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COMPOSITE VOLUME TABLES FOR TIMBER AND THEIR APPLICATION IN THE LAKE STATES
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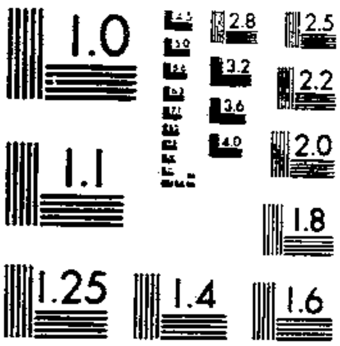

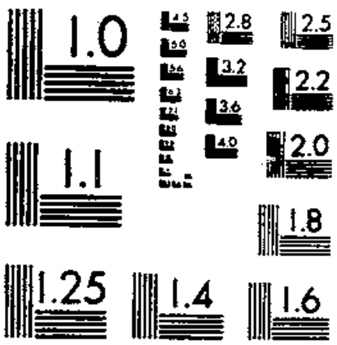

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Composite Volume Tables for Timber and Their Application in the Lake States

By

S. R. GEVORKIANTZ, Forester

and

L. P. OLSEN, Analytical Statistician

Lake States Forest Experiment Station

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Composite Volume Tables for Timber and Their Application in the Lake States[1]

By S. R. GEVORKIANTZ,[2] *Forester*, and L. P. OLSEN, *Analytical Statistician, Lake States Forest Experiment Station,*[3] *Forest Service*

INTRODUCTION

Volume tables showing the contents of trees of given sizes according to some unit of measure are essential to most forestry work. They are used in estimating the amount of standing timber for timber sales, forest management plans, forest surveys, appraisal of damage, and forest valuation in general. They are essential for studies of volume and growth.

The present trend is toward the use of fewer tables which can be modified or adjusted on the basis of observed differences in stand composition and the factors affecting both total and utilizable volume of tallied trees. Such an approach is not only more convenient in field application but also more accurate than the use of many of the common tables for individual species because it requires an appraisal of the characteristics that affect the volume of the timber to which the table is to be applied.

The purpose of this publication is to explain the development and use of a series of Lake States tables for which there has been considerable demand. The concept used is that for any unit of measure there will be a single table applicable to the average run of timber throughout the Lake States, regardless of species. Composite tables reflect the frequency of occurrence of the different species within the region and the average form and bark thickness of all species. Since extreme precision in gross volume estimates is seldom necessary, the application of such a table to stands occupying large areas or to smaller stands which do not differ to a marked degree from the average run usually gives estimates sufficiently accurate for the purposes of most users. Only a stand tally and height curves are required for estimation of these stands. For the occasional stand showing wide differences from the average in form, in bark thickness, in merchantability, etc., correction factors can be applied to make adjustments for these dif-

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[1] Submitted for publication May 20, 1954.

[2] Acknowledgment is made to the numerous foresters who have participated in testing these tables and who have contributed valuable suggestions on how such tables could be made more useful.

[3] Maintained by the U. S. Department of Agriculture, Forest Service, in cooperation with the University of Minnesota, St. Paul 1, Minn.

ferences. Similarly, these correction factors can be used to correct small divergencies in valuable timber.

The concept of composite tables is applicable to other regions. In fact, some Lake States composite tables are being used with considerable success in the Central States region and in some of the Eastern and Southern States. With the recently developed adjustment factors presented in this report, the composite tables can be more easily applied in other regions; the same base can be used in any locality with adjustments for variations in the chief factors affecting tree volume. Corrections for form class, upper taper, bark, and merchantability are not local but, rather, general in application. Species adjustments can be developed locally when necessary.

The basic pattern of the tables, their use and accuracy, and the various adjustment factors are presented in this report.

COMPOSITE TABLES VERSUS SPECIES TABLES

All volume tables have limitations. Most of those which have been constructed in the past are tables for individual species. One volume table for each species, however, is not the final answer, as trees of a given species may differ in form class, bark, and merchantability from one region to another and even in the same relatively restricted area, depending on site, density, age, and management and utilization practices. Hence, a large number of volume tables for each species are required within a region. For example, several jack pine tables would be needed to depict local differences among the various sections of Minnesota. On the other hand, it is probable that none of these local tables would correctly represent the species over the entire State.

Although a number of volume tables do exist for many of the major species in the Lake States, most of them were developed either from sample trees covering a large area and hence are not necessarily applicable to small stands, or they were based on measurements from cut trees on one or two logging operations and thus might not be representative of other areas.

In place of numerous tables to cover all possible stand variations, it is more practical to use one table with a set of corrections for form class, bark, and taper which will enable the user to apply the table to any specified stand. Such a procedure requires that valuable timber be scrutinized for stand variations in order to provide a proper basis for necessary adjustment. It also alerts the cruiser for changes in timber form and gives him training that pays off in more accurate estimates.

During an analysis of some 47 samples of stands distributed throughout the Lake States region and including 17 species, it became apparent that species differences are of little practical significance in estimating board-foot scale. In fact, as much variation existed within a species as between species. After accounting for form class and taper variations, all based on inside bark dimensions, the residual errors appeared to be random and showed no correlation with species.

Using no corrections for either form class or taper differences, 56 comparisons of composite table estimates were made (fig. 1) with those

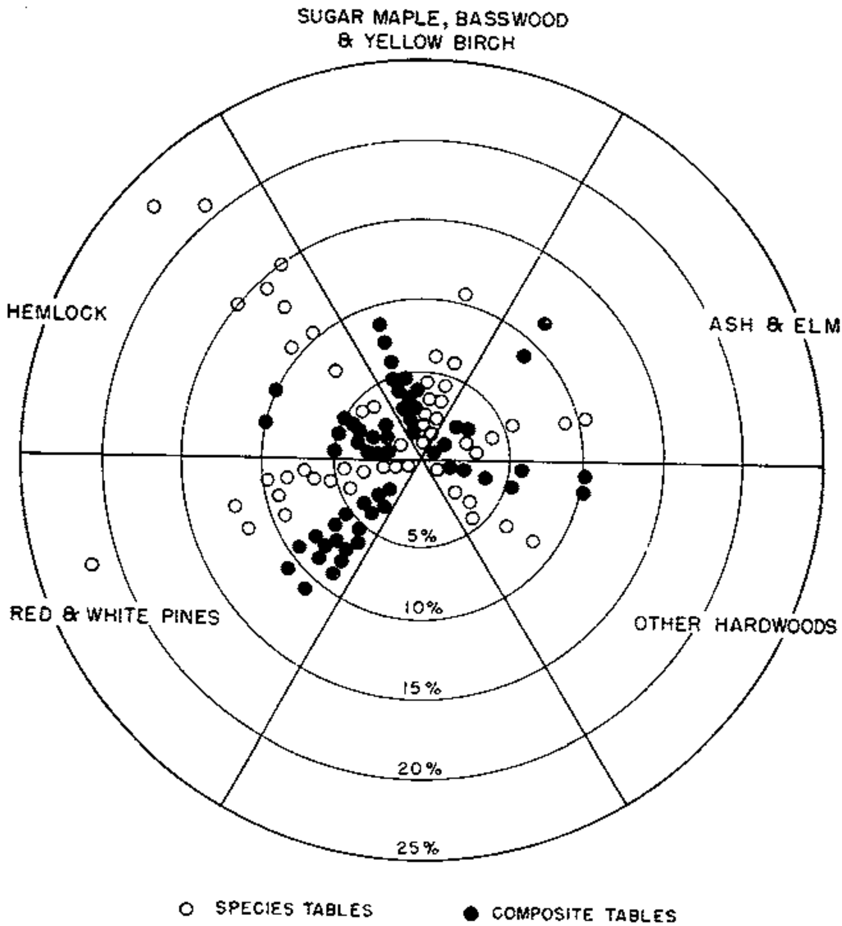

FIGURE 1.—Percent deviations from actual volumes of 56 estimates made with composite and species volume tables.

based on some of the existing species tables[4] with the following results:

Percent deviation from actual volume:	Number of trials: Composite table estimates	Number of trials: Species table estimates
0–4.0	24	17
4.1–8.0	18	21
8.1–12.0	14	10
12.1+	0	8
Total tests	56	56

[4] Forest Survey Staff. Volume tables used in connection with the Forest Survey. U. S. Forest Serv., Lake States Forest Expt. Sta. Econ. Note 8, [35] pp. 1937. [Processed.]

Brown, R. M., and Gevorkiantz, S. R. Volume, yield, and stand tables for tree species in the Lake States. Minn. Univ. Agr. Expt. Sta. Tech. Bul. 39, 208 pp. 1934. (Rev. and enl.)

The local species tables are not superior to the composite tables. In fact, the use of some of the species tables resulted in large errors ranging from 12 to 22 percent. Some of these large errors arise from local taper differences; a species table may be applied very well in one place and be as much as 10 percent in error in another place.

Other difficulties develop from the use of the existing species tables. The measurements in some tables are to a fixed top, and others are to a variable top. Some tables are based on total height, others on merchantable height. Nearly all differ in regard to taper. Their correct application requires knowledge of the implied taper and the stand characteristics upon which the tables are based. Such information is seldom given, or, if available, can rarely be used in practice.

The composite tables, on the other hand, are few in number and the user can easily become familiar with their basic premises. Since they are based on a large representative sample, he can apply them without correction to large areas. In other stands with local peculiarities, when accurate estimates are needed, he is provided with the information necessary to make adjustments.

Previously, an attempt was made to incorporate "species correction factors" in the two composite board-foot tables presented in this report. It became apparent, however, that these corrections were in reality the combined effects of form class and taper differences which can be associated with certain species over the entire Lake States area. In this sense they may be called species correction factors. If they were obtained in a random manner over a large area, these species correction factors might improve estimates considerably when applied to large areas. They would be less satisfactory in more restricted stands because taper is greatly influenced by the past history of the stand, density of stocking, age, and cuttings. These individual stand variations frequently obliterate the species effect. It is preferable, therefore, to relate adjustments more directly to form class and taper whenever it is possible or practicable to do so.

Success in estimating sawlog stands depends entirely on the ability of the estimator to recognize and correct for form class and taper peculiarities as compared to the taper shown in the volume table, whether it be a composite or a species table. There are a few species which, because of large inherent differences in bark thickness or taper, will always require a relatively large adjustment for accurate estimates. These include such species as beech, dense old-growth pines, and white oak.

COMPOSITE TABLES AND STANDARDS OF MERCHANTABILITY

Six composite tables are presented on the following pages: Tables 1 and 2 show board-foot volume based on the Scribner and International ¼-inch rules; table 3 shows the cubic-foot volume of the entire tree stem; tables 4 and 5 show cordwood volume by total height assuming minimum top diameters inside bark of 4 and 3 inches, respectively; and table 6, also a cordwood table, shows volume by number of bolts. All volumes are gross.

The Scribner and International rules were selected because they are those most commonly used in the Lake States region. In general, the Scribner rule is used by industry and both Scribner and International rules by State and Federal agencies. Cubic-foot measure is of interest primarily to research workers in estimating tree growth. Cordwood measure is used by the pulpwood industry as well as by companies using box bolts or wood for container veneer.

The standards of merchantability assumed in the following tables are:

Board-foot volume.—This is the gross scale above a 1-foot stump to a point on the stem where merchantability is limited by branches, defect, or deformity. Top diameters are variable, the minimum being 8.0 inches inside bark for hardwoods other than

TABLE 1.—*Composite table: gross volume*[1] *in board-feet (Scribner rule) by number of 16-foot logs*

Diameter breast high (inches)	Volume when number of 16-foot logs is—								
	½	1	1½	2	2½	3	3½	4	5
	Board-feet	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*
8	**10**	**16**	**24**	**31**	------	------	------	------	------
9	13	**23**	**31**	**39**	**46**	------	------	------	------
10	17	30	**40**	**49**	**57**	**62**	------	------	------
11	22	38	51	**62**	**71**	**78**	------	------	------
12	28	48	66	78	**89**	**100**	**108**	------	------
13	34	59	81	96	112	**126**	**138**	**145**	------
14	40	70	96	116	141	160	**170**	**178**	------
15	47	81	113	137	166	188	204	**220**	------
16	54	93	129	158	191	224	248	263	------
17	63	106	148	182	218	257	285	308	340
18	72	122	168	207	248	292	325	355	395
19	81	137	190	234	280	328	368	405	455
20	90	156	212	262	317	366	415	450	520
21	100	173	238	293	351	405	460	505	585
22	111	194	262	328	392	450	510	560	660
23	123	215	290	360	435	500	560	620	730
24	137	236	319	400	470	550	620	690	800
25	149	258	348	440	520	600	680	760	880
26	165	281	381	480	565	650	740	820	950
27	179	305	415	520	620	710	800	890	1,030
28	195	331	450	560	670	760	860	960	1,120
29	210	356	485	600	720	830	930	1,030	1,200
30	227	383	520	650	770	890	1,000	1,110	1,290
31	245	410	560	700	830	950	1,080	1,200	1,380
32	260	440	600	740	890	1,020	1,150	1,280	1,470
33	279	470	640	790	950	1,080	1,230	1,370	1,560
34	294	500	680	840	1,010	1,160	1,300	1,460	1,670
35	312	530	720	900	1,080	1,230	1,390	1,560	1,790
36	330	565	770	960	1,140	1,310	1,480	1,650	1,900
37	349	600	820	1,020	1,210	1,390	1,570	1,750	2,010
38	365	630	860	1,070	1,270	1,470	1,660	1,840	2,120
39	384	660	900	1,130	1,330	1,550	1,750	1,940	2,240
40	405	700	950	1,180	1,400	1,630	1,850	2,050	2,350

[1] The bold figures in the upper portion of the table show volume to a top diameter of 6.0 or more, but less than 8.0 inches and hence are applicable only to softwoods.

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aspen and 6.0 inches inside bark for conifers and aspen. The standard log assumed is 16 feet in length.

Cubic-foot volume.—This is the total gross volume excluding bark. It includes stump, stem, and tip, but no branches.

Cords.—Volume measured is standard rough (unpeeled) cords—a cord being 4 by 4 by 8 feet. It includes the stem wood above a 1-foot stump, measured in 8-foot bolts, to a point on the bole where merchantability is limited by branches, defects, or deformity. Top diameters are variable but not less than 4.0 inches (3.0 inches for composite table 5) inside bark. Careful piling is assumed, equivalent to 79 cubic feet of wood or 92 cubic feet of wood and bark per cord. Such piling is characteristic of pulpwood loaded in railroad cars.

