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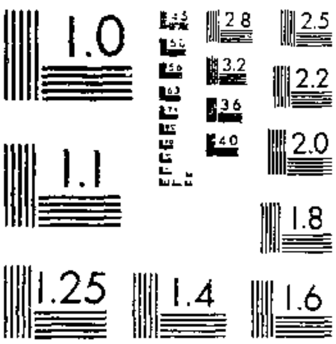

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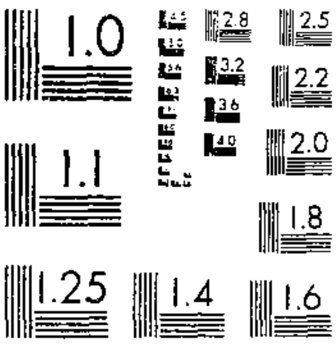

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TECHNICAL BULLETIN No. 142 — NOVEMBER, 1929

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YIELDS OF SECOND-GROWTH SPRUCE AND FIR IN THE NORTHEAST

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CONTENTS

INTRODUCTION

The phenomenal growth of the pulp and paper industry in the northeastern United States has had many important consequences, among which not the least is a necessity for focusing attention upon adequate supplies of raw materials, upon which the welfare of the industry must be based. According to a late authentic report (*36*) [1] the New England States and New York account for 47 per cent of the total pulpwood consumption of the country. According to the same figures the Northeastern States manufacture 53 per cent of the total quantity of wood pulp and 41 per cent of the total quantity of paper. Under these circumstances the effect upon local supplies of raw materials is not surprising. The industry is consuming far more pulpwood than it can harvest in the Northeast, and the quantity of pulpwood being harvested annually in this region already exceeds by a wide margin the estimated growth. Virgin timber is rapidly disappearing. Mills are taking more and more of the new timber coming in on the cut-over lands, and the need is already felt to have available correct information regarding the possible yields of this second-growth timber.

[1] Italic numerals in parentheses refer to Bibliography, p. 50.

The interest in second-growth yields is especially keen because of the fact that the tree species desired at the present time for pulping processes are very few. Mills manufacturing pulp by the mechanical and sulphite processes are by far the most common in this region, and the limitations of these processes serve further to restrict the desirable species.

The pulpwood in the Northeastern States most desired is red spruce (*Picea rubra*). Next in importance is balsam fir (*Abies balsamea*), and third in importance is white spruce (*P. glauca*). A fourth species of less importance is black spruce (*P. mariana*).

Studies of the growth and yields of red and white spruce and balsam fir are nonexistent, with the exception of one set of red spruce yield tables (*15*) prepared by L. S. Murphy.[2] These tables are based upon 51 sample plots and are applicable to pure second-growth stands on old fields and pastures.

The present study includes Murphy's 51 plots, measurements of 7 permanent sample plots at Corbin Park, N. H., and the records of some 350 additional temporary sample plots scattered throughout Maine, New Hampshire, and Vermont. (Fig. 1.) Very few plots were taken in New York State, because of the lack of fully stocked second-growth red spruce stands.

Of the entire 400 plots the data from 201 were finally chosen as the basis for the red spruce tables presented here. The first plots to be eliminated were those having only moderate proportions of red spruce. Others were rejected because of abnormal basal areas, that is to say, total basal area exceeding or underrunning the limits set for variation from type values. These plots discarded because of abnormal basal area contributed later, however, to a study of the effect of density of stocking.

The character and composition of these sample plots were found to change in a very interesting manner with changes in region. In southeastern Maine, along the coast, a mixture of balsam fir, white spruce, and red spruce is prevalent. Small pure patches of any of the three species can be expected in many places. On second-growth areas throughout all Maine a mixed stand seems to be characteristic, the percentages of the component species varying greatly even on small areas. The same sort of mixed stand is found in New Hampshire north and east of the White Mountains; but south and west of the main White Mountain range white spruce is almost entirely lacking from the mixture. Even balsam fir is not as important here as it is to the north and east. Pure second-growth red spruce stands occur commonly in this region and in Vermont, but rarely in a fully stocked condition below 1,600 feet elevation.

In all portions of the region, the fully stocked, even-aged stands, pure or mixed, are most commonly found on old pastures and old fields and occasionally on old burns, cuttings, and blow downs. The reversion of lands formerly used chiefly for grazing is an interesting study, especially when one finds so often that a fence line may be the division between two distinct forest types, such as a pure hardwood stand and a pure spruce stand. Both portions may have been originally cut clean and grazed, but where the spruce type is, grazing evidently continued for a longer period. The underlying

[2] For a description of the silvical characteristics and the management of red spruce, see (*15*), in which the tables mentioned are included, and, for balsam fir, (*24*).

reasons for subsequent development into coniferous or hardwood stands are for the present only a matter of conjecture.

