Before the leaf samples were oven-dried, their area was determined with an area meter (AAC-100, Hayashi Denkoh Co., Ltd., Tokyo) for calculating specific leaf area. The specific leaf area tended to decrease from the upper layer to the bottom layer of the tree, ranging from 46.7 to 61.3 $cm^2\ g^{-1}$. Ratios of dry weight to fresh weight of the samples were determined and used for estimating the dry weight of a branch and leaves on the branch. The leaf weight was converted into the corresponding leaf area using the specific leaf area of the leaf samples.

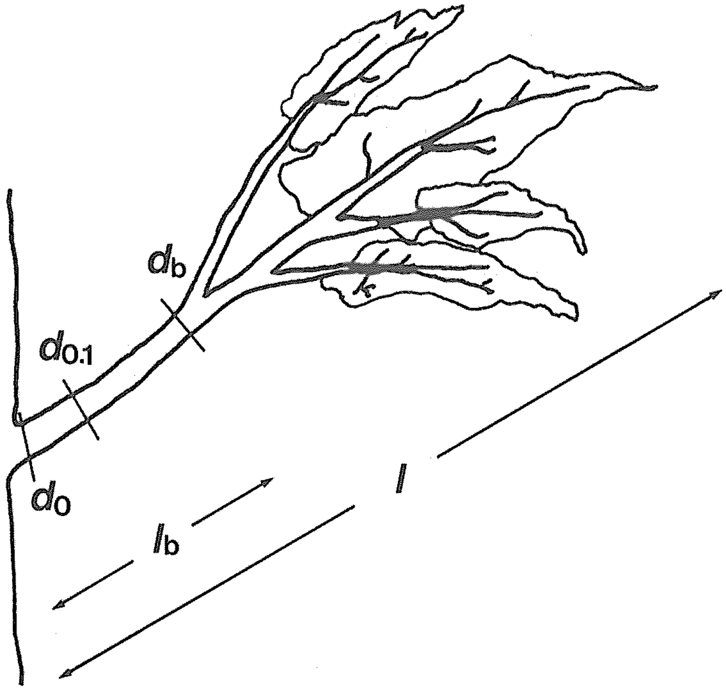

Fig. 1. Diagrammatic representation, showing dimensions of a branch attaching directly to the stem. l, total length; l_b, clear length from the base to the point just before secondarily branching; d_0, diameter at the base; d_b, diameter at the point just before secondarily branching; $d_{0.1}$, diameter at a distance of l/10 from the base.

Table 1. Values of the allometric constant h and the constant A in Eq. (1). d_0, diameter at the base; d_b, diameter at the point just before secondarily branching; $d_{0.1}$, diameter at a distance of one-tenth of total length; l, total length; l_b, clear length.

Variable x	Variable y								
	Branch weight w_c [g]			Leaf weight w_f [g]			Leaf area u [dm^2]		
	h	A	r^2	h	A	r^2	h	A	r^2
[cm]									
d_0	3.67±0.09	10.8	0.93	2.46±0.10	33.6	0.85	2.47±0.10	17.6	0.86
d_b	3.46±0.15	19.0	0.83	2.41±0.11	50.7	0.82	2.43±0.11	26.7	0.83
$d_{0.1}$	3.40±0.06	25.2	0.97	2.26±0.08	59.0	0.87	2.28±0.08	31.0	0.88
[cm^3]									
$d_0^2 l$	1.18±0.02	0.0658	0.97	0.79±0.03	1.11	0.88	0.79±0.03	0.572	0.89
$d_b^2 l$	1.18±0.03	0.100	0.94	0.81±0.03	1.39	0.89	0.81±0.03	0.714	0.90
$d_{0.1}^2 l$	1.12±0.01	0.153	0.99	0.74±0.03	1.96	0.89	0.75±0.02	1.01	0.90
[cm^3]									
$d_0^2(l-l_b)$	1.21±0.02	0.0677	0.96	0.82±0.03	1.09	0.90	0.82±0.03	0.561	0.90
$d_b^2(l-l_b)$	1.18±0.04	0.114	0.90	0.82±0.03	1.46	0.88	0.82±0.03	0.751	0.89
$d_{0.1}^2(l-l_b)$	1.15±0.02	0.157	0.98	0.77±0.02	1.95	0.91	0.78±0.02	1.01	0.91

The value of h is represented with the standard error SE.