TABLE 2.—*Composite table: gross volume*[1] *in board-feet (International ¼-inch rule) by number of 16-foot logs*

Diameter breast high (inches)	Volume when number of 16-foot logs is—								
	½	1	1½	2	2½	3	3½	4	5
	Board-feet	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*	*Board-feet*
8	**15**	**24**	**35**	**46**	------	------	------	------	------
9	18	**32**	**44**	**54**	**63**	------	------	------	------
10	21	39	**54**	**68**	**76**	**81**	------	------	------
11	25	48	68	**82**	**91**	**98**	------	------	------
12	30	57	80	100	**114**	**124**	**130**	------	------
13	36	68	96	118	134	**149**	**161**	**171**	------
14	42	79	110	140	163	184	**194**	**205**	------
15	50	92	128	160	188	214	232	**250**	------
16	59	105	147	180	213	247	274	295	**326**
17	66	118	166	208	245	281	314	340	378
18	74	135	188	235	278	320	360	400	440
19	83	152	212	265	314	360	405	450	500
20	92	170	236	295	350	400	450	500	570
21	102	189	262	328	390	450	505	550	635
22	112	209	290	362	430	495	555	610	715
23	122	228	316	396	470	540	610	680	800
24	133	252	346	430	510	595	670	740	870
25	145	275	376	470	555	645	730	810	950
26	158	300	410	510	605	700	790	880	1,020
27	172	325	440	550	650	760	850	950	1,100
28	187	348	480	595	700	810	920	1,020	1,190
29	203	378	515	640	760	870	990	1,100	1,280
30	220	410	550	685	810	930	1,060	1,180	1,360
31	237	440	595	740	870	1,000	1,140	1,260	1,450
32	254	470	635	790	930	1,070	1,210	1,350	1,550
33	270	500	680	840	990	1,140	1,290	1,440	1,650
34	291	530	725	900	1,060	1,210	1,380	1,530	1,760
35	311	565	770	950	1,120	1,290	1,460	1,630	1,880
36	333	600	820	1,010	1,190	1,370	1,550	1,725	2,000
37	353	635	860	1,070	1,260	1,450	1,640	1,830	2,120
38	374	670	910	1,120	1,330	1,530	1,730	1,930	2,240
39	394	705	960	1,180	1,400	1,620	1,830	2,040	2,360
40	415	745	1,010	1,250	1,480	1,700	1,930	2,160	2,480

[1] The bold figures in the upper portion of the table show volume to a top diameter of 6.0 or more, but less than 8.0 inches and hence are applicable only to softwoods.

TABLE 3.—*Composite table: gross peeled volume in cubic feet, entire stem, by total height*

Diameter breast high (inches)	Volume when total height is—								
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
3	0.5	0.6	0.8	1.0					
4	.8	1.1	1.5	1.8	2.2				
5	1.3	1.7	2.3	2.9	3.4	4.0			
6	1.9	2.5	3.3	4.1	4.9	5.8			
7	2.6	3.4	4.5	5.6	6.7	7.8	9.0		
8		4.4	5.9	7.3	8.8	10.3	11.7	13.2	
9		5.6	7.4	9.3	11.1	13.0	14.9	16.7	18.6
10		6.9	9.2	11.4	13.7	16.0	18.3	20.6	22.9
11			11.1	13.9	16.6	19.4	22.2	24.9	27.7
12			13.2	16.5	19.8	23.1	26.4	29.7	33.0
13			15.5	19.4	23.2	27.1	31.0	34.9	38.7
14			18.0	22.4	26.9	31.4	35.9	40.4	44.9
15			20.6	25.8	30.9	36.1	41.2	46.4	51.5
16			23.5	29.3	35.2	41.0	46.9	52.8	58.6
17			26.5	33.1	39.7	46.3	53.0	59.6	66.2
18			29.7	37.1	44.5	51.9	59.4	66.8	74.2
19			33.1	41.3	49.6	57.9	66.2	74.4	82.7
20			36.7	45.8	55.0	64.2	73.3	82.5	91.6
21				50.5	60.6	70.7	80.8	90.9	101
22				55.4	66.5	77.6	88.7	99.8	111
23				60.6	72.7	84.8	96.9	109	121
24				66.0	79.2	92.4	106	119	132
25				71.6	85.9	100	115	129	143
26				77.5	93.0	108	124	139	155
27				83.6	100	117	134	150	167
28				89.9	108	126	144	162	180
29				96.4	116	135	154	174	193
30				103	124	144	165	186	206

TABLE 4.—*Composite table: gross volume in rough cords to a variable top diameter inside bark of not less than 4.0 inches, by total height*

Diameter breast high (inches)	Volume when total height is—									Percent of total height utilized [1]
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Percent*
5	0.006	0.008	0.011	0.015	0.018	0.021				23
6	.013	.018	.025	.032	.038	.046				39
7	.021	.028	.039	.048	.058	.070	0.080			46
8		.039	.054	.068	.082	.097	.111	0.126		51
9		.052	.072	.089	.108	.128	.147	.168		55
10		.066	.091	.114	.138	.163	.187	.212	0.236	58
11			.111	.140	.170	.200	.230	.265	.295	61

See footnote at end of table.

TABLE 4.—*Composite table: gross volume in rough cords to a variable top diameter inside bark of not less than 4.0 inches, by total height*—Con.

Diameter breast high (inches)	Volume when total height is—									Percent of total height utilized [1]
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Percent*
12	----	----	.136	.173	.210	.247	.280	.320	.357	63
13	----	----	.164	.208	.252	.297	.335	.380	.43	65
14	----	----	.192	.243	.295	.347	.40	.45	.50	67
15	----	----	.225	.285	.347	.40	.46	.52	.58	69
16	----	----	.257	.325	.394	.46	.53	.60	.67	70
17	----	----	.292	.370	.45	.53	.60	.68	.76	72
18	----	----	.328	.42	.50	.59	.68	.77	.86	73
19	----	----	.367	.47	.56	.66	.76	.86	.96	74
20	----	----	.41	.52	.63	.74	.85	.96	1.07	75
21	----	----	----	.58	.70	.82	.94	1.07	1.19	76
22	----	----	----	.64	.77	.91	1.04	1.18	1.31	77
23	----	----	----	.70	.85	1.00	1.15	1.29	1.44	78
24	----	----	----	.76	.93	1.09	1.26	1.42	1.58	78
25	----	----	----	.83	1.01	1.18	1.37	1.54	1.72	79
26	----	----	----	.90	1.09	1.27	1.47	1.65	1.85	80
27	----	----	----	.97	1.18	1.38	1.59	1.80	2.00	80
28	----	----	----	1.04	1.27	1.49	1.71	1.93	2.15	81
29	----	----	----	1.13	1.37	1.60	1.85	2.08	2.32	82
30	----	----	----	1.21	1.47	1.72	1.98	2.24	2.49	83

[1] This includes a stump height of 1 foot which must be deducted in estimating number of bolts. If actual percent is greater or less than that indicated, the estimated volume will be correspondingly in error.

TABLE 5.—*Composite table: gross volume in rough cords to a variable top diameter inside bark of not less than 3.0 inches, by total height*

Diameter breast high (inches)	Volume when total height is—									Percent of total height utilized [1]
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	
4	0.005	0.007	0.010	0.012	0.015	----	----	----	----	33
5	.010	.013	.019	.024	.029	0.034	----	----	----	44
6	.016	.022	.030	.037	.045	.054	----	----	----	50
7	.023	.032	.043	.054	.065	.078	0.088	----	----	55
8	----	.043	.059	.074	.090	.106	.121	0.137	----	59
9	----	.056	.076	.095	.117	.137	.157	.178	----	61
10	----	.070	.095	.120	.145	.171	.197	.222	0.248	62
11	----	----	.115	.145	.175	.208	.237	.270	.300	63
12	----	----	.138	.175	.212	.250	.287	.324	.361	65
13	----	----	.164	.208	.252	.297	.338	.382	.43	66
14	----	----	.192	.243	.295	.347	.40	.45	.50	68
15	----	----	.225	.285	.347	.40	.46	.52	.58	69
16	----	----	.257	.325	.394	.46	.53	.60	.67	70
17	----	----	.292	.370	.45	.53	.60	.68	.76	72
18	----	----	.328	.42	.50	.59	.68	.77	.86	73
19	----	----	.367	.47	.56	.66	.76	.86	.96	74
20	----	----	.41	.52	.63	.74	.85	.96	1.07	75
21	----	----	----	.58	.70	.82	.94	1.07	1.19	76

TABLE 5.—*Composite table: gross volume in rough cords to a variable top diameter inside bark of not less than 3.0 inches, by total height*—Con.

Diameter breast high (inches)	Volume when total height is—									Percent of total height utilized [1]
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet	
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	
22				.64	.77	.91	1.04	1.18	1.31	**77**
23				.70	.85	1.00	1.15	1.29	1.44	**78**
24				.76	.93	1.09	1.26	1.42	1.58	**78**
25				.83	1.01	1.18	1.37	1.54	1.72	**79**
26				.90	1.09	1.27	1.47	1.65	1.85	**80**
27				.97	1.18	1.38	1.59	1.80	2.00	**80**
28				1.04	1.27	1.49	1.71	1.93	2.15	**81**
29				1.13	1.37	1.60	1.85	2.08	2.32	**82**
30				1.21	1.47	1.72	1.98	2.24	2.49	**83**

[1] This includes a stump height of 1 foot which must be deducted in estimating number of bolts. If actual percent is greater or less than that indicated, the estimated volume will be correspondingly in error.

TABLE 6.—*Composite table: gross volume in rough cords to a variable top diameter inside bark, by number of bolts* [1]

Diameter breast high (inches)	Volume when number of bolts is—							
	1	2	3	4	5	6	7	8
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*
4	**0.007**	**0.011**						
5	.011	.019	**0.022**					
6	.017	.028	.040	**0.047**				
7	.023	.038	.053	.068	**0.076**			
8	.031	.050	.068	.087	.106	**0.116**		
9	.040	.065	.088	.109	.130	.153	**0.170**	
10	.049	.082	.111	.133	.160	.188	**.211**	
11	.060	.100	.137	.165	.190	.221	**.250**	**0.270**
12	.070	.121	.165	.198	.225	.260	.300	**.330**
13	.082	.143	.197	.236	.268	.305	.350	.42
14	.095	.167	.228	.273	.311	.353	.40	.47
15	.107	.193	.262	.318	.364	.41	.46	.52
16	.122	.220	.300	.367	.42	.47	.53	.59
17	.138	.250	.340	.42	.48	.54	.59	.66
18	.155	.282	.382	.47	.55	.60	.65	.73
19	.173	.318	.43	.53	.61	.68	.73	.81
20	.194	.353	.48	.59	.68	.76	.81	.89
21	.217	.395	.54	.66	.76	.84	.90	.98
22	.240	.44	.60	.73	.84	.93	1.00	1.07
23	.262	.48	.66	.80	.92	1.03	1.10	1.17
24	.288	.52	.72	.88	1.00	1.12	1.21	1.28
25	.312	.58	.78	.96	1.10	1.23	1.33	1.38
26	.340	.62	.84	1.04	1.19	1.33	1.44	1.51
27	.363	.67	.91	1.13	1.29	1.45	1.56	1.63
28	.388	.72	.97	1.20	1.38	1.55	1.67	1.76
29	.41	.76	1.03	1.29	1.49	1.66	1.80	1.90
30	.43	.80	1.10	1.37	1.59	1.7	1.93	2.04

[1] The bold figures in the upper portion of the table are to a minimum top diameter (inside bark) of 3.0 or more, but less than 4.0 inches. Other top diameters are variable but not less than 4.0 inches.

The cubic-foot and cordwood volume tables are based on the assumption of utilization typical of coniferous species. Their application to hardwoods is subject to difficulties. The tables can always be applied rather well to the portion of the stem below forks and large branches. If merchantable height is measured above these forks and branches, the volume will be overestimated in the tables. It is recommended, therefore, that the upper portion of hardwoods be estimated separately by means of conversion factors or by reduction of merchantable heights.

BASIC PATTERN OF COMPOSITE TABLES

Board-Foot Volume Tables

The composite tables given on the previous pages showing board-foot volume by the Scribner and International ¼-inch rules were based on thousands of measurements obtained in the Lake States over a period of 25 years, and represent the average volume found in trees of different diameters and merchantable heights. It was found that trees of commercial size in this region generally average around 78–79 in the Girard form class (diameter inside bark at the top of the first log as a percent of the diameter at breast height outside bark), with slight variations depending on tree diameter and the number of logs in the tree. On the average, the upper logs follow the pattern shown in table 7.

Table 7.—*Average taper factors*[1] *for sawlog trees in the Lake States region*

Position of log	Taper factors when number of 16-foot logs in tree is—				
	1	2	3	4	5
Butt[2]	[3] 78	[3] 78	79	80	81
Second		66	70	71	73
Third			59	62	64
Fourth				52	54
Fifth					44
Sum of taper factors	78	144	208	265	316

[1] Top diameter of log inside bark (d. i. b.) as a percent of the diameter outside bark at breast height (d. b. h.).
[2] The taper factor of the butt log is also the Girard form class.
[3] Trees less than 15.0 inches d. b. h. have a slightly higher form class, 79.

This basic pattern of taper, including allowances for the effect of tree diameter and merchantable height as indicated by large numbers of tree measurements, was used in constructing composite board-foot volume tables 1 and 2. The process included four major steps: (1) Preparing relative tapers by d. b. h. (diameter at breast height) and merchantable height, (2) converting relative taper into inches of log diameter, (3) scaling each log in the tree and summing the total volume, and (4) curving these total volumes with d. b. h. and merchantable height as coordinates.

Cubic-Foot Volume Tables

Table 3 shows the number of cubic feet inside bark in the entire stem including stump and tip. In developing this table, it was found that when all species are combined, the cubic-foot volume of the average tree in the Lake States region generally is close to 42 percent of the volume of a cylinder of the same diameter and height. Thus, the formula for the cubic-foot table is

$V=0.42\ BH$, where
V=the peeled cubic-foot volume,
B=the basal area in square inches computed from the diameter outside bark at breast height, and
H=the tree's total height in feet.

This simple formula is very useful for interpolating between composite table values when a calculator is available.

Volume for trees less than 30 feet tall cannot be estimated accurately with this formula. In short trees, the 4.5-foot height (d. b. h.) where diameter is measured is relatively high in the tree; hence the form factor 0.42 is too low. The cubic-volume estimates in the composite table represent a form factor of 0.48 for 20-foot trees.

The form factor is an expression of the relative fullness of the tree bole. It cannot be measured accurately, however, in standing trees. In order to approximate the form factor, the diameter outside bark halfway up the tree as a percent of d. b. h., known as form quotient,[5] is often used. If this percent is determined accurately, it gives a good measure of tree form. On the average, the form quotient in the Lake States is approximately 68. The form factor of 0.42 represents the general taper for trees of various heights as shown in table 8.

Table 8 will be found useful for estimating the diameters along the tree stem. Table 9, developed on the basis of the tapers assumed above, shows the height utilization-volume relationships along the stem for the average tree. With the aid of this table the cubic-foot volume in various sections of the stem can be estimated.