The quantity of white spruce in second-growth stands in most portions of Maine is also interesting. Although the original forests contained a great deal more red spruce than white spruce, the second-growth stands, especially on old pastures and fields, show a contrary tendency.

In gathering the data for this study, pure, fully stocked, even-aged stands were selected, both because this is the form in which many

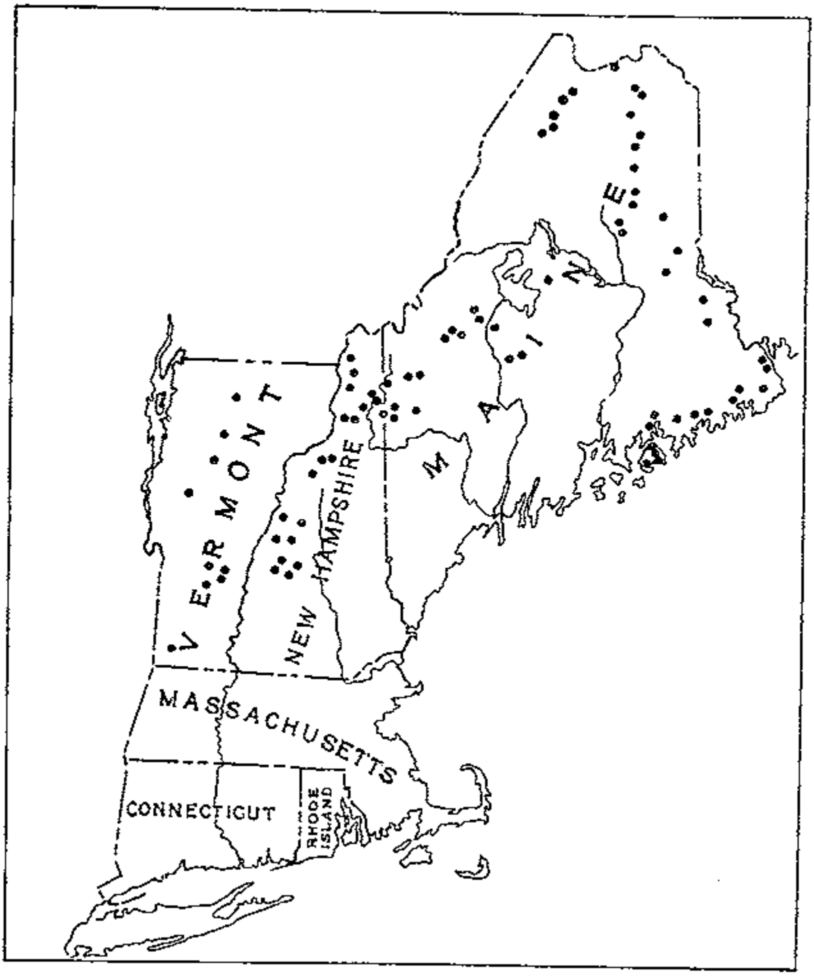

FIGURE 1.—Locations of temporary sample plots in the spruce-fir yield study, each spot representing a locality where one or more plots were taken

second-growth stands occur, and because these lend themselves most readily to the study of growth and yields. Mixtures of several species, variability of stocking, and age add complexities which are often difficult to solve. A certain freedom of selection must be maintained in the preliminary field work, since at that time the ideal composition and stocking can not be accurately estimated. One grade of stocking may lead to highest total cubic-foot volume, another to highest total board-foot volume, and still another to highest volume of best-quality lumber. In collecting the data it is necessary to make due allowance for this by some liberality in the determination of what constitutes good stocking. Yield tables made up from data collected in this manner are known as normal-yield tables, since they indicate yields that at least approximate the normal, or those which may be expected of well-stocked stands. It is of course recognized that normal yields can not be realized over any large areas; they are more or less the ideal which stands will approach under good care or uniformly favorable natural conditions.

Some foresters insist that yield tables should be "empirical," or representative of the average conditions. However, average conditions for one area are not the same as average conditions for another. Consequently, an empirical table that is to be used in different places must be adjusted to these different conditions by proper converting factors if it is to be sufficiently accurate. Since converting factors are needed in any event, it is assumed that they may be more easily and accurately employed as between the normal and the particular conditions, than as between two different sets of average conditions.