III. Results and Discussion

The allometric equation holds quite well between two different dimensions of a tree (OGAWA and KIRA, 1977). This relationship is of the form:

$$y=Ax^{h}, \quad (1)$$

where A and h are constants specific to each case.

Equation (1) was applied to branches of hinoki, in which equation the dependent variable y was the weight of a branch or the weight (or the area) of leaves on the branch, while the independent variable x was a dimension of the branch : diameter at the base, d_0 ; diameter at the point just before branching, d_b ; diameter at a distance of one-tenth of total length from the base, $d_{0.1}$; diameter squared times total length, $d_0^2 l$, $d_b^2 l$, $d_{0.1}^2 l$; diameter squared times length of a part bearing leaves, $d_0^2(l-l_b)$, $d_b^2(l-l_b)$, $d_{0.1}^2(l-l_b)$.

Equation (1) was fitted through a data set of 112 branches (for branch weight) and of 111 branches (for leaf weight and area) except for two branches, which belonged to a 6.3-7.3 m height layer and whose tops were broken (see Appendix 1), by the method of least squares. Results of the regression are summarized in Table 1. The coefficient of determination r^2 had higher values in the case of branch weight, where the value ranged from 0.83 to 0.99, than in the cases of leaf weight and area, where the value ranged from 0.82 to 0.91. The branch weight showed a better regression on diameter squared times l, while the leaf weight and area tended to have a better correlation with diameter squared times $l-l_b$. The best fit was dimensions of $d_{0.1}^2 l$ and $d_{0.1}^2(l-l_b)$ respectively for the branch weight, and for the leaf weight and area.

Figures 2, 3, and 4 represent the respective regressions of branch weight w_c, leaf weight w_f, and leaf area u on branch diameter at the base d_0. In the branch weight the fit of the data to the regression line was satisfactorily good over the whole range of strata, where branches were attached to the stem (Fig. 2), while in the leaf weight and area the data were more or less scattered around the respective regression lines (Figs. 3 and 4). The coefficient of determination was 0.93 for the branch weight, 0.85 for the leaf weight, and 0.86 for the leaf area. These values were not so small in comparison with values in the other cases (Table 1).

Measurement of branch dimensions tends to be tedious and time-consuming. The branch diameter at the base is the most easily measurable characteristic of the branch dimensions. It may be concluded that the branch diameter at the base d_0 is the most appropriate dimension for estimating the weight of a branch and the weight and area of leaves on the branch of forest trees, though the use of d_0 inevitably lead to lessening accuracy of their estimates to some extent, especially in the leaf weight and area.