Bark volume was assumed to be 14 percent of the total unpeeled volume (average for all species). This corresponds to a double bark thickness of about 7 percent of the diameter at breast height.

For most species, therefore, the cubic-foot volume of trees with bark averaging about 14 percent and a form quotient of approximately 68 will be estimated rather accurately with the composite table. Unless the errors are compensating, however, the estimates from the composite table will decrease in accuracy as the deviations of bark volume or form quotient from these averages increase.

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[5] There are several different "form quotients" in use. Throughout the text, the definition as given above should be kept in mind.

TABLE 8.—*General taper used for trees of various heights*

Percent of total height [1]	Taper factors [2] when the total height is—								
	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet
0 (ground line)	100	101	102	104	107	109	110	110	110
10	99	96	94	91	89	88	88	87	86
20	94	90	85	81	80	80	81	81	81
30	87	82	76	75	75	75	76	76	76
40	78	73	69	69	69	69	70	70	70
50 [3]	66	63	63	63	63	63	63	63	63
60	54	52	55	56	56	56	56	56	56
70	39	40	44	47	48	48	48	48	48
80	26	26	31	36	38	38	38	38	38
90	14	14	18	22	24	24	24	24	24
100	0	0	0	0	0	0	0	0	0

[1] Includes a 1-foot stump.
[2] The diameter inside bark (at specified intervals along the stem) as a percent of d. b. h.
[3] When the d. i. b. at half the height is 63 percent of d. b. h., the d. o. b. at the same point is assumed to be 68 percent.

TABLE 9.—*Percent of total cubic-foot volume at any given percent of total tree height*

Percent of total height utilized [1]	Percent of total cubic-foot volume [2]	Percent of total height utilized [1]	Percent of total cubic-foot volume [2]
10	22	45	73
15	32	50	77
20	40	55	82
25	47	60	86
30	54	70	93
35	61	80	97
40	67	90	99

[1] Stem from ground to actual point of utilization.
[2] Percents given include volume of stump.

CORDWOOD VOLUME TABLES

Composite tables 4, 5, and 6 were derived from composite cubic-foot table 3. In these tables 79 cubic feet of solid wood, 13 cubic feet of bark, and 36 cubic feet of void space per cord are assumed. These are the averages attained by careful piling such as is done when shipping by rail.

Composite tables 4 and 5, based on total height, further represent utilization which is typical of the softwoods in the Lake States region (table 10). The degree of utilization for hardwoods is somewhat lower. Obviously, therefore, the tables will not apply to hardwoods unless adjusted as described in a later section.

TABLE 10.—*Merchantability assumed for softwoods for composite cordwood tables 4 and 5*

Diameter breast high (inches)	Cordwood table 4		Cordwood table 5	
	Height utilization [1]	Top diameter inside bark	Height utilization [1]	Top diameter inside bark
	Percent	*Inches*	*Percent*	*Inches*
4			33	3.0
5	23	4.0	44	3.2
6	39	4.2	50	3.5
8	51	4.8	59	3.8
10	58	5.3	62	5.0
12	63	5.6	65	5.5
16	70	6.2	70	6.2
20	75	6.5	75	6.5
24	78	6.8	78	6.8
30	83	7.0	83	7.0

[1] From the ground up. In computing number of bolts, 1 foot should be subtracted for stump.

Composite tables 4 and 5 were derived from tables 3, 9, and 10. An example of the calculation of the cordwood volume in a 12-inch, 60-foot tree is as follows:

Volume of entire tree (table 3) ---------- 19.8 cubic feet.
Height utilized (table 10) ---------- 63 percent.
Corresponding portion of total cubic-foot volume utilized (table 9) ---------- 88 percent.
Volume in merchantable stem and stump=0.88 x 19.8 ---------- 17.4 cubic feet.
Volume of 1-foot stump ---------- 0.9 cubic foot.
Volume of merchantable stem excluding stump=17.4−0.9 ---------- 16.5 cubic feet.
Corresponding cordwood volume=16.5/79 or 0.209 cords as compared with the curved value of 0.210, shown in table 4.

Composite table 6, based on the number of 8-foot bolts, shows total heights related to d. b. h. and to the numbers of bolts utilized (table 11).

Composite cubic-foot table 3 was used together with tables 9 and 11 to obtain the cordwood volumes shown in composite table 6. For example, the cordwood volume of a 12-inch, 4-bolt tree was computed as follows:

Total height assumed (table 11) ---------- 63 feet.
Volume of entire tree (table 3) ---------- 20.8 cubic feet.
Total height utilized (four 8-foot bolts plus 1-foot stump) as a percentage of the total height ---------- 52 percent.
Total volume utilized (table 9) ---------- 79 percent.
Volume of merchantable stem and stump=0.79×20.8 ---------- 16.4 cubic feet.
Volume of 1-foot stump ---------- 0.9 cubic foot.
Volume of merchantable stem=16.4−0.9 ---------- 15.5 cubic feet.
Corresponding cordwood volume=15.5/79 cubic feet ---------- 0.196 cord.
When curved with other volumes this resulted in 0.198 cord, as shown in table 6.

As a general rule, the volume estimated from table 6 is more accurate than that based on total height where the assumed utilization may sometimes deviate considerably from the actual.

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TABLE 11.—*Total heights assumed in composite cordwood table 6 for trees with varying numbers of 8-foot bolts*

Diameter breast high (inches)	Height when the number of 8-foot bolts is—							
	1	2	3	4	5	6	7	8
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
6	43	44	50					
8	51	51	51	60	70			
10	57	57	57	57	66	76		
12	63	63	63	63	64	72	83	
14	67	67	67	67	67	70	79	90
16	71	71	71	71	71	71	76	87
18	74	74	74	74	74	74	76	84
20	77	77	77	77	77	77	77	82
24	81	81	81	81	81	81	81	81
30	84	84	84	84	84	84	84	84

THE USE OF COMPOSITE TABLES: THEIR ACCURACY AND LIMITATIONS

For many jobs the composite volume tables without modification are sufficiently accurate. The board-foot composite tables have been used successfully in the Lake States since 1943 for estimating volume of pine and hardwood commercial stands. Because of compensating tendencies in the factors affecting tree volume, particularly when large areas are cruised, estimates from these tables have seldom deviated from actual gross scale by more than 6 or 7 percent. Larger errors occasionally may occur in estimating stands of exceptionally good form or of very poor form.

Since the cubic-foot table (table 3) and the cordwood tables (tables 4 and 5) have not been published previously, there have been no reports from the field on their accuracy. However, tests applied to data gathered over a period of years indicate that errors in cubic-foot volume will seldom be over 6 percent. A number of pulpwood companies report that satisfactory results have been obtained with the use of cordwood table 6[6] based on number of bolts. No checks are available for cordwood tables 4 and 5. The accuracy of all the cordwood tables depends partly on the cubic-foot table on which they were based. More important causes for errors are the lack of care in piling and any large differences between the actual height and those assumed in the tables.

A number of tests were made to determine the applicability of the board-foot and cubic-foot volume tables to different types of timber. Samples were selected to represent both normal and abnormal types of timber in order to evaluate the effects of form class and taper on

[6] This table is a revision of the table presented in U. S. Forest Serv., Lake States Forest Expt. Sta. Tech. Note No. 241, October 1945. For the general run of timber by d. b. h. and merchantable height the differences between the two tables are rather small.

volume. Since they were not random samples, the distributional pattern of errors obtained should not be considered representative of the usual run of errors likely to result from regular cruises. Although large errors do occur, they are much less frequent than indicated in the tabulation below, showing the results of the tests:

Percent of deviation from actual volume:	Number of trials: Composite board-foot table [1]	Number of trials: Composite cubic-foot table
0 — 4.0	19	23
4.1— 8.0	15	11
8.1—12.0	10	4
12.1—20.0	3	1
	47	39

[1] Volume estimates were made from composite table 1, Scribner. Distribution of errors of estimates made from the International rule table would be about the same.

It appears that, with certain exceptions, volumes may be estimated from the composite tables if an accuracy within 6 or 7 percent is satisfactory. These estimates might include those taken on most reconnaissance cruises, those of the less valuable timber, and those of periodic cruises made for the purpose of determining growth.

Stands which probably will require adjustment because of an abnormal pattern and which produce inadequate compensation include those which are open-grown or culled-over and apt to be considerably below average in form, those of dense old growth which may have exceptionally good form, those of species which are on the edge of their natural habitat, and any in which especially good utilization is practiced, resulting in top logs of excessive taper.

Special caution should be exercised in using the cordwood composite tables based on d. b. h. and total height. Since the actual stem utilization in some species, particularly hardwoods, is considerably below the utilization represented in the tables, some discount is often required. It should also be recognized that the factor of 79 cubic feet of solid wood per standard cord of bolts stacked with the bark on represents good care in piling. If such close piling is not common practice in a given locality, the results of the cordwood estimates will be low. The latter point applies, of course, to all cordwood composite tables. The allowances for differences in piling and in stem utilization are discussed in the section on "Factors Affecting Volume and Methods of Adjusting Estimates."

Experienced foresters may use the composite tables on almost any type of cruise provided they study the detailed discussion of factors affecting volume. On the basis of such study they should be able to recognize the conditions that indicate a stand is not composed of the average run of timber as is represented in the tables.

The application of the composite tables requires only a stand tally of trees by diameter classes and a sufficient number of measurements to represent log-height utilization or total tree height, depending on the table to be used. Rules for their application follow:

1. Use the merchantability standards given on page 5 in the preceding section. Different standards will require some correction if accurate results are desired.

2. Tally the number of trees for the various species by diameter classes.

3. Measure heights on a sufficient number of sample trees of each important species to be able to draw a representative height over diameter curve. To use the board-foot tables (1 and 2) and the cordwood table (6) based on number of bolts, obtain merchantable heights. To use the other three tables (3, 4, and 5), collect information on total heights. In order to avoid bias, these sample trees should be selected at random and should cover the range of the diameter classes present. (An alternative to making merchantable height curves is to tally all trees by d. b. h. and number of logs or bolts.)

4. For each species make a volume table based on the height over diameter curve and the composite table. For example, the table made with the use of composite table 1 might appear as follows:

Diameter breast high (inches):	*Merchantable height*[1] *(feet)*	*Volume, Scribner*[2] *(board-feet)*
10	16	30
11	21	46
12	24	66
13	27	87
14	29	108
15	30	131

[1] From merchantable height curve; excludes 1-foot stump.
[2] Interpolated from composite table 1.

If preferred, the volume of each sample tree estimated from the table could be plotted directly over d. b. h. and a volume curve drawn without the use of a height curve. The difference between the two methods is very small.

5. Apply the volumes obtained in step 4 to the tree tally by diameter class.

6. Remember that suitable volume estimates are obtained only when the taper of timber cruised does not deviate sufficiently from the basic patterns of the composite tables to result in a larger error than is tolerable for the job. The cruiser should always be watchful for abnormal taper while observing sample trees. If deviations appear excessive and are not compensating, some correction should be made. In such cases, even a rough allowance in the right direction is better than no correction at all. (See "Factors Affecting Volume and Methods of Adjusting Estimates" for guidance on amount of correction required.)

APPLICABILITY CHECK

How It Is Made

Frequently, in a new territory, the estimator lacks assurance that the composite tables will apply to the general run of timber on the tract. He may suspect that the tables will either overrun or underrun certain species, blocks, or condition classes. When an especially accurate cruise is required or when the timber of certain species is of high value, the composite tables should be checked against the measured volumes of trees obtained from the stands to be estimated. The most direct way would be to compare volumes of felled trees to the corresponding estimates from the volume table.

There are some cuttings going on in the forest every year. These may be large logging operations or scattered small timber sales. Such operations provide the cruiser with the opportunity to use felled trees to train his eye in observing differences in taper. The felled trees can also be used for making applicability checks. Such checks, however, require a representative sample to depict and weigh all the essential characteristics of the timber. Three major conditions should be observed:

Good scatter.—Sample trees for a given species should be well distributed throughout the timber to which the volume table will be applied.

Proportionate representation.—No special sizes, types, or growing conditions should be unduly represented in the sample.

Lack of bias from cut trees.—The sample of cut trees should be representative of the remaining timber. If the logging operations are taking only the best or the poorest trees, then the estimator should make allowances for this fact or select an independent sample.

The number of sample trees needed for the check depends, of course, on the accuracy demanded from them. Unless a precise estimate is required, a few sample trees of the important species will be sufficient.

When volume-table errors only are considered, experience indicates that in 9 cases out of 10 the following number of sample trees will be required for each species or group of species in order to stay within the limits of accuracy specified below:

Limits of accuracy (percent)	*Sample trees required (number)*
±6	25
±5	36
±4½	44
±4	56
±3½	73
±3	100
±2½	144

It is doubtful whether an accuracy better than ±2 percent of gross volume will ever be required from a volume table or should even be anticipated with complete assurance; no sample of any limited size is likely to be exactly representative of the tract in question.

In measuring trees these four rules should also be observed:

1. Diameters along the tree bole, both outside and inside of bark, should be taken at regular 8-foot intervals above a 1-foot stump. Diameters should also be measured at the stump and at breast height, or 4½ feet above the ground.

2. Diameters should be measured to the nearest one-tenth inch and the bark thickness to the nearest one-twentieth inch.

3. Abnormalities, such as knots, swellings, or constrictions, appearing at regular points of measurement, should be avoided by taking measurements either below or above the deformity. Bark thickness should be measured at its highest and lowest ridges at the crosscut

sections, and the two readings averaged; it is not measured at crevices, because the diameter tape or the calipers touch the ridges only.

4. Total and merchantable heights should be recorded to the nearest foot. The merchantable height, as described on page 5, is a relatively clear portion of the bole. If better utilization extends beyond the first large limb or fork and thus includes rapidly tapering logs or bolts, this should be noted. Otherwise all the composite tables will tend to overestimate the volume.

The measurements of cut trees will provide the necessary information to test the applicability of the composite tables to the species or timber in question and to make adjustments if necessary. The data will also reveal the reasons for agreement or disagreement between the measured and the table volumes. Deviations may be attributed to differences in form, class, bark thickness, taper of the upper logs, butt-swell, etc., as discussed under "Factors Affecting Volume." If the discrepancies are consistently in one direction or the aggregate difference is large enough to be significant, general adjustments or corrections can be made. The following two examples illustrate the adaptation of volume tables to specific tracts by means of test samples.

Example 1

A block of hardwood timber appeared to have form consistently poorer than average. Butt-swell was pronounced, particularly in large trees, and some reduction in volume apparently was necessary, at least for the two valuable species, sugar maple and yellow birch. A patch of similar timber was being cut nearby. As anticipated, the analysis of the measurements for 100 randomly selected felled trees disclosed that uniformly occurring butt-swell (affecting 70 percent of trees) required a discount of the estimated volume. A comparison of the actual volumes of the measured trees with the volumes of the same trees taken from the composite table is shown in table 12. The summaries by diameter classes are for the entire samples of the two species tested.