The character of the reduction which must ordinarily be made in the application of yield tables to average stands, and the method of its application, are much-debated questions. Several investigations are in progress which may develop new and greatly improved methods of applying yield tables, but until these can be more definitely stated than at present, older, if less satisfactory methods must be still relied upon.

The first step in the application of a yield table is to obtain an accurate knowledge of the area to which it is to be applied. If stands already exist on the area a strip survey should be made, in which all nonstocked areas must be determined, site divisions and pronounced differences in stocking marked out, and ages recorded. Tally sheets should be changed with each change in site, stocking, or age. Further consideration of application of the tables will be given in the course of the discussion.

In this presentation of spruce and fir yields it has seemed best to present the material under two main divisions. The first includes the presentation of the tables and charts with only a general discussion of their use and a few remarks on the application of yield tables as a whole. The second part takes up some of the technical considerations of the study, the character of the material upon which the tables are based, the reliability and limitations of the various tables, and a discussion of several of the tables based on observations of permanent sample plots. Throughout the first part of the bulletin chances for technical discussion are apparent, but will necessarily be postponed for treatment later on.

RED SPRUCE TABLES AND THEIR APPLICATION

AGE OF STAND

The age of a stand is taken as the average age of the dominant and codominant trees.[3] This age was obtained by boring many of the dominants and codominants at breastheight, 4.5 feet above the ground, counting off the age, and then averaging the various ages counted. To this average value, called the breastheight age, a period of 15 years was added to allow for growth from origin of stand to breastheight. The length of this period was based on a seedling study which will be described later in detail. In the following sets of tables whenever age is mentioned, total age is meant, unless otherwise stated.

In the application of yield tables age is obtained either by increment borings or stump counts. If borings are made at breastheight, 15 years should be added to get total age; if ages are determined on a 1-foot stump, seven years should be added. Only ages of the dominant and codominant tree classes are taken. An average of all the counted ages is then made and used as the stand age. The range in ages of these dominants should not be much more than 10 years, otherwise the stand will be thrown out of the even-aged class. The stand which is being surveyed should be tested in many places, especially where age class seems to be changed.

SITE INDEX

The indicator of site used in this study is the height in feet of the average dominant and codominant red spruce, or the tree having the average basal area of all the dominants and codominants in the stand. The height of this average tree is read from the height curve of the stand. By use of Figure 2 or Table 1 the relative position of the determined height can be found and the site index read off. The site index is numbered from the value of the height of the average dominan. and codominant at 65 years total age. Thus a stand of site index 57 is a stand which at 65 years of age has a height of average dominants and codominants amounting to 57 feet.

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[3] Definitions of the crown classes adopted in this study are briefly as follows:
Dominant.—The large trees of the stand with well-developed crowns extending above the general level; with full light above and part on the sides.
Codominant.—Trees forming the greater part of the main canopy, receiving full light from above, and a little on the sides.
Intermediate.—Trees below the main canopy, but still extending into it, receiving only a little top light; hemmed in on all sides.
Suppressed.—Trees entirely below the main canopy, practically no top light; very poor crown development.
For more detailed definitions the reader may refer to the forest terminology adopted by the Society of American Foresters (*51*).

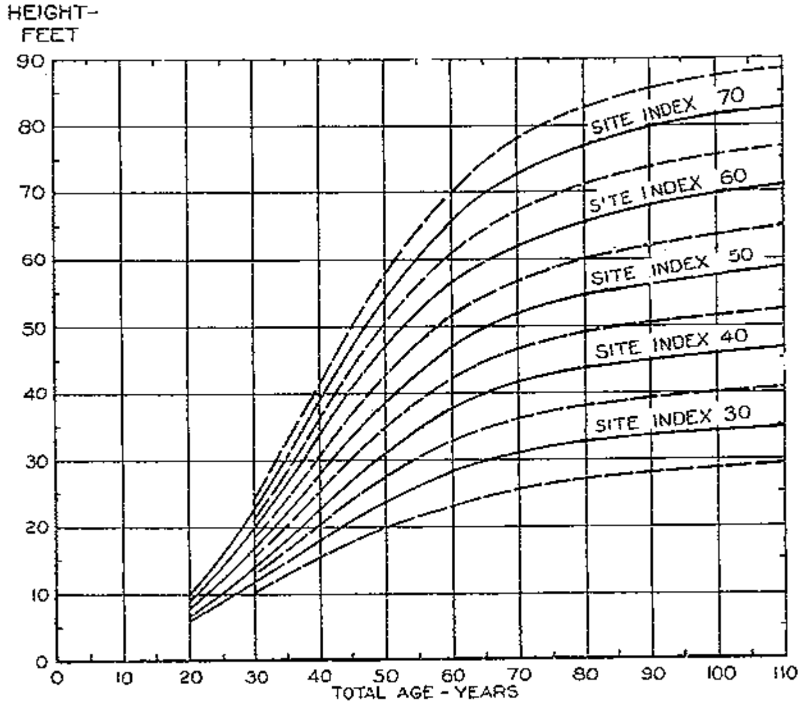


FIGURE 2.—Red spruce site index based upon the height of the average dominant and codominant tree