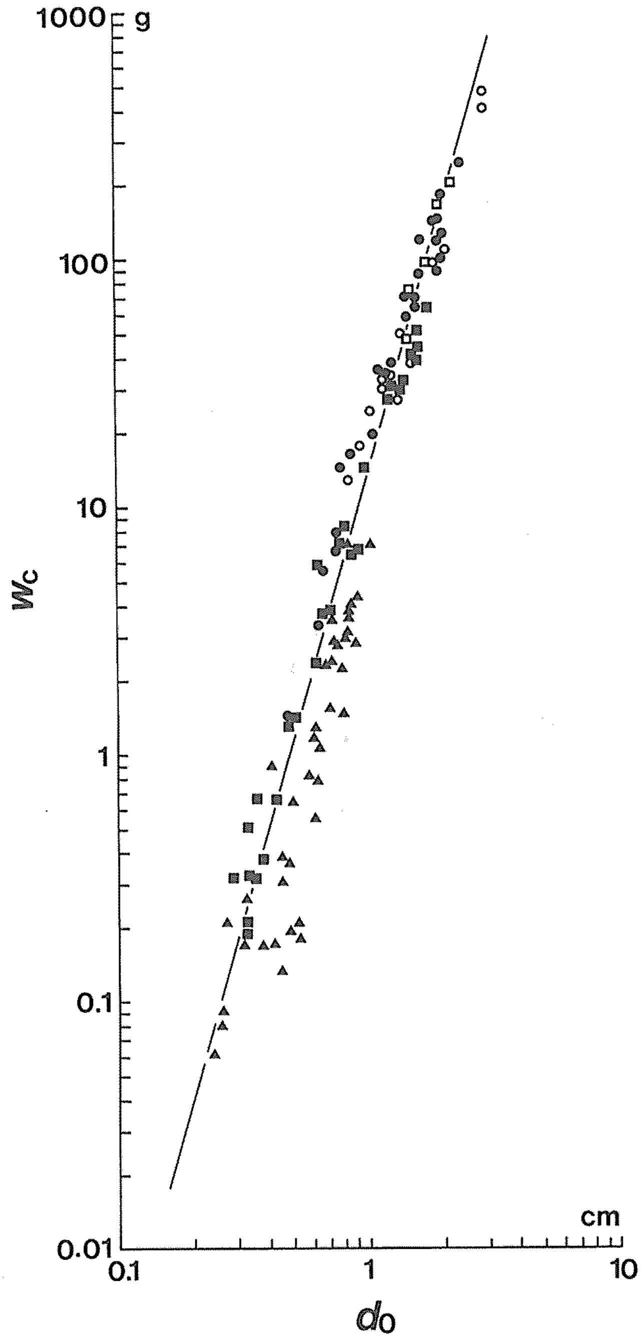

Fig. 2. Regression of branch weight w_c [g] on branch diameter at the base d_0 [cm] plotted on logarithmic coordinates. □, 5.3-6.3 m; ○, 6.3-7.3 m; ●, 7.3-8.3 m; ■, 8.3-9.3 m; ▲, 9.3-10.3 m. The straight line corresponds to an approximation by Eq. (1): $w_c=10.8\ d_0^{3.67}$ ($r^2=0.93$).