The table indicates the volume deficiency of yellow birch in all diameter classes, fluctuating between a −6 and a −11 percent. Since there is no correlation of the relative difference with d. b. h., a flat reduction of −8.5 percent should be used. The correction can be applied directly to the total volume of all tallied yellow birch trees estimated from composite table 1.

A similar deficiency in volume is observed in sugar maple. Some correlation appears between the percentage differences and tree diameters. Because of this correlation, the correction should be made separately for each diameter group, ranging from practically no correction for small trees to +11 percent for very large trees. However, if this is deemed troublesome, a flat reduction can also be used provided that the test sample was obtained in some proportionate or representative way, so that it could be considered a miniature replica of the diameter tally of the entire tract. Then the average correction of −5.3 percent obtained for the entire sample could be safely used to discount the composite volume table estimates for sugar maple. If the sample is not proportionate, then weighting is required. This would either reduce or increase the deduction of 5.3 percent, depending on the relative weights of small versus large trees.

TABLE 12.—*Comparison of the measured and estimated volumes of sample trees for yellow birch and sugar maple, by diameter class*

YELLOW BIRCH SAMPLE

D. b. h. class (inches)	Sample trees	Volume		Difference
		Measured	Estimated [1]	
	Number	*Board-feet*	*Board-feet*	*Percent*
10.0–12.9	16	632	708	−10. 7
13.0–15.9	16	1, 425	1, 521	−6. 3
16.0–18.9	14	2, 350	2, 571	−8. 6
19.0–21.9	10	2, 794	2, 977	−6. 1
22.0–24.9	10	3, 572	3, 954	−9. 7
25.0–27.9	2	961	1, 045	−8. 0
28.0–30.9	2	1, 435	1, 620	−11. 4
31.0–33.9				
Aggregates	70	13, 169	14, 396	−8. 5

SUGAR MAPLE SAMPLE

D. b. h. class (inches)	Sample trees	Measured	Estimated [1]	Difference
10.0–12.9	6	287	290	−1. 0
13.0–15.9	4	495	497	−. 4
16.0–18.9	5	1, 083	1, 102	−1. 7
19.0–21.9	3	867	924	−6. 2
22.0–24.9	5	2, 225	2, 271	−2. 0
25.0–27.9	3	1, 540	1, 650	−6. 7
28.0–30.9	2	1, 330	1, 410	−5. 7
31.0–33.9	2	1, 685	1, 900	−11. 3
Aggregates	30	9, 512	10, 044	−5. 3

[1] Estimated from composite table 1.

Example 2

In another example the volumes shown in composite table 1 were applied to a tract of oak in southern Wisconsin. A sample of 600 tree measurements of red oak from southern Wisconsin was available for the test. The sample represented wide coverage of area and was obtained on many logging operations. The analysis of the data disclosed that although volume estimates for some individual trees varied from the measured volume by as much as 28 percent, the positive and negative differences almost compensated one another. There was no discernible trend of differences with d. b. h., and the aggregate difference between the measured and the estimated volumes was quite small. It was also observed that a small representative sample (10 percent of the original) could provide nearly the same information as a very large one (table 13). The figures clearly indicate that the composite table can be applied to all merchantable sizes of trees and that no correction is needed since a compensating tendency is apparent throughout.

TABLE 13.—*Comparison of the measured and estimated volumes of a sample of red oak, by d.b.h. class*

D. b. h. class (inches)	Sample trees	Measured volume	Estimated volume [1]	Difference
	Number	*Board-feet*	*Board-feet*	*Percent*
13.0–15.9	14	2,010	2,045	−1.7
16.0–18.9	10	2,003	1,943	+3.1
19.0–21.9	9	3,041	3,106	−2.1
22.0–24.9	21	9,257	8,895	+4.1
25.0–27.9	4	2,084	2,223	−6.3
28.0–30.9	3	2,130	2,110	+.9
31.0–33.9				
34.0–36.9	1	870	860	+1.2
Aggregates	62	21,395	21,182	+1.0

[1] From composite table 1.

SIGNIFICANCE OF DIFFERENCES

The above tests invite the question: How large should the aggregate difference in volume be in order to be judged significant? To determine the answer, the relative variance of individual tree volume differences should be known, as well as the number of trees used in the test sample. Roughly, if the aggregate difference of the test sample does not exceed two times the standard deviation divided by the square root of the number of trees used in the test, the difference is not considered significant and may be disregarded. This general rule will be helpful in determining the significance of observed differences.

The standard deviation of individual tree volumes from the composite table is known to be a ±15 percent for board-feet and a ±10 percent for cubic feet. If the same standard deviations are assumed in test samples, the maximum allowable difference between the aggregate actual volumes and the composite table estimates without correction would be as follows:

	Maximum difference allowed in—	
Trees in test sample (number):	*Board-foot volume (percent)*	*Cubic-foot volume (percent)*
20	±6.7	±4.5
30	±5.5	±3.6
40	±4.7	±3.2
60	±3.9	±2.6
80	±3.4	±2.2
100	±3.0	±2.0
150	±2.4	±1.6

If, however, the individual tree volumes in the test sample deviate by consistently similar percentages from the composite table estimates, smaller aggregate differences would be required for significance. When this occurs, it is desirable to compute the standard deviation independently in order to determine a more accurate estimate of the maximum allowable difference.

From the tabulation above it is apparent that the measured volume of yellow birch (table 12), with the aggregate difference of 8.5 percent, deviates significantly from the volume table estimate. This actual difference is considerably larger than the maximum difference allowed for nonsignificance. For red oak, however, no correction should be made. A sample of 62 trees could be as much as ±3.9 percent off in total volume (instead of 1.0 percent) and still be considered a part of the original or basic data.

The sugar maple sample (table 12), however, presents a problem; the difference of a −5.3 percent is within the maximum allowable difference of 5.5 percent required for a sample of 30 trees. An examination of the individual tree differences, however, showed consistently similar deviations from the composite table volumes, nearly all of them on the negative side. When the composite table estimates were reduced by 5.3 percent, the measured volumes showed small deviations, both negative and positive, from these estimates. The standard deviation of these differences proved to be only a ±8 percent. This is considerably less than the 15 percent assumed previously and would require a maximum allowable difference of $\frac{2\times 8}{\sqrt{30}}$ or 2.9 percent instead of the 5.5 percent as specified by the rule of thumb.

Most test samples show about the same deviations from the corrected table volumes as the average run of individual trees used in the composite tables. The problem encountered above with sugar maple will seldom occur in practice.

Limitations

A number of such applicability checks have been made and reported by various agencies in the north-central area. The applicability of composite board-foot volume tables 1 and 2 to different species or species groups was tested (table 14). The samples varied in size and distribution over the region.

Scrutiny of the basic data involved in these tests revealed some rather interesting facts. A number of tests, for example, indicated close agreement with the composite tables. The individual irregularities in taper appeared to be averaging out over the area. The errors tended to compensate, particularly when large samples covering different conditions were involved.

However, some species showed consistent deviations from the composite tables. As expected, consistent differences in form and bark thickness appeared in such species as yellow-poplar, black tupelo (blackgum), beech, willows, blackjack oak, and redcedar. The application of composite tables to such species or conditions without any corrections would, of course, be a mistake. However, such clear-cut exceptions are a matter of common knowledge and are usually taken care of in every locality whenever they occur.

Most species, however, belong to another group in which the differences between the measured and the estimated volumes result not from species peculiarities but from stand-to-stand variations in form class and taper. In several instances, the Kansas, Illinois, and Lake States samples showed different correction factors for the same species. Such discrepancies have occurred even among samples from the same locality.

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TABLE 14.—*Some applicability checks of composite tables 1 and 2 in the north-central area*

Species	Percentage differences between measured and estimated volumes reported in various studies			
	Forest Survey [1]	Illinois study [2]	Kansas and Missouri samples [3]	Region 9 studies [4]
1. Usually no adjustment required:				
Sugar maple	0	0		
Yellow birch	0			
Bur oak	0		0	
Hackberry, black cherry, redgum, honeylocust, mulberry, Kentucky coffeetree				0
Post oak		0	0	
Basswood	−2			
2. Adjustment required—consistent difference in form and bark:				
Elms	+5	+5	+5	
Yellow-poplar, blackgum		+13		+15
Beech	+15	+15		
Baldcypress and sassafras				−7
Paper birch				−7
Willow and blackjack oak		−20		
3. Adjustment required depending on form and taper:				
Red maple	+5	0		
Ash, white and green	0	+8	+3	+3
Ash, black				−5
Red oak	−3	+10	+6	
White oak	−3	+8		
Black oak		+7		
Aspen	−7			
Hickory, scarlet oak, pin oak		+6	+6	
Cottonwood		−3	+7	
Sycamore		−7	+7	
Black walnut		−10	−3	
Butternut				−10
Hemlock	−8			
White pine	−4			
Red pine	+4			
Shortleaf and loblolly pine				−4
Tamarack and white spruce				−10
Redcedar		−20		

[1] Based on a large number of measurements obtained by the Forest Survey in Wisconsin and Michigan in 1935–36.

[2] Study reported in Aids for Computing Tree Volumes in Illinois, U. S. Forest Serv., Central States Forest Expt. Sta. Tech. Paper 115. 1950.

[3] Data by E. R. Ware obtained in 1935 in southeastern part of Kansas and adjoining Missouri.

[4] Corrections reported by C. B. Stott and W. W. Barton in 1951, State and Private Forestry, Milwaukee, Wis.

Thus, ideally, applicability checks should be made in each area characterized by certain growth conditions and should be used only in the area from which the sample is drawn or in areas where the same conditions are known to exist. Applicability checks also are very desirable when important cruises are made without the help of experienced timber estimators. Many formal studies, such as extensive surveys, should also utilize these checks. On such jobs the work of obtaining samples can be mechanical, and satisfactory correction factors can be obtained for the important species or types of timber in each specified area.

Such checks, however, would become too costly if made for each species on relatively small areas. On smaller jobs quicker methods are needed, even though less reliable. One method requires the ability to evaluate form class and taper differences directly in standing trees. An experienced estimator, for example, while following the cruise lines, would have noticed that both the yellow birch and sugar maple shown in table 12 were of relatively poor form. He would have estimated the form class as approximately 76, requiring a 6-percent reduction. Such a correction obtained directly on standing trees during the process of cruising would have been found sufficient for all practical purposes and would have saved much time and inconvenience.

It is recognized that the ability to differentiate between actual and normal taper requires training, but the timber cruiser will find it invaluable during his career and well worth the effort. Frequent practice on felled trees or on standing trees where a check can be made is indispensable.

In the next section the factors affecting timber volume are described with the twofold purpose of further clarifying the main causes of volume discrepancies and showing how the various correction factors can be applied on the basis of direct observations of standing trees. Many conscientious cruisers will want to know the chief causes of volume variation; they should find the discussion of adjustment factors very helpful.

FACTORS AFFECTING VOLUME AND METHODS OF ADJUSTING ESTIMATES

The effects of site, density, and past history of the stand are reflected in the form, height, and bark thickness of individual trees. These volume characteristics together with current methods of utilization and care in piling may differ from the averages assumed in the preparation of volume tables. When these differences are large and not compensating, adjustments are needed in order to avoid underestimating or overestimating the true volume. The additional time spent observing form class and taper characteristics generally will more than pay for itself in accuracy of the final estimate, particularly when valuable timber is involved. Even when less accurate estimates are acceptable, the cruiser should always observe the stands for abnormal taper and degree of utilization. It was such training as this, subconscious though it may have been, that enabled some of the oldtime cruisers to obtain accurate volume estimates without the aid of the more technical methods available today.

If more accuracy is desired, measurements on cut or felled timber are needed, or instruments especially designed for aiding the cruiser in estimating stem diameters from the ground should be used. Some such instruments have been designed [7] and several are in the process of development. A simple and practical instrument would replace eye estimates and could make it possible to use adjustment factors with greater accuracy.

Most cruises require taking sample trees uniformly throughout the area to obtain total or merchantable heights by diameter classes and species. This is done either on sample plots or along the strip lines within each condition class of timber. Regardless of the type of sampling employed, the cruiser, as stated on p. 16, should make all possible effort to consider the relative importance of each area, size-class, and species on the tract. It is these sample trees that the cruiser should study for the factors affecting volume.

BOARD-FOOT VOLUME

Check of Composite Table Estimates in Different Types of Stands

To determine the effects of form class and taper on board-foot volume, an analysis was made of 47 samples of various stands selected from different parts of the Lake States. No trees having less than two 16-foot logs were used in the samples, and all logs were measured in 16-foot lengths. The samples were chosen purposely to represent both average and abnormal types of timber. The stands tested were placed in four categories: (1) Following the normal pattern shown in table 7; (2) departing from the normal pattern but with compensating tendencies in the taper of individual logs; (3) having the form patterns of the entire stem generally higher or lower than normal; and (4) showing marked irregularities in taper with little or no compensation. The accuracy of the estimates from composite table 1 (Scribner) has been computed for these four groups of stands (table 15).[8] Similar results would be obtained with the International rule.

The results of the tests clearly indicate both the accuracy of composite tables and the limitations in their application to various types of stands on actual cruising jobs (table 15, col. 3). As mentioned previously, they apply very well when taper of the timber agrees with the pattern implied in the tables. The errors are within 3 percent of

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[7] Ferree, Miles J. The pole caliper. Jour. Forestry 44: 594–595, illus. 1946.

Godman, R. M. The pole diameter tape. Jour. Forestry 47: 568–569, illus. 1949.

Vaux, C. H. Instrument for determination of tree diameters in inches at any height. Jour. Forestry 50: 601–604, illus. 1952.

[8] To make it unnecessary to present table 15 several times in this bulletin, the results of each series of tests are shown in the various columns; consequently, frequent reference will be made to table 15.