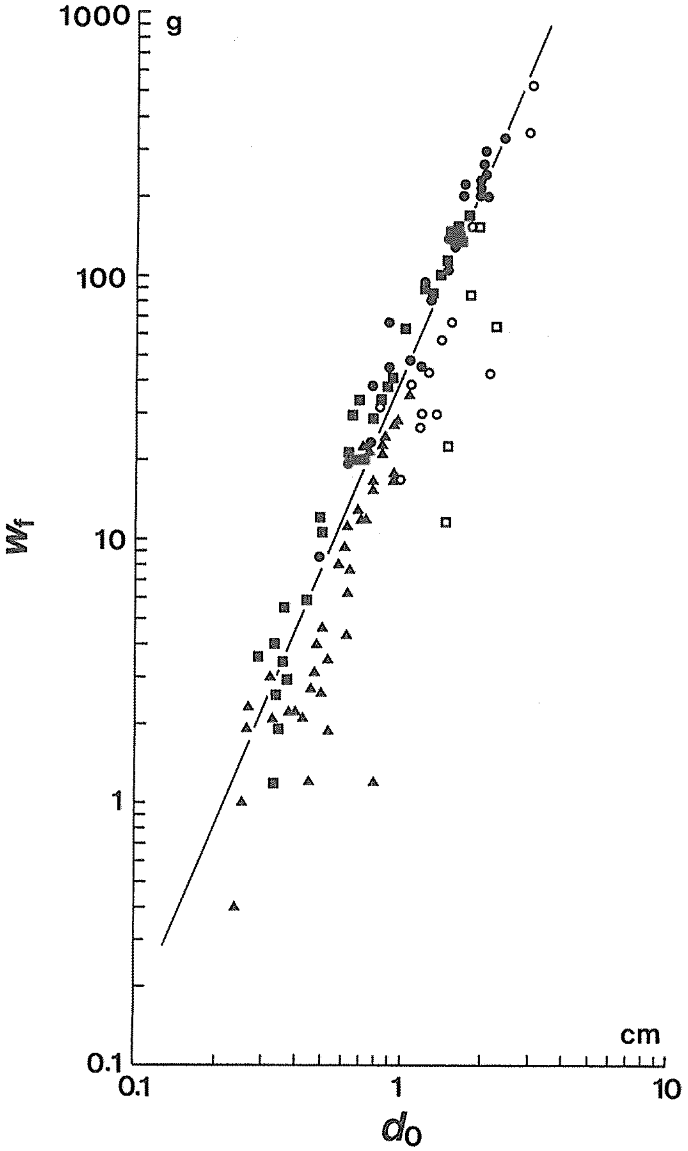

Fig. 3. Regression of leaf weight w_f [g] on branch diameter at the base d_0 [cm] plotted on logarithmic coordinates. The symbols are the same as in Fig. 2. The straight line corresponds to an approximation by Eq. (1) : $w_f = 33.6\ d_0^{2.46}$ ($r^2 = 0.85$).

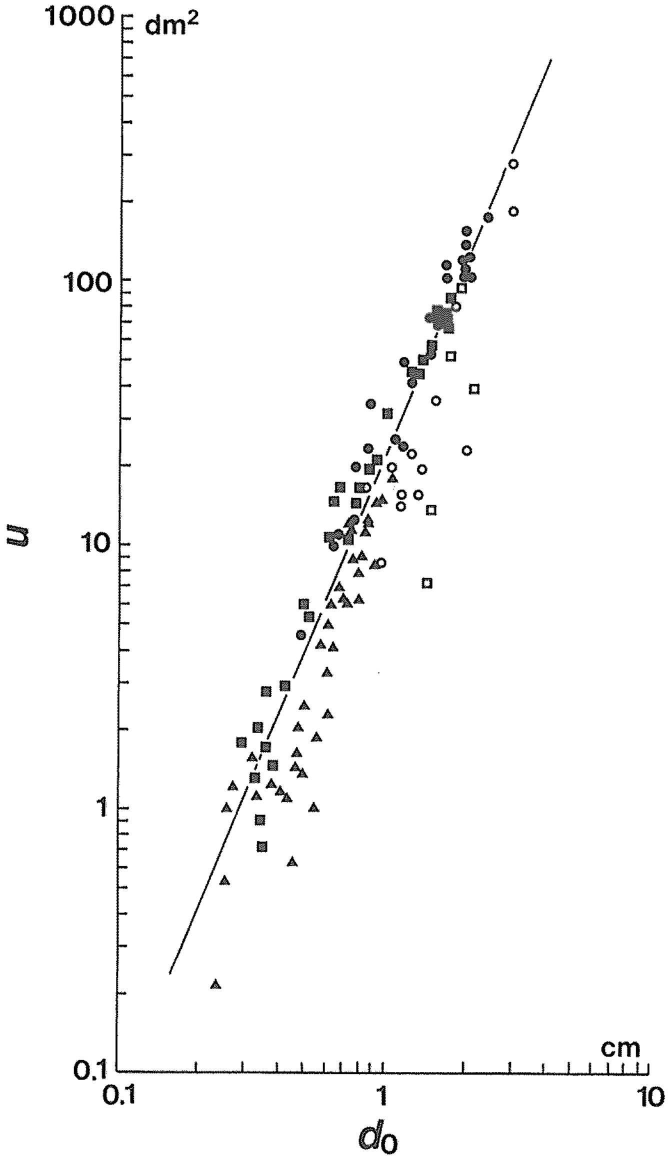

Fig. 4. Regression of leaf area u [dm^2] on branch diameter at the base d_0 [cm] plotted on logarithmic coordinates. The symbols are the same as in Fig. 2. The straight line corresponds to an approximation by Eq. (1) : $u=17.6\ d_0^{2.47}$ ($r^2=0.86$).

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ヒノキの枝直径と枝重，葉重および葉面積との相対成長関係

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26年生のヒノキ個体に付着する114本の枝全部を層別に幹から切取り，各枝の全長，2次枝の付け根までの長さ，元口の直径，2次枝の付け根の直径および全長の1/10での直径を測定した。直径または直径の自乗に長さを乗じた値と枝重，葉重または葉面積との相対成長関係をそれぞれ調べた。枝重と元口径との間には，枝が採取された層毎に分離することのない相対成長関係が認められた。葉重および葉面積と元口径との間の相対成長関係は層間で分離する傾向であったが，元口径の測定の容易さから，元口径から枝重，葉重および葉面積を推定することが妥当であろうと判断された。元口径を d_0[cm]，枝重を w_c[g]，葉重を w_f[g]，葉面積を u[dm^2]とすると，相対成長式はそれぞれ $w_c=10.8\,d_0^{3.67}(r^2=0.93)$，$w_f=33.6\,d_0^{2.46}$ $(r^2=0.85)$，$u=17.6\,d_0^{2.47}$ $(r^2=0.86)$ であった。

Appendix. 1. Statistics of branches. d_0, diameter at the base; $d_{0.1}$, diameter at a distance of one-tenth of total length; d_b, diameter at the point just before secondarily branching; l, total length; l_b, clear length; w_f, leaf dry weight; w_c, branch dry weight; u, leaf area.