TABLE 15.—*Tests of the accuracy of various estimates of board-foot volume (Scribner)*

GROUP 1—STANDS FOLLOWING NORMAL PATTERN

Species	Basis: trees	Deviation from actual volume of estimates based on— Composite table 1	Composite table with correction for form class [1]	Form class tables [2]	Composite table with log-by-log corrections	Average deviation from normal form class in units
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
Jack pine	39	+2.0	+3.6	+5.7	+0.6	½
White pine	19	+3.3	+3.5	+10.2	+3.3	0
Hemlock	86	−1.8	+1.3	+4.4	+.8	1
Sugar maple	30	−2.0	+.9	[3]	[3]	1
Do	27	−.5	−2.0	−1.6	−.5	½
Do	30	−2.4	−3.4	−2.8	+.5	½
Yellow birch	28	−1.3	+1.3	[3]	−.7	1
Do	31	+.9	+.3	−.8	+2.4	0
Ash	50	−1.9	+.7	+3.0	+1.3	1
Do	17	+2.7	+2.0	[3]	[3]	0
Red oak	62	−1.1	+1.6	+4.4	−.8	1
Beech	29	+2.4	+2.2	+2.0	+3.2	0

GROUP 2—STANDS DEPARTING FROM NORMAL PATTERN BUT WITH COMPENSATING TENDENCIES

Species	Basis: trees	Composite table 1	Composite table with correction for form class [1]	Form class tables [2]	Composite table with log-by-log corrections	Average deviation from normal form class in units
Hemlock	40	−1.9	−5.8	+2.4	−2.2	1½
Do	17	−.8	+7.3	+14.5	+3.7	2½
Basswood	83	+4.3	−5.0	−1.2	−1.6	3
Yellow birch	28	+2.0	−2.6	+1.4	[3]	1½
Elm	30	−.1	+3.2	[3]	[3]	1
Do	74	−.9	−3.3	−.5	−1.4	1

GROUP 3—STANDS WITH FORM PATTERN OF ENTIRE STEM GENERALLY HIGHER OR LOWER THAN NORMAL

Species	Basis: trees	Composite table 1	Composite table with correction for form class [1]	Form class tables [2]	Composite table with log-by-log corrections	Average deviation from normal form class in units
Red pine	25	−3.3	+3.3	+2.8	+3.4	2
White pine	12	+7.7	+.8	+4.7	+1.9	2½
Do	46	+6.6	+2.7	+6.1	+1.3	1½
Tamarack	82	−10.2	−2.2	+.3	−1.2	2½
Hemlock	55	+5.1	+.5	+3.9	−1.0	1½
Aspen	111	−7.7	−1.0	−1.1	+1.2	2
Sugar maple	73	+5.8	−2.0	+1.1	−.6	2½
Yellow birch	82	+4.7	+1.6	+5.0	−1.2	2
Do	18	+8.5	+2.0	[3]	[3]	2
Ash	53	−9.2	−.7	+.2	−.5	3
Red maple	85	−6.6	+1.2	+3.5	−.3	2½
Do	23	−6.1	−.1	[3]	[3]	2
Paper birch	11	+3.7	+.1	+1.4	0	1
Do	12	+13.6	+2.8	+1.8	−2.3	3½
Basswood	30	+6.8	0	[3]	[3]	2

See footnotes at end of table.

TABLE 15.—*Tests of the accuracy of various estimates of board-foot volume (Scribner)*—Continued

GROUP 4—STANDS WITH MARKED IRREGULARITY IN TAPER AND LITTLE OR NO COMPENSATION

Species	Basis: trees	Deviation from actual volume of estimates based on—				Average deviation from normal form class in units
		Composite table 1	Composite table with correction for form class [1]	Form class tables [2]	Composite table with log-by-log corrections	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
Red pine	104	−11. 6	−3. 9	−2. 9	+0. 9	2½
Do	21	+6. 2	+8. 8	+7. 2	+1. 9	1
Do	42	+18. 3	+19. 3	+21. 2	+2. 1	½
White pine	72	−7. 4	−3. 7	+. 1	+1. 6	1
Do	19	+8. 1	+4. 8	(3)	(3)	1
Do	26	+9. 5	+12. 0	(3)	(3)	1
White spruce	30	+15. 8	+11. 4	+10. 6	+. 8	1½
Balsam fir	29	+10. 6	+12. 3	+10. 2	+. 6	½
Hemlock	23	+5. 1	+6. 2	(3)	(3)	½
Do	32	+10. 3	+7. 6	+8. 8	+2. 2	1
Sugar maple	51	−5. 2	−4. 4	(3)	0	½
Basswood	25	−4. 7	−4. 6	−1. 6	−. 2	0
Elm	13	−12. 0	−10. 3	−5. 6	−1. 3	½
Red oak	30	+11. 3	+8. 6	(3)	(3)	1

[1] Using the 3-percent rule.
[2] Tables prepared for Forest Service use by Clement Mesavage and James W. Girard.
[3] Not computed; insufficient data.

the actual scale. Good results are also obtained when the departure from the normal pattern is compensating; that is, when rapid taper in one or two of the logs is offset by a somewhat better than average form in other logs. Under these conditions the errors will vary according to the degree of compensation but will usually remain below plus or minus 5 percent. Most stands will fall in one or the other of these two groups.

Occasionally stands will be found in which form-class differences are marked and compensation in taper does not take place. For such stands the estimates from the composite tables will deviate from the true scale by a considerable amount. In these deviations the application of Girard form-class corrections is clearly desirable. A more detailed discussion of the form-class correction will follow.

There are rare occasions, however, when the most meticulous corrections for form class result in estimates deviating from the true scale by as much as 15 percent or more. This fact has caused some cruisers to question the practicability of form-class corrections. Such deviations are noted in open-grown timber, culled-over stands, and particularly when, as in recent years, better utilization practices force the merchantable height into the crown of the tree where the top logs are irregular or abnormally small. In a stand of this kind, corrections for upper taper are also needed. A practical approach to handling these rather complex situations is suggested in the section on "Irregular Taper in Upper Logs."

Girard Form Class[9]

The average taper expected in the Lake States region is shown in table 7. Occasionally the form class of a stand may be considerably higher or lower than average. This is especially likely to occur in disturbed stands where either the best trees have been cut, leaving those of poorer form, or where the least silviculturally desirable trees have been removed, leaving only those of better form. Also old stands or stands that have grown under unusually dense conditions may have trees with very little taper.

The Girard form class is obviously affected by bark thickness. When the bark is unusually thick, the form class is lower than indicated by the general taper of the tree, and vice versa. It has also been noted that relative bark thickness is not the same at the top of the first log as at d. b. h. for some species. Elm, sugar maple, and basswood have relatively thicker bark at 17 feet above ground than at d. b. h. In hemlock, tamarack, and white pine the reverse is generally true. These differences should be kept in mind when judging form class.

When the average form class of a stand deviates from the regional average, it is to be expected that the taper of the upper logs will also vary accordingly. For example, if the form class of a stand of trees averaging about three logs in merchantable height is 82 instead of 79, the taper factors of the second and third logs normally will be, not 70 and 59 as indicated in table 7, but something higher than that. A rule of thumb has been developed to indicate approximately what taper factors are to be expected in trees of any given form class. These factors are related to the top d. i. b. of the first log as follows:

Ratio of top d. i. b. of indicated log to the top d. i. b. of butt log

Position of log in tree:	
Second	$^{9}/_{10}$
Third	$^{3}/_{4}$
Fourth	$^{2}/_{3}$
Fifth	$^{1}/_{2}$

Thus, for 3-log trees with form class 82, the taper factor of the second log should be about $^{9}/_{10}$ of 82 or 74, and that of the third log should be about $^{3}/_{4}$ of 82 or 62. These factors of 74 and 62 replace the "normal" ones of 70 and 59.

In the past, cruisers have customarily made a 3-percent allowance in volume for every unit difference from the average Girard form class.

[9] Definition given on p. 10.

If, for example, the actual form class of the timber runs close to 80 and the table shows the regional average of 78, the correction would be 2 x 3 or 6 percent to be added to the volume estimate. Likewise, an average form class of 75 would require a 3 x 3 or 9-percent reduction in the volume estimate. This rule gives satisfactory results when the taper above the first log changes in proportion to the increase or decrease in form class. However, where the taper fails to conform to the normal pattern in relation to the change in form class, the 3-percent rule does not work. The requirements for the proper application of the 3-percent rule have been investigated and portrayed (fig. 2). The normal pattern of taper for trees of varying numbers of logs (as given in table 7) has been expressed for simplicity as the sum of "taper factors" or the sum of the top d. i. b.'s of each log as percents of the d. b. h. These sums vary from 78 to 316 for 1- and 5-log trees, respectively (table 7).

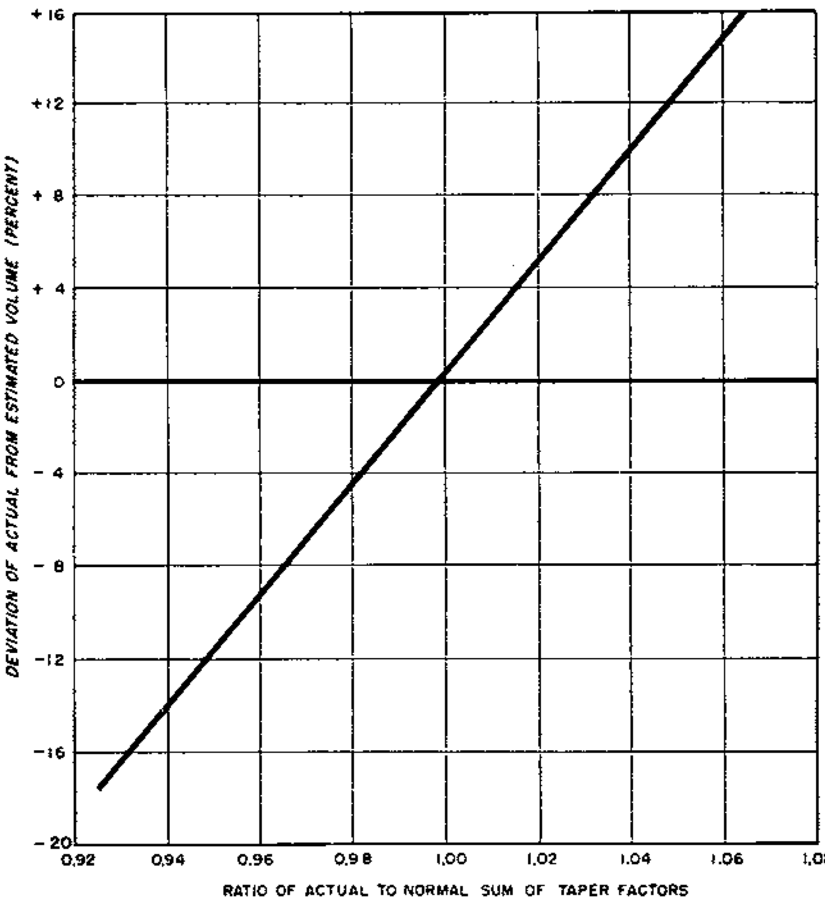

FIGURE 2.—The effect of taper factors on board-foot volume.

The percent deviation of actual from composite volume (P) related to the ratio of actual (S) to normal sums (S_o) of taper factors can be expressed by the formula:

$$P=234\left[\frac{S}{S_o}-1\right]$$

To compare the use of percent deviation (fig. 2) with the 3-percent rule, consider two 20-inch, 3-log trees with varying taper factors (table 16).

TABLE 16.—*Log measurements and scale volumes of two 20-inch 3-log trees with varying taper factors*

Position of log	Normal taper factors	Tree No. 1			Tree No. 2		
		Top d. i. b. of log	Taper factors	Scale volume	Top d. i. b. of log	Taper factors	Scale volume
		In.		*Bd.-ft.*	*In.*		*Bd.-ft.*
Butt	79	15.0	75	144	15.0	75	144
Second	70	13.2	66	107	13.8	69	119
Third	59	11.2	56	73	12.0	60	86
Total	208		197	324		204	349

The various volume estimates and methods of calculation are as follows:

	Tree No. 1	Tree No. 2
Volume estimate from table 1 (board-feet)	366	366
Revised estimate by the 3-percent rule:		
Number of units deviation from normal form class	4	4
First estimate reduced by 4 x 3, or 12 percent (board-feet)	322	322
Revised estimate based on sum of taper factors:		
Ratio of actual to normal sum of taper factors:		
Tree No. 1=197/208	.947	
Tree No. 2=204/208		.981
Corresponding percent deviation of actual volume from first estimate (fig. 2)	−12.4	−4.4
Revised estimate (board-feet):		
Tree No. 1=366(1−.124)	321	
Tree No. 2=366(1−.044)		350
Actual volume per table 16 (board-feet)	324	349

Both trees have the same dimensions and consequently are given the same volume estimate of 366 board-feet from the composite table. Furthermore, since they both have the same Girard form class of 75, correction by the 3-percent rule lowers both estimates to 322 board-feet. However, although the upper logs in tree No. 1 taper approximately in a normal fashion for form class 75, those in tree No. 2 do not taper as much as would be expected. Accordingly, the estimate for tree No. 1 by the 3-percent rule is very close to the correct scale, but in the case of tree No. 2, the rule underestimates the correct volume by allowing too much reduction in top.

The failure of the upper logs to follow the pattern expected with changes in the form class explains the inaccuracies of some volume estimates based on form-class corrections alone. It is sometimes contended that the 3-percent rule is not sufficiently accurate to take care of changes in form class and that a special series of form-class tables would be more accurate in application.

Such a series of tables has been made [10] and was tested in comparison with the 3-percent rule (table 15, col. 4 and 5) on most of the 47 samples analyzed. Estimates from the special form-class tables were generally higher than the estimates based on the 3-percent rule. The reason is that, with some variations by diameter class, the form-class tables assume slightly less taper in the upper logs than shown in the basic pattern (table 7). There is little choice between the two methods in accuracy. In actual practice, therefore, it appears unnecessary to construct and apply a series of form-class tables (which are frequently cumbersome) so long as equally good results can be obtained from one composite table with a 3-percent correction rule whenever adjustments are required.

When to correct estimates from composite tables for form class is a question of paramount importance. The answer lies in the comparison between columns 3 and 4, table 15, by the four groups of stands presented. Stands in group 1 by definition require no correction for form class. They are the stands showing agreement with the normal taper. Group 2 stands also require no correction for form class. In fact, corrections here can do more harm than good, because the taper in the upper logs more or less compensates for the difference in form.

For stands in group 3, form corrections obviously improve the estimates. This improvement is in direct proportion to the difference between actual and normal form class. For example, the type of stand in which form-class adjustment is effective may be illustrated by data on the average taper factors for a sample of 53 ash trees (table 17).

TABLE 17.—*Stand of 53 ash trees in which adjustment for form class is effective*

Position of log	Taper factors [1] in—			
	2-log trees (Basis: 41 sample trees)		3-log trees (Basis: 12 sample trees)	
	Normal	Actual	Normal	Actual
Butt	78	81	79	81
Second	66	69	70	74
Third			59	63
Total	144	150	208	218

[1] Top d. i. b. of a log as a percent of d. b. h.

[10] Tables prepared for Forest Service use by Clement Mesavage and James W. Girard.

In the 2-log trees, the taper factors were three units higher than normal in both the butt and second logs. In the 3-log trees, the butt log taper was two units higher and the second and third logs were four units higher than normal. Although the upper logs did not always conform exactly to what might be expected in consequence of the differences in form class, their deviations were so small that correction for form class by the 3-percent rule gave very accurate results. The estimate from the composite table was 9 percent lower than the actual volume. The 3-percent rule reduces the error of estimation to less than 1 percent.

Form-class adjustments are desirable and increase accuracy considerably when the average form class of a stand differs greatly from the normal, and the upper logs conform to the pattern expected in accordance with the change in form class. Densely stocked stands or those selectively logged should be inspected with great care for possible deviations from average form class.

Irregular Taper in Upper Logs

Stands represented in group 4 (table 15) present the most difficult problem. Neither estimates from the composite tables nor adjusted estimates based on form class alone are sufficiently accurate for those stands with marked irregularity of form. For the occasional stands with only a very slight taper in the upper logs, volume will be underestimated by either method. On the other hand, volume estimates on stands in which the top log shows excessive taper will be too high. Accurate estimates on these types of stands can be obtained only by analysis of the taper of individual logs. This is illustrated by the erratic taper of the logs in a red pine sample (table 18).

TABLE 18.—*Stand of red pine in which adjustment for form class is ineffective*

Position of log	Taper factors [1] in—					
	2-log trees (Basis: 37 sample trees)			3-log trees (Basis: 5 sample trees)		
	Normal	Actual	Units difference	Normal	Actual	Units difference
			Number			*Number*
Butt	78	78	0	79	81	2
Second	66	57	9	70	68	2
Third	------	------	------	59	42	17
Total	144	135	------	208	191	------

[1] Top d. i. b. of a log as a percent of d. b. h.

The composite table overestimates the volume of this stand by 18.3 percent. The correction for the above-normal form class of the 3-log trees increases this overestimate to 19.3 percent. Inspection of the taper factors of the upper logs in both the 2- and 3-log trees indicates that they are much below normal, whereas the form class of both sizes of trees is normal or better. Hence the estimates from the composite table should be considerably reduced for excessive taper.

Such cases can be handled through log-by-log adjustments which show the percent of total tree volumes to be added or subtracted for each unit of difference between the actual and the normal taper factors for each log (table 19).

The adjustments (table 19) indicate the effects of the deviations from normal of individual log taper on the entire tree volume. They are expressed as a percent of the estimates from the composite volume table. The table reveals one interesting point, namely, that even a deviation of a few units in the top logs may produce considerable error in the total volume estimate. For example, an increase of five units in the normal taper factor in the third log of a 3-log tree will result in a 5×0.9 or 4.5-percent increase in the total volume. This is seldom realized by field men.

TABLE 19.—*Log-by-log adjustments of tree volume estimates from the composite tables when log taper is abnormal*

Logs in tree (number)	Position of log	Normal taper [1]	Correction for each unit of difference from normal taper [2]
			Percent
1	Butt	[3] 78	±3.0
2	Butt	[3] 78	±2.0
	Second	66	±1.5
3	Butt	79	±1.5
	Second	70	±1.2
	Third	59	±.9
4	Butt	80	±1.3
	Second	71	±1.0
	Third	62	±.8
	Fourth	52	±.5
5	Butt	81	±1.2
	Second	73	±.9
	Third	64	±.7
	Fourth	54	±.5
	Fifth	44	±.4

[1] Top d. i. b. of given log as percent of d. b. h.

[2] For simplicity this is assumed to be a constant rate. Large deviations from normal taper actually have slightly higher correction percentages. Some of the discrepancies between actual volume and that estimated from log-by-log corrections are due to the use of the constant rate.

[3] For trees less than 15 inches, the normal taper is 79.

In the red pine example (table 18) the total corrections are as follows:

	Percent
2-log trees:	
Butt-log adjustment	0
Second-log adjustment, 9× −1.5 percent, or	−13.5
Total adjustment on 2-log tree volumes	−13.5
3-log trees:	
Butt-log adjustment, 2× +1.5 percent, or	+3.0
Second-log adjustment, 2× −1.2 percent, or	−2.4
Third-log adjustment, 17× −0.9 percent, or	−15.3
Total adjustment on 3-log tree volumes	−14.7

The combined reduction is about 14 percent. The composite table overestimated the volume by 18.3 percent. The net error after adjustment (since the correction of 14 percent is on the estimate from the composite table) is 1.183 (1−0.14) − 1, or +0.017, which is equivalent to a 1.7-percent deviation from actual volume.

The theory of log-by-log adjustments is neither complicated nor new. It only requires knowing the taper on which a volume table is based and the amount of correction needed for any departures from that normal. The application is difficult, for it requires judging the taper along the merchantable stem—an accomplishment requiring considerable training and frequent practice. In stands of very irregular taper, however, it is the only way of insuring any degree of accuracy. James Girard, famed for his accuracy in estimating volume, always supplemented his form-class estimates with an inspection of and allowance for upper log taper.

The first step in the log-by-log analysis is to become familiar with the normal taper recognized in the composite table (table 20). An estimate of the size of the deviations from normal is then made for each log if the sample tree, whether felled or standing, appears either abnormally cylindrical or conical in shape. These differences should be translated in terms of inches from the normal diameter. They can then be converted to percent corrections to be applied to the total tree volume (table 21).

A skillful cruiser can detect as much as ½-inch difference from the normal top diameters, particularly in the lower portion of the stem. The unskilled cruiser should not attempt to evaluate by eye differences of less than 1 inch and should constantly be on guard against systematically overestimating or underestimating diameters. All cruisers should check their ocular estimates frequently. If the cruiser is unable to differentiate satisfactorily between the actual and the normal taper, he may at least detect those trees with a 2-inch difference from normal in the butt or upper logs and thus avoid occasional large errors in estimating timber volume.

The procedure in estimating the correction percent for a 20-inch, 3-log tree is illustrated in table 22. If correction percents are similarly estimated for a number of sample trees in a systematic manner, the comparison between the revised estimates and the direct estimates from the composite table will indicate the amount of adjustment needed.

TABLE 20.—*Log top diameter inside bark as used in the composite board-foot tables*

Diameter breast high (inches)	Top d. i. b. of individual logs when number of logs in tree is—														
	1	2		3			4				5				
	Butt	Butt	2d	Butt	2d	3d	Butt	2d	3d	4th	Butt	2d	3d	4th	5th
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
10	7. 9	7. 9	6. 7	------	------	------	------	------	------	------	------	------	------	------	------
12	9. 5	9. 5	7. 9	------	------	------	------	------	------	------	------	------	------	------	------
14	11. 0	11. 1	9. 2	11. 1	9. 8	8. 4	------	------	------	------	------	------	------	------	------
16	12. 4	12. 5	10. 6	12. 6	11. 3	9. 3	12. 8	11. 4	9. 9	8. 3	------	------	------	------	------
18	14. 0	14. 0	11. 9	14. 3	12. 7	10. 7	14. 4	12. 8	11. 2	9. 4	14. 6	13. 1	11. 5	9. 7	7. 9
20	15. 6	15. 6	13. 1	15. 8	14. 0	11. 8	16. 0	14. 2	12. 4	10. 4	16. 2	14. 6	12. 8	10. 8	8. 8
22	17. 2	17. 2	14. 5	17. 3	15. 3	13. 0	17. 6	15. 6	13. 6	11. 4	17. 9	16. 2	14. 2	12. 0	9. 9
24	18. 7	18. 7	15. 8	19. 0	16. 8	14. 2	19. 2	17. 1	15. 0	12. 6	19. 5	17. 6	15. 5	13. 1	10. 8
26	20. 3	20. 3	17. 2	20. 5	18. 1	15. 3	20. 8	18. 6	16. 2	13. 6	21. 1	19. 1	16. 7	14. 2	11. 6
28	21. 9	21. 8	18. 5	22. 0	19. 5	16. 4	22. 4	19. 9	17. 4	14. 6	22. 8	20. 5	18. 0	15. 2	12. 4
30	23. 4	23. 4	19. 8	23. 6	20. 9	17. 6	24. 0	21. 3	18. 6	15. 6	24. 3	22. 0	19. 3	16. 3	13. 3
32	25. 0	25. 0	21. 0	25. 2	22. 3	18. 8	25. 6	22. 7	19. 9	16. 7	25. 9	23. 4	20. 5	17. 3	14. 1
34	26. 5	26. 5	22. 3	26. 7	23. 7	19. 9	27. 2	24. 1	21. 2	17. 8	27. 5	24. 8	21. 8	18. 4	15. 0
36	28. 1	28. 1	23. 8	28. 3	25. 0	21. 1	28. 8	25. 6	22. 4	18. 8	29. 2	26. 3	23. 0	19. 4	15. 8
38	29. 6	29. 6	25. 1	29. 9	26. 4	22. 3	30. 4	27. 0	23. 6	19. 8	30. 8	27. 7	24. 3	20. 5	16. 7
40	31. 2	31. 1	26. 2	31. 3	27. 7	23. 4	32. 0	28. 4	24. 8	20. 8	32. 4	29. 2	25. 6	21. 6	17. 6

Table 21.—*Adjustment of composite volume estimate for each inch deviation from normal top diameter of individual logs*

Diameter breast high (inches)	Adjustment for each inch deviation when number of logs in tree is—														
	1	2		3			4				5				
	Butt	Butt	2d	Butt	2d	3d	Butt	2d	3d	4th	Butt	2d	3d	4th	5th
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10	38.0	23.0	20.0												
12	26.0	17.0	14.0												
14	21.0	13.5	11.5	9.0	8.1	7.0									
16	18.0	11.0	9.5	8.0	6.9	5.8									
18	15.5	9.7	8.2	7.1	6.0	5.0	5.6	5.0	4.4	3.5					
20	14.0	8.5	7.2	6.3	5.4	4.4	5.0	4.4	3.8	3.1	4.3	3.9	2.9	2.8	2.3
22	12.5	7.6	6.4	5.6	4.8	4.0	4.5	4.0	3.3	2.8	3.9	3.4	2.5	2.5	2.0
24	11.5	6.8	5.8	5.0	4.4	3.6	4.1	3.6	3.0	2.5	3.6	3.1	2.2	2.2	1.8
26	10.5	6.2	5.3	4.6	4.1	3.4	3.8	3.3	2.7	2.3	3.3	2.9	2.1	2.0	1.6
28	9.8	5.7	4.8	4.2	3.8	3.1	3.5	3.0	2.5	2.2	3.0	2.7	1.9	1.9	1.5
30	9.0	5.3	4.5	3.9	3.5	2.9	3.2	2.8	2.4	2.0	2.8	2.5	1.8	1.8	1.4
32	8.4	4.9	4.2	3.6	3.3	2.7	3.0	2.6	2.2	1.9	2.6	2.3	1.7	1.7	1.3
34	7.8	4.6	3.9	3.4	3.1	2.6	2.8	2.5	2.1	1.8	2.4	2.2	1.6	1.6	1.3
36	7.4	4.4	3.7	3.2	2.9	2.4	2.6	2.3	2.0	1.7	2.3	2.1	1.5	1.5	1.2
38	7.0	4.2	3.5	3.0	2.7	2.2	2.5	2.2	1.9	1.6	2.2	2.0	1.5	1.4	1.1
40	6.7	4.0	3.3	2.9	2.6	2.1	2.3	2.1	1.8	1.5	2.1	1.9	1.4	1.4	1.1

TABLE 22.—*Illustration of procedure for estimating correction for abnormal taper of 20-inch, 3-log tree*

Position of log	Top d. i. b. of log		Approximate difference	Correction [2]
	Normal [1]	Actual		
	Inches	*Inches*	*Inches*	*Percent*
Butt	15.8	16½	+½	+3.2
Second	14.0	14½	+½	+2.7
Third	11.8	12	0	0

Total percent correction = +5.9.
Volume estimate from composite table 1 = 366 board-feet.
Revised estimate = 366 (1 + .059) = 388 board-feet.

[1] From table 20.
[2] Based on percents in table 21.

Example of Application

If, because of the irregularities in the upper taper, it appears that the 3-percent rule is inapplicable, and the cruiser is sufficiently trained to analyze the taper of the stem or has down timber to guide him, he can use another procedure (table 23). This procedure should be based on an unbiased sample of trees taken along the cruise lines of the entire area. This sample would ordinarily consist of 15 to 50 trees per major species, depending on the size of the tract cruised. Such procedure automatically weighs the contribution of each tree in proportion to its size.

In an example based on 11 yellow birch trees (table 23) the sample trees on the average tapered more than normal, so the volume estimate from the composite table should be reduced by 9.8 percent. This correction for taper may be considered important, particularly when a valuable species such as yellow birch is involved. A number of ½-inch as well as 1-inch deviations are shown. If only 1-inch deviations were estimated, the total correction would not be as accurate.

Short Log Lengths

The board-foot composite tables assume standard 16-foot logs, but frequently logs are cut in shorter lengths. The Scribner rule does not allow for taper, and scaling in short lengths results in a slight increase in volume:

Log length (feet):	*Additional volume obtained (percent)*
16	0
14	1
12	3
10	8
8	9
Estimated average for the Lake States	4

Table 23.—*Illustration of procedure for adjusting volume estimates when taper is abnormal, 11 yellow birch trees*

Diameter breast high (inches)	16-foot logs	Difference from normal taper in inches and percent correction						Total correction	Volume from composite table [3]	Corrected volume estimate
		1st log		2d log		3d log				
		Difference [1]	Correction [2]	Difference [1]	Correction [2]	Difference [1]	Correction [2]			
	Number	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Percent*	*Board-feet*	*Board-feet*
10	1	0	0					0	30	30
20	3	−1	−6.3	−1½	−8.1	−1	−4.4	−18.8	366	297
12	2	0	0	−½	−7.0			−7.0	78	73
14	2	−½	−6.8	0	0			−6.8	116	108
12	2	+½	+8.5	+½	+7.0			+15.5	78	90
10	1	−½	−19.0					−19.0	30	24
14	2	0	0	0	0			0	116	116
10	1½	0	0	([4])				0	40	40
16	3	−1	−8.0	−½	−3.4	−½	−2.9	−14.3	224	192
12	1	−½	−13.0					−13.0	48	42
24	2½	−½	−3.4	−1	−5.8	([4])		−9.2	470	427
Total									1,596	1,439

Correction percent for the cruise data $= \frac{1,439}{1,596} - 1 = -9.8$ percent.

[1] Estimate based on table 20.
[2] From table 21.
[3] From table 1.
[4] Portions of logs are ignored.

In actual practice, however, logs are cut in varying lengths and corrections should be adjusted to the predominant length. Usually in the Lake States region, the average correction will be about 4 percent. Since the International ¼-inch rule allows for taper, the correction for short lengths is so small that it could be omitted.

Accuracy of Revised Estimates

When stands follow the normal pattern, adjustment for form class and upper taper of logs contribute little additional accuracy and can be omitted. (Compare columns 3 and 6, table 15.) The same comment applies to stands with compensating tendencies in the factors affecting volume.

In stands which differ only in the Girard form class, the correction for form reduces the error considerably. Even though such accuracy as is shown in column 4, table 15, cannot be attained with ocular estimates of form, deviations of 8 percent or more (as shown in column 3) would not occur if reasonable care in estimating form class were used and if the taper of the upper logs were not too drastically different from the normal pattern (group 3).