Branch No.	d_0 [cm]	$d_{0.1}$ [cm]	d_b [cm]	l [cm]	l_b [cm]	w_f [g]	w_c [g]	u [dm²]
5.3-6.3m								
1	1.740	1.275	1.650	172.9	3.0	81.8	94.74	50.13
2	1.435	1.290	1.280	116.9	21.0	11.7	46.84	7.17
3	1.500	1.230	1.060	153.8	35.0	22.1	72.63	13.54
4	1.915	1.765	1.295	182.7	67.0	153.8	162.11	94.26
5	2.190	1.940	1.660	203.6	71.0	62.9	202.64	38.55
6.3-7.3m								
6	0.835	0.800	0.620	68.5	13.5	32.1	13.01	16.68
7	1.150	0.955	0.835	123.0	44.5	26.9	30.71	13.98
8	2.930	2.560	2.320	237.0	68.0	355.0	400.81	184.46
9	1.050	0.870	0.685	108.0	42.5	38.5	24.47	20.01
10	0.945	0.789	0.460	110.0	52.5	16.5	17.70	8.57
11	1.505	1.295	1.005	118.0	17.0	66.5	38.00	34.55
12*	1.185	1.020	0.900	77.0	21.0	3.5	12.49	1.82
13*	1.290	1.040	1.105	105.0	24.0	15.3	24.47	7.95
14	1.170	0.980	0.585	132.0	64.5	29.5	33.83	15.33
15	1.230	1.070	0.980	100.8	26.0	43.3	33.83	22.50
16	1.810	1.570	1.365	143.8	38.5	155.6	92.40	80.85
17	1.380	1.095	0.800	124.7	50.0	56.8	39.56	29.51
18	1.330	1.060	0.750	93.0	43.0	29.9	27.07	15.54
19	2.110	1.610	1.405	171.0	48.0	42.9	109.83	22.29
20	3.005	2.665	2.455	227.0	36.0	538.1	465.62	279.60
7.3-8.3m								
21	1.905	1.485	1.500	148.8	17.3	227.3	89.14	119.25
22	1.575	1.290	1.085	135.0	20.0	137.1	64.31	71.93
23	1.670	1.400	1.360	169.0	44.5	218.7	122.42	114.74
24	1.640	1.290	1.420	134.0	11.0	199.3	84.62	104.56
25	0.770	0.660	0.665	98.5	7.0	38.3	7.90	20.09
26	1.025	0.855	0.710	88.5	24.0	48.4	19.75	25.39
27	1.480	1.210	1.085	122.5	19.5	138.6	71.08	72.71
28	1.955	1.525	1.655	130.5	6.5	199.3	100.99	104.56
29	0.745	0.595	0.690	65.8	2.0	23.7	6.77	12.43
30	0.480	0.335	0.330	48.0	6.9	8.6	1.41	4.51
31	0.625	0.475	0.625	57.0	6.3	18.9	3.27	9.92
32	2.000	1.780	1.685	151.0	14.0	238.2	124.12	124.97
33	0.880	0.710	0.780	82.0	2.5	65.1	14.39	34.15
34	1.980	1.615	1.980	132.0	0.2	265.4	120.17	139.24
35	2.365	2.180	2.020	190.0	24.7	335.4	243.00	175.96
36	0.660	0.495	0.480	69.5	12.5	20.6	5.64	10.81
37	1.190	0.945	0.940	167.0	15.5	94.3	34.70	49.47
38	1.985	1.795	1.475	137.0	31.5	199.3	144.43	104.56
39	1.540	1.315	1.230	122.5	20.0	130.5	71.08	68.46
40	1.170	1.015	1.015	96.5	21.3	44.5	35.54	23.35
41	1.450	1.200	1.100	121.5	27.5	103.2	57.54	54.14
42	0.855	0.765	0.690	92.0	17.5	44.9	16.36	23.56
43	1.240	1.060	1.025	110.5	13.5	80.7	37.80	42.34
44	1.960	1.800	1.890	159.0	14.3	211.0	146.68	110.70
45	2.000	1.940	1.670	167.9	27.4	296.5	181.66	155.55
8.3-9.3m								
46	0.505	0.380	0.505	39.5	0.2	10.5	1.39	5.28
47	0.985	0.735	0.830	92.2	2.4	63.4	14.35	31.90
48	1.215	1.000	1.120	103.8	3.6	88.7	27.32	44.63
49	1.745	1.400	1.595	124.5	6.0	167.7	64.36	84.38
50	1.570	1.180	1.160	106.6	12.7	139.1	41.67	69.99
51	1.610	1.280	1.405	131.2	3.1	136.5	51.86	68.68
52	0.640	0.510	0.640	69.0	0.1	29.9	5.56	15.05
53	0.760	0.630	0.680	59.6	2.2	29.2	6.95	14.69
54	1.420	1.140	1.420	113.1	0.1	112.0	31.95	56.36
55	1.580	1.260	1.580	117.1	0.3	150.0	42.60	75.48
56	1.370	1.100	1.075	93.0	8.0	100.7	30.56	50.67