Stands with marked irregularity in taper and little or no compensation do not occur frequently, but the occasional stands of this kind encountered are probably responsible for most errors above 10 percent. Therefore, a correction for the taper of upper logs is essential. Even rough estimates of taper would reduce considerably the errors of volume estimates for such stands.

Cubic-Foot Volume

Check of Composite Table Estimates in Different Types of Stands

Tests were made of the accuracy of estimates from the composite cubic-foot table on 39 different stands, which cover a wide range in factors affecting volume. A random selection would have included more stands with average form, and very few representing the extremes; hence the estimates generally would have shown a greater degree of accuracy. Even with the nonrandom selection, the composite table estimates on 29 of the 39 tests were within 5 percent of the actual volume. Only two of the tests were over 10 percent in error.

The stands used in the tests (table 24) are divided into two groups. Group 1 includes those stands in which the factors affecting volume are either average or compensating. Group 2 includes the stands in which form quotient, bark volume, species taper, or some combination of these factors is considerably above or below the average and corrections of the composite table estimates are required.

In this study the differences between the actual volumes and those estimated from the composite table are considered to be caused by three factors, namely, bark, form class, and species taper. Each of these items is discussed in detail.

TABLE 24.—*Accuracy of cubic-foot volume estimates and the adjustment required for the factors affecting volume, on various sample stands*

GROUP 1—STANDS IN WHICH FACTORS AFFECTING VOLUME ARE EITHER AVERAGE OR COMPENSATING

Species	Basis: trees	Deviation of composite table estimate from actual	Adjustment required for—				Deviation of revised estimate from actual
			Form quotient	Bark volume	Species taper	Net correction	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Red pine	20	+1.2	+0.6	−1.8	0.0	−1.2	0.0
White pine	21	+.6	+.2	−.4	−2.0	−2.2	−1.6
Do	18	+4.8	+1.0	−1.8	−2.0	−2.8	+1.9
Jack pine	25	−2.1	−1.3	−2.1	+3.0	−.4	−2.5
Do	30	+3.0	−4.0	−.4	+3.0	−1.4	+1.6
Balsam fir	43	+1.0	−7.0	+2.0	+3.0	−2.0	−1.0
Black spruce	27	+.4	+.5	−2.0	+2.0	+.5	+.9
Do	20	−3.4	+.5	+.3	+2.0	+2.8	−.7
Do	24	−.2	−4.0	+4.4	+2.0	+2.4	+2.2
Do	25	−3.2	(1)	(1)	(1)	(1)	(1)
White-cedar	18	−3.1	−6.5	+1.3	+5.0	−.2	−3.3
Hemlock	39	−.1	+3.2	−4.0	−2.0	−2.8	−2.9
Do	18	−.7	+6.8	−4.1	−2.0	+.7	0
Aspen	80	−1.6	+.5	+.5	0	+1.0	−.6
Sugar maple	10	−.2	+10.5	−4.0	−4.0	+2.5	+2.3
Yellow birch	23	−.1	−1.5	+.7	0	−.8	−.9
Do	16	−2.9	+2.7	+1.0	0	+3.7	+.7
Basswood	28	+2.5	+4.2	−5.4	0	−1.2	+1.3

GROUP 2—STANDS IN WHICH FACTORS AFFECTING VOLUME DEVIATE FROM THE AVERAGE AND ARE NOT COMPENSATING

Species	Basis: trees	Deviation of composite table estimate from actual	Form quotient	Bark volume	Species taper	Net correction	Deviation of revised estimate from actual
Red pine	25	−10.0	+9.3	+1.3	0.0	+10.6	−0.5
Do	25	−14.6	+18.2	−1.0	.0	+17.2	+.1
Jack pine	80	−11.9	+6.2	+3.5	+3.0	+12.7	−.7
Balsam fir	21	+3.1	−6.8	+.8	+3.0	−3.0	.0
Do	27	−8.0	+3.5	+2.0	+3.0	+8.5	−.2
Do	25	+6.5	−13.7	+2.0	+3.0	−8.7	−2.8
Black spruce	20	−7.7	+.2	+4.6	+2.0	+6.8	−1.4
White-cedar	29	−3.3	−2.6	+1.4	+5.0	+3.8	+.4
Tamarack	11	−5.5	(1)	(1)	(1)	(1)	(1)
Hemlock	18	+8.8	+1.0	−5.0	−2.0	−6.0	+2.3
Do	25	−5.2	+9.3	−2.4	−2.0	+4.9	−.6
Aspen	45	−4.8	+1.0	+2.5	.0	+3.5	−1.5
Do	48	−3.6	+5.0	+1.5	.0	+6.5	+2.7
Sugar maple	16	+6.9	−2.5	−.8	−4.0	−7.3	−.9
Do	23	+6.0	+4.5	−5.8	−4.0	−5.3	+.4
Do	30	+9.4	(1)	(1)	(1)	(1)	(1)
Basswood	30	+2.8	+.5	−4.5	.0	−4.0	−1.3
Do	16	+3.7	+1.5	−5.3	.0	−3.8	−.2
Oak	27	−4.4	+7.0	−6.3	+7.0	+7.7	+3.0
Do	41	+3.8	−9.5	−3.5	+7.0	−6.0	−2.4
Do	39	+5.5	−11.0	−2.4	+7.0	−6.4	−1.3

[1] Insufficient data to compute corrections.

Bark Volume

Bark volume of trees in the Lake States varies considerably among species. Some species are noted for their thin bark, particularly beech, tamarack, spruce, and balsam fir; others such as the oaks have unusually thick bark. Regional averages for bark volume have been computed by species for three stand-size classes (table 25).

Since bark thickness is affected by stand density, age, site, etc., there is frequently wide variation not only among different species but also among different stands of the same species. Jack pine bark, for example, is rather thin in and near the Superior National Forest and relatively thick in Hubbard County, Minn. Similar tendencies

TABLE 25.—*Proportion of bark to total unpeeled cubic-foot volume by species and stand size*

Species	Proportion of bark when stand is—		
	Poletimber (4–10 inches d. b. h.)	Sawtimber (12 inches d. b. h. and larger)	
		Second growth	Old growth
Conifers:	*Percent*	*Percent*	*Percent*
Balsam fir	12	12	----------
White-cedar, northern	14	14	14
Hemlock	17	17	19
Pine:			
Jack	17	14	10
Red	16	13	11
White	14	16	18
Spruce:			
Black	12	11	----------
White	15	12	10
Tamarack	12	11	----------
Hardwoods:			
Ash:			
Black	16	15	14
Green	17	16	19
White	17	16	19
Aspen	13	13	----------
Basswood	18	20	20
Beech	8	8	7
Birch:			
Paper	11	12	----------
Yellow	13	15	15
Cottonwood	17	17	18
Elms	17	18	19
Hickories	15	16	----------
Maple:			
Red	15	15	14
Sugar	15	17	18
Oaks:			
Red	18	20	20
White	20	20	22

have also been noted in white pine and oak. For this reason it is recommended that the estimator check the bark thickness of a number of trees in a stand to determine whether it approximates fairly closely the general average of the species or how far it deviates from the 14-percent average assumed in the composite table. Double bark thickness expressed in percent of d. b. h. can then be converted into bark volume by certain multiplying factors (table 26).

TABLE 26.—*Multiplying factors for converting bark percent at d. b. h. to bark volume in percent*

Species	Multiplying factors [1]	Species	Multiplying factors [1]
Oak	2.2	Spruces	2.0
Elm	2.2	Hemlock	2.0
Sugar maple	2.2	Tamarack	2.0
Basswood	2.2	Aspen	1.8
Ashes	2.0	Beech	1.8
Birches	2.0	Jack pine	1.8
Red maple	2.0	Red and white pine	1.6
Balsam fir	2.0		

[1] To be applied to the double bark thickness as a percent of d. b. h. outside bark.

As bark volume was assumed to be 14 percent in the composite table, corrections must be estimated from this figure. For example, if the bark of a stand is thick and its volume is estimated at 18 percent, the difference of 4 percent must be subtracted from the composite table volume. If the bark volume is less than 14 percent, the difference should be added to the estimate from the composite table.

The adjustment needed for differences in bark volume among 36 tests has been computed (table 24, column 5). Eleven of the stands had bark volume sufficiently different from the 14 percent assumed in the composite table to require 4 percent or more correction. For example, 5.4 percent was subtracted from the composite volume estimate for the basswood sample in group 1, indicating that the bark volume must have been 14.0+5.4, or 19.4 percent. In 16 of the 21 stands in which the bark volume deviation was 2 percent or more, the final estimate was improved by making the correction.

Form Quotient

The form quotient, or the diameter outside bark at one-half of the height as a percent of d. b. h., generally indicates the fullness of the bole and is definitely correlated with the form factor. Since a form factor of 42 percent of the cylinder volume was used in the composite table, the deviations of actual volume from the composite volume should likewise be correlated with the actual form quotient. Deviations for about 135 trees randomly selected from various samples have been calculated (fig. 3). Although there is considerable variation

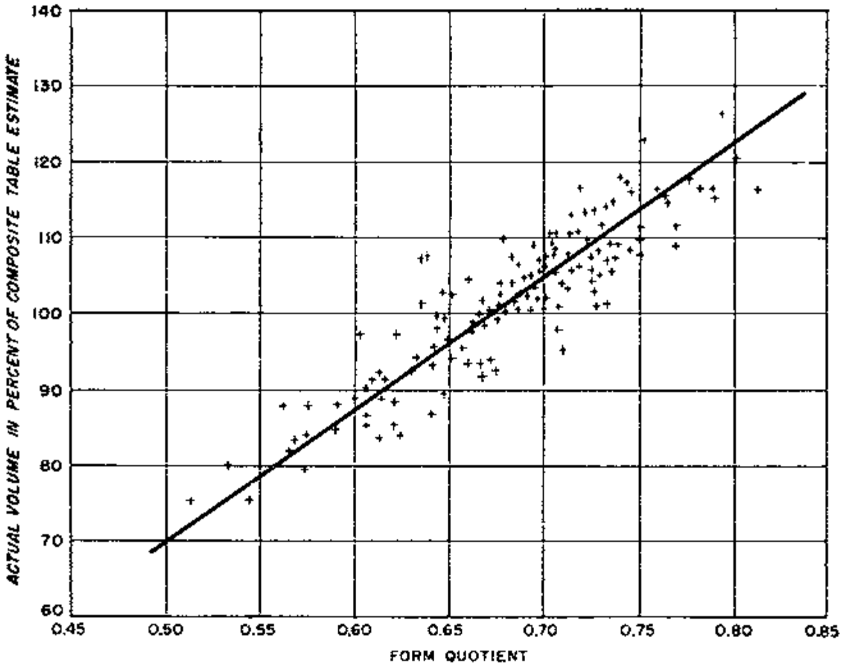

FIGURE 3.—The effect of form quotient on cubic-foot volume.

within each form quotient group, the trend indicates that on the average much accuracy will be gained by recognizing form quotient.

There appears to be a tendency for some species to have a higher form quotient than others. For example, red pine and old-growth hemlock generally show less taper than white-cedar or balsam fir. As is true of bark, however, stand density and age affect form quotient. Old-growth and dense timber is generally noted for its better form. As a rule, suppressed and intermediate trees within a stand have better form than the dominants.

The studies indicated that the composite table estimate should be increased or diminished by about 1.75 percent for each unit of deviation from the average form quotient of 68. In 36 tests, the amount of correction needed for form quotient variations ranged from 0.2 to 18.2 percent (table 24, column 4). In 19, or over half of the tests, the form quotients were at least two units different from the average, and required a correction of 3.5 percent or more. The final estimates in 15 of these 19 stands were improved by making the correction.

To assist in making adjustments for form quotient the normal diameters outside bark at one-half the total height for each diameter class, together with volume adjustment percents for each inch of deviation from the normal, have been computed (table 27). If, for example, a 14-inch tree shows a diameter outside bark of 10.5 inches at one-half the total height, the composite volume estimate should be increased by 12.5 percent.

TABLE 27.—*Normal diameter outside bark at one-half the total height and percent adjustment for each inch of difference from normal* [1]

Diameter breast high (inches)	Normal diameter at one-half total height	Volume correction for each inch deviation from normal	Diameter breast high (inches)	Normal diameter at one-half total height	Volume correction for each inch deviation from normal
	Inches	*Percent*		*Inches*	*Percent*
6	4.1	29.0	19	12.9	9.0
7	4.8	25.0	20	13.6	8.5
8	5.4	22.0	21	14.3	8.5
9	6.1	19.5	22	15.0	8.0
10	6.8	17.5	23	15.6	7.5
11	7.5	16.0	24	16.3	7.0
12	8.2	14.5	25	17.0	7.0
13	8.8	13.5	26	17.7	6.5
14	9.5	12.5	27	18.4	6.5
15	10.2	11.5	28	19.0	6.0
16	10.9	11.0	29	19.7	6.0
17	11.6	10.5	30	20.4	6.0
18	12.2	9.5			

[1] All diameter measurements are outside bark.

A skilled cruiser should be able to estimate deviations from normal of 1 inch on the large trees and one-half inch on the smaller trees. Checks of ocular estimates should be made frequently to avoid a constant bias in one direction. Although form quotient estimates may be subject to considerable error, the estimator should be able to detect large deviations from normal in a stand and make some correction for them.

As mentioned previously, special instruments that are both relatively accurate and practical could replace ocular estimates and thus improve the accuracy of form-class estimation. Adjustment factors (table 27) would then become more useful to the average cruiser in applying the measurements of the composite volume tables to individual tracts.

Species Taper

Because of the wide variation in bark thickness and form quotient within a species, these factors cannot properly be combined into a species correction. It was found, however, that even after allowances had been made in the sample stands for differences in these two factors there still remained for some species a small but systematic discrepancy between the estimated and actual volume. This discrepancy is attributed to the fact that, of two trees with the same form quotient, one may taper differently than the other up to or beyond the halfway point on the stem. Much of the variation within the same form quotient group (see fig. 3) is explained by this one factor, which may be called species taper.

After the composite table estimates have been adjusted for form quotient and bark thickness, the volumes of oak, white-cedar, jack pine, balsam fir, and black spruce are still generally underestimated from 2 to 7 percent (table 28). The volumes of white pine, hemlock, and sugar maple, on the other hand, are overestimated by 2 to 4 percent. Other species apparently need no adjustment.

Very frequently, the effects of form and bark in combination tend to obliterate the species differences. Therefore, the species adjustment should be used only if allowances have also been made for form and bark thickness.

TABLE 28.—*Adjustment of composite cubic-foot estimates for species taper differences*

Species [1]	Percent of adjustment	Species [1]	Percent of adjustment
Oak	+7	Aspen	0
White-cedar	+5	Yellow birch	0
Jack pine	+3	Basswood	0
Balsam fir	+3	White pine	−2
Black spruce	+2	Hemlock	−2
Red pine	0	Sugar maple	−4

[1] Data were not available for all Lake States species.

Twenty-five of 36 tests made were for species that have a correction for species taper (table 24). On 17 of these, adjustments improved the final estimates.

Example of Application

The procedure followed in estimating and applying the adjustment factors is shown in table 29.

1. Correction for form quotient: 243.3/225.0=1.081, or 8.1 percent to be added to the composite volume estimate.

2. Correction for bark volume: 11.80/141.1=0.084, indicating that on the average 8.4 percent of the d. b. h. is bark. 0.084 x 1.8 (see table 26) =0.151, indicating that 15.1 percent of the total unpeeled volume is bark. 0.140−0.151=−0.011, or −1.1 percent. This is the percent difference in bark volume from that assumed in the composite table. Since the bark volume is greater than normal, the volume estimate should be reduced by 1.1 percent.

3. Correction for species taper: According to table 28, 3 percent should be added to the volume estimate for jack pine.

4. Correction percents for all three factors added algebraically: +8.1−1.1+3.0=+10.0 percent.

5. Assuming that the volume estimate from the composite table for the cruise data is 2,800 cubic feet per acre, the corrected estimate is: 2,800×1.10=3,080 cubic feet.

By taking into consideration all three factors affecting cubic volume, the first estimate of volume was increased by 10 percent. In this case there was a difference in form sufficiently large to warrant an extra effort to correct the original estimate from the composite table.

TABLE 29.—*Illustration of procedure for adjusting the cubic-foot estimate from the composite table on a jack pine stand*

Diameter breast high (inches) (1)	Total height (2)	Volume estimate [1] (3)	Normal mid-diameter outside bark [2] (4)	Deviations from normal mid-diameter [3] (5)	Correction [2] (6)	Corrected volume estimate [4] (7)	Double bark thickness (8)
	Feet	*Cubic feet*	*Inches*	*Inches*	*Percent*	*Cubic feet*	*Inches*
6.9	51	5.6	4.7	+½	+12.5	6.3	0.52
9.1	46	8.7	6.2	+1	+19.5	10.4	.76
9.5	42	8.7	6.5	+¼	+9.2	9.5	.86
11.0	62	17.2	7.5	+½	+8.0	18.6	.95
11.3	45	13.2	7.7	+1	+15.5	15.2	.84
11.7	54	16.9	8.0	0	0	16.9	.91
12.0	47	15.5	8.2	+1	+14.5	17.7	1.14
12.0	62	20.4	8.2	−1	−14.5	17.4	1.06
12.2	54	18.4	8.3	0	0	18.4	.96
13.7	55	23.6	9.3	+½	+6.5	25.1	1.14
15.2	65	34.4	10.3	+1	+11.5	38.4	1.50
16.5	68	42.4	11.2	+1½	+16.5	49.4	1.16
Total 141.1		225.0				243.3	11.80

[1] From composite table 3.
[2] From table 27.
[3] Estimated by eye or instrument.
[4] Column 3 corrected by percents in column 6.

Accuracy of Revised Estimates

For 36 stands tested, the deviations of the corrected cubic-foot volume estimates from the actual measured volume were no more than 3½ percent in error; most of them were within 1 or 2 percent (table 24, column 8).

The results, however, are not a good indication of what may be expected in regular cruises for two reasons. First, the samples used were not random but were selected purposely to obtain wide variation in factors affecting volume. A similar number of random tests should show better results from the composite table and less variation in form quotients and bark volumes. Second, it cannot be expected that estimates of bark and ocular estimates of form made on standing trees will be as accurate as was possible in these tests, where exact measurements of the bark all along the stem and of form quotient at half the height were available. Nevertheless, with practice, most cruisers should be able to detect any marked departure from the average and to make some adjustment for it.

Of the 36 stands tested, 8 were very close to average in every respect; that is, very little adjustment had to be made for any of the factors (table 24). In 9 of the stands, larger adjustments were made for 2 or 3 of the factors, but the net correction was small because the deviations tended to be compensating. In the remaining 19 stands, an error from 3 to 14 percent would have resulted if no adjustments had been applied to the composite table estimates. Since the samples were selected especially to illustrate the effects on volume of abnormal form quotients, such stands would be encountered only occasionally in practice. When they do occur, however, large errors in estimates can result from the failure to take form quotient into consideration.

Of the three factors affecting volume, it is easiest to correct for species taper, simply by adjusting the first estimate by the percent given in table 28. Adjustment for bark volume, also, is not difficult because it requires relatively few borings to determine double-bark thickness used in conjunction with table 26. Adjusting for form quotient, however, is a different matter; the cruiser must be skilled in ocular estimates or must make frequent checks either on felled trees or by climbing standing trees.

Because of the relative difficulty of obtaining form quotient measurements, the cruiser may be inclined to make adjustments for bark volume and species taper only and to assume that the majority of estimates will thereby be improved. This is true if the form quotient is average or requires adjustment in the same direction as the net correction for species taper and bark volume. For example, if the bark volume of an oak stand measures 18 percent, a correction of a minus 4 percent must be made on the estimate from the composite table which assumes bark volume of 14 percent. The species taper adjustment for oak is a plus 7 percent, making a net correction for species taper and bark volume of a plus 3 percent.

The composite table will overestimate a stand if it has a form quotient below average; hence the estimate would become less reliable if net adjustments for bark volume and species taper only were used. Had the form quotient been average or better, the estimate would have been improved. This is because an above-average form quotient always requires a plus correction. Since this is in the same direction as the combined bark volume and species taper correction, an improvement would necessarily be made. If the net correction for these two factors had been a minus 3 percent instead of a plus 3 percent, the opposite would have been true; application of the net correction factor would have improved the final estimate only if the stand had an average or below-average form quotient.

The conclusion, then, is that before deciding to make use of the species and bark correction factor only, the estimator must at least determine whether the form quotient of the stand is average, below average, or above average.

Cordwood Volume

In using composite cordwood tables 4, 5, and 6, the estimator should consider (a) the care exercised in piling, (b) large differences in form and taper, and (c) the degree of actual utilization.

Care in Piling

The composite tables assume careful piling equivalent to 79 cubic feet of wood or 92 cubic feet of wood and bark per standard cord of unpeeled bolts. If local practice (woods piling, piling on trucks, etc.) indicates looser piling, some correction will be required. For example, sometimes in average woods piling only 75 cubic feet of wood are stacked per rough cord, which obviously implies that 5 percent more stacked material, (79–75) ÷ 75, would be needed to equal the amount shown in the composite table. Special consideration should be given to this question of care in piling since loose piling is often the cause of large discrepancies in estimates of cordwood volumes.

Large Differences in Form

Moderate variations in form and species taper and in bark thickness have a very small effect on volume of stacked material. Although good form results in more cubic volume of bolts, such bolts are apt to pile better and thus have more volume per cord. The reverse is true of poor form. If the bolts have thin bark there will be more units per rough cord and also a higher solid content. Therefore, the cordwood volume estimated from composite tables will seldom need adjustment for variation in bark and form and will commonly suffice for all practical purposes. When large variations from the averages occur, especially when they tend in the same direction, some adjustment must be made. It is assumed that with careful piling the solid content of a rough cord will very seldom be less than 75 or more than 83 cubic feet.

Degree of Actual Utilization

The merchantable height in terms of bolts is the usable height to a point on the stem where defect, branches, or deformity limit actual merchantability and is not to a fixed top diameter. The minimum top diameters, either 3.0 or 4.0 inches inside bark, are merely the smallest sizes acceptable to the pulpwood industry.

The degree of actual utilization determines the yield in bolts from standing trees. This factor should always be carefully ascertained in cruising. The composite tables, whether based on total height or bolt height, are based on certain utilization standards (see tables 10 and 11). If the relation of the merchantable height to the total height varies considerably from the standards assumed in the tables, adjustments should be made.

It is essential, therefore, that cruisers who prefer to use tables 4 and 5 based on total height should, while measuring total heights, also take enough merchantable height estimates to establish the similarity between the actual utilization and that assumed in table 10.

For convenience, adjustments for actual utilization have been combined with those for form quotient class and species taper, both for use with cordwood volume tables 4 and 5, based on total height (see table 30) and cordwood volume table 6, based on number of bolts (see table 31).

If cordwood volume is estimated from composite table 6 requiring a tally by number of bolts instead of total height, a correction should be applied if actual total heights are considerably higher or lower than the assumed heights given in table 11.

TABLE 30.—*Adjustment of cordwood estimates based on composite tables 4 or 5*

Species group	Form quotient class [1]	Percent adjustment when the ratio of actual merchantable height to assumed merchantable height is—							
		0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Balsam fir, spruce, tamarack, red and white pines, hemlock, aspen, birch, ash, and maple.	Poor	−37	−27	−19	−13	−7	−2	+3	+7
	Average	−30	−20	−12	−6	0	+5	+10	+14
	Good	−23	−13	−5	+1	+7	+12	+17	+21
Cedar, jack pine, cottonwood, elm, and basswood.	Poor	−32	−22	−14	−8	−2	+3	+8	+12
	Average	−25	−15	−7	−1	+5	+10	+15	+19
	Good	−18	−8	0	+6	+12	+17	+22	+26
Oak	Poor	−27	−17	−9	−3	+3	+8	+13	+17
	Average	−20	−10	−2	+4	+10	+15	+20	+24
	Good	−13	−3	+5	+11	+17	+22	+27	+31

[1] Form quotient classes: Poor, 65 or less; average, 66–70; good, 71 or more. See discussion on form quotient and figure 3.

TABLE 31.—*Adjustment of cordwood estimates based on composite table 6*

Species group	Form quotient class [1]	Percent adjustment when the ratio of actual height to assumed height is—					
		0.70	0.80	0.90	1.00	1.10	1.20
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Balsam fir, spruce, tamarack, red and white pines, hemlock, aspen, birch, ash, and maple.	Poor	−22	−17	−12	−7	−2	+3
	Average	−15	−10	−5	0	+5	+10
	Good	−8	−3	+2	+7	+12	+17
Cedar, jack pine, cottonwood, elm, and basswood.	Poor	−17	−12	−7	−2	+3	+8
	Average	−10	−5	0	+5	+10	+15
	Good	−3	+2	+7	+12	+17	+22
Oak	Poor	−12	−7	−2	+3	+8	+13
	Average	−5	0	+5	+10	+15	+20
	Good	+2	+7	+12	+17	+22	+27

[1] Form quotient classes: Poor, 65 or less; average, 66–70; good, 71 or more. See discussion on form quotient and figure 3.

Example of Application

For example (table 32), the correction factor was obtained from sample trees in an aspen stand with the poor average form quotient of 62.

TABLE 32.—*Basis for adjusting cordwood volume estimated from composite table 4 for an aspen stand*

Diameter breast high (inches)	Total height	Volume estimate [1]	8-foot bolts	
			Actual	Assumed [2]
	Feet	*Cords*	*Number*	*Number*
8	50	.068	2.5	3.1
10	60	.138	3.0	4.2
12	70	.247	4.0	5.4
8	60	.082	2.5	3.7
16	70	.460	5.0	6.0
14	60	.295	4.0	4.9
12	60	.210	4.0	4.6
12	60	.210	4.0	4.6
10	70	.163	3.5	5.0
8	50	.068	2.0	3.1
Total		1.941	34.5	44.6

[1] Values from composite table 4.
[2] Estimated from table 10.

The ratio of actual to assumed number of bolts is 34.5/44.6, or 0.77 (table 32).

The form quotient of 62 indicates poor form for the trees in this stand. (See discussion on form quotient in cubic-foot section.)

The correction factor for this aspen stand is a minus 21 percent (see table 30).

The new cordwood estimate of sample trees becomes 1.941 (1−0.21), or 1.53 cords.

Using the same example, but basing the estimate on the number of bolts, gives slightly different results (table 33).

The ratio of actual to assumed total height is 610/594, or 1.03.

The form quotient of 62 indicates poor form for the trees in this stand. (See discussion on form quotient in cubic-foot section.)

The correction factor for this aspen stand is a minus 6 percent (see table 31).

The adjusted cordwood estimate of sample trees becomes 1.688 (1–0.06), or 1.59 cords.

For this stand the cordwood estimate based on total height required a reduction of 21 percent because of the poor form and the fact that the actual number of bolts was considerably less than that assumed in the composite table. On the other hand, the estimate based on number of bolts needed a reduction of 6 percent, primarily because of poor form. The corrected estimates, based on generalized correction factors, were not exactly the same for both methods, but either method would provide much more satisfactory estimates than those obtained directly from the composite tables.

TABLE 33.—*Basis for adjusting cordwood volume estimated from composite table 6 for an aspen stand*

Diameter breast high (inches)	Bolts	Volume estimate [1]	Total height	
			Actual	Assumed [2]
	Number	*Cords*	*Feet*	*Feet*
8	2.5	0.059	50	51
10	3.0	.111	60	57
12	4.0	.198	70	63
8	2.5	.059	60	51
16	5.0	.420	70	71
14	4.0	.273	60	67
12	4.0	.198	60	63
12	4.0	.198	60	63
10	3.5	.122	70	57
8	2.0	.050	50	51
Total		1.688	610	594

[1] Estimated from composite table 6.
[2] From table 11.

Accuracy of Revised Estimates

The accuracy of any cordwood table is difficult to judge because of the variation in the closeness of piling. Nevertheless, composite table 6,[11] which shows volume based on number of bolts, has been used for some years by foresters and pulpwood industry men, and opinion thus far indicates that a satisfactory degree of accuracy is obtainable without adjustment. This implies that commercial stands on which the table has been used generally have shown no extreme variations in form and total height. It is probable that adjustment factors rarely will be needed when merchantable height is measured.

Estimates based on the cordwood tables by total height are apt to require adjustment more frequently than those based on number of bolts, since variations in merchantability can cause errors of considerable magnitude. It is especially important when using these tables to make certain that the utilized height closely approximates the standards used in the tables.

[11] See footnote 5, p. 11.

SUMMARY

This report explains the development of a set of composite volume tables for the Lake States and their application in the field.

Six basic composite tables have been prepared that can be adjusted by means of correction factors to fit any particular stand. The tables have been tested extensively in the field and have been found to be a satisfactory replacement for the numerous local species volume tables formerly used in the Lake States.

When large areas are evaluated, a considerable amount of compensation among the factors affecting volume occurs, and adjustment of the basic composite tables usually is not required. The estimates are also sufficiently accurate on small tracts for reconnaissance surveys or for timber of relatively low value.

For the purchase or sale of more valuable timber, or in areas where the timber clearly departs from the average pattern, adjustments should be made. This requires either additional work in making applicability checks or the ability to estimate significant differences in form class of trees, bark thickness, taper associated with species and the condition of the stand, degree of utilization, and local practices. Methods for making these adjustments are given.

A satisfactory estimate, using any volume table, is always dependent on adequate consideration of the character of the timber being cruised. To use the adjustment factors presented in this report, it is necessary to evaluate local differences in timber stands often overlooked when using species tables. This fosters improved estimates.

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