Branch No.	d_0	$d_{0.1}$	d_b	l	l_b	w_f	w_c	u
	[cm]			[cm]		[g]		[dm^2]
57	1.565	1.230	1.565	100.0	0.5	148.9	40.74	74.92
58	1.230	1.025	1.280	91.6	1.5	86.4	31.48	43.47
59	0.670	0.510	0.620	51.8	1.3	32.2	3.66	16.20
60	0.810	0.590	0.810	71.2	0.3	32.9	8.33	16.55
61	0.620	0.470	0.575	48.6	1.2	21.3	2.32	10.72
62	0.905	0.655	0.860	59.9	1.0	41.2	6.71	20.73
63	0.860	0.680	0.755	60.1	2.1	38.6	6.57	19.42
64	0.710	0.545	0.595	53.2	4.4	21.1	3.75	10.62
65	0.360	0.385	0.355	35.0	0.7	5.5	0.65	2.77
66	0.490	0.395	0.490	43.2	0.3	12.0	1.30	6.04
67	0.425	0.300	0.355	36.1	1.6	5.9	0.65	2.97
68	0.325	0.285	0.265	34.3	3.9	4.0	0.51	2.01
69	0.290	0.250	0.230	30.4	2.9	3.5	0.32	1.76
70	0.360	0.260	0.300	27.9	1.7	3.4	0.32	1.71
71	0.330	0.245	0.235	25.4	2.7	2.6	0.19	1.31
72	0.375	0.270	0.245	25.9	3.5	2.9	0.37	1.46
73	0.330	0.270	0.190	26.9	7.2	1.4	0.21	0.70
74	0.340	0.280	0.260	21.2	3.2	1.8	0.32	0.91
9.3-10.3m								
75	0.915	0.635	0.915	52.0	0.4	27.5	4.34	14.49
76	0.860	0.635	0.860	47.0	0.2	24.4	4.04	12.86
77	1.030	0.680	1.045	75.2	0.7	35.7	7.06	18.81
78	0.830	0.600	0.830	45.0	0.7	21.1	3.02	11.12
79	0.820	0.545	0.780	51.0	1.0	17.3	2.98	9.12
80	0.255	0.220	0.255	12.0	0.0	1.0	0.08	0.53
81	0.715	0.510	0.680	50.4	1.0	22.8	3.53	12.01
82	0.950	0.665	0.945	71.2	0.6	28.2	6.94	14.86
83	0.835	0.595	0.820	56.0	1.3	23.4	3.92	12.33
84	0.740	0.555	0.740	55.5	0.0	21.8	3.87	11.49
85	0.715	0.555	0.590	47.5	0.5	11.5	2.34	6.06
86	0.905	0.520	0.655	50.6	1.0	16.4	2.81	8.64
87	0.665	0.480	0.565	48.0	0.7	12.9	2.30	6.80
88	0.710	0.440	0.710	43.5	0.0	11.5	1.53	6.06
89	0.800	0.495	0.800	40.5	0.0	1.2	1.45	0.63
90	0.790	0.675	0.615	40.4	1.7	15.0	2.26	7.90
91	0.610	0.405	0.610	35.8	0.0	9.4	1.15	4.95
92	0.765	0.545	0.630	47.5	0.7	16.7	2.72	8.80
93	0.620	0.415	0.620	39.0	0.0	11.1	1.28	5.85
94	0.630	0.420	0.630	36.0	0.0	6.3	0.77	3.32
95	0.480	0.290	0.415	22.0	0.5	3.9	0.36	2.06
96	0.405	0.285	0.290	21.0	0.3	2.2	0.89	1.16
97	0.325	0.220	0.230	25.5	3.8	2.1	0.26	1.11
98	0.270	0.210	0.215	22.9	2.2	2.3	0.21	1.21
99	0.500	0.355	0.485	31.6	0.0	4.6	0.64	2.42
100	0.320	0.205	0.225	29.0	2.3	2.9	0.17	1.53
101	0.640	0.425	0.640	36.5	0.0	7.7	1.04	4.06
102	0.575	0.365	0.515	31.0	0.6	7.9	0.81	4.16
103	0.465	0.320	0.465	25.0	0.2	3.1	0.30	1.63
104	0.615	0.360	0.615	23.5	0.0	4.3	0.55	2.27
105	0.450	0.265	0.450	17.3	0.0	1.2	0.13	0.63
106	0.530	0.315	0.470	24.5	1.0	1.9	0.21	1.00
107	0.530	0.320	0.405	21.6	0.6	3.5	0.18	1.84
108	0.500	0.310	0.405	22.0	0.5	2.6	0.19	1.37
109	0.380	0.315	0.395	19.0	0.8	2.4	0.17	1.26
110	0.425	0.300	0.385	20.6	0.6	2.1	0.17	1.11
111	0.460	0.250	0.300	18.5	1.2	2.7	0.38	1.42
112	0.260	0.220	0.260	14.4	0.2	1.9	0.09	1.00
113	0.240	0.185	0.240	11.0	0.0	0.4	0.06	0.21
114	0.850	0.620	0.825	52.2	1.0	—	3.57	—

* Top of the branch was broken.