For the average quality of site (site index 50), the average heights range from 8 feet at 20 years to 59 feet at 110 years. At 70 years a height of 52 feet is already attained. Beyond this age the rise is much more gradual.

TABLE 1.—*Red spruce site index based upon height of average dominant and codominant tree*

Total age	Site index 70	Site index 60	Site index 50	Site index 40	Site index 30
	Height of average dominant and codominant tree				
Years	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
20	10	9	8	7	6
30	23	20	17	14	12
40	39	34	28	23	18
50	54	47	39	31	24
60	66	57	47	38	28
70	73	62	52	42	31
80	77	66	55	44	33
90	80	68	56	45	34
100	82	70	58	46	34
110	83	71	59	47	35

In applying the table, common practice will be simply to average the heights of 20 or more dominant and codominant trees in a stand; but any tendency to take the heights of the largest trees only should be guarded against, since the average height of the chart refers to all diameter classes of the dominant and codominant trees. Site determination by use of Figure 2 should be repeated and checked in various portions of the area, especially where there is an apparent change of site.

The total range of sites for red spruce in Figure 2 is somewhat wider than will ordinarily be found; practically all the second-growth stands lie between site indices 35 and 65, the most common site index being 50. The outer sites 30 and 70 are given for the sake of interpolation of values which may lie below site index 40 (pl. 1) or above site index 60. They are very extreme values and should not be included if there is any desire to use the system of classifying sites as I, II, and III. Site I corresponds to site index 60, Site II to site index 50, and Site III to site index 40.

The relation between site and the recognized forest types (*34, 43*) is not clear-cut, since the ranges of site indices overlap from one type to another. On the whole the majority of stands in the various types have site indices between the following values:

Spruce swamp		Site index range 30 to 45.
Spruce flat		Site index range 35 to 50.
Spruce slope	Lower portion	Site index range 35 to 60.
	Upper portion	Site index range up to 45.
Old pasture and old field		Site index range 40 to 65.

DEGREE OF STOCKING

Basal area is usually taken as a measure of the degree of stocking. Number of trees can be used, but only if the trees are well spaced and not placed groupwise. Where distribution is good a decrease in number of trees would be expected to be accompanied by an increase in average diameter and, further, an increase in total board-foot volume.

The plots of this study were chosen with evenness of stocking as a requisite, and therefore they tend to maintain this relation between number of trees and board-foot volume as is indicated in Figure 3, where number of trees and board-foot volume are expressed in percentages of the normal values, or the values stated in the yield tables. The board-foot curve rises steeply to a maximum at 60 per cent of normal number of trees, then falls off, passing through the 100–100 per cent point and decreases less rapidly from this point on. The cubic-foot curve shows an entirely different trend, a rapid increase in the lower percentages slows down at approxmiately 90 per cent, but keeps on rising slowly through the remainder of the range of stocking.

No plots under 45 years total age are included in Figure 3 because the board-foot values for these low ages, although small in absolute amounts, may give unduly high percentages when compared to yield-table values. Forty-five years was chosen by inspection as the age above which these extreme eccentricities disappeared. Beyond this limit, age was found to have very little effect on the relation between board-foot volume and normal volume.

According to Figure 3, the average full stand of second-growth red spruce is too dense for maximum board-foot volume. The necessity of judicious thinning which is made apparent in this way is also indicated in the continuous decline in rate of diameter growth from the time of origin of the stand and especially after the total age of 75 years.

Unfortunately the quality of the board-foot volume can not be simply shown. If the maximum amount of good-quality lumber is desired, the density of the stand should undoubtedly be kept up until natural pruning has accomplished much of its work, after which the thinnings aiming to maintain the diameter growth and to attain the maximum volume may be started. (Pls. 2 and 3.)

White spruce stands and balsam fir stands studied in the light of the red spruce tables exhibit very similar trends. White spruce attains its maximum board-foot volume at 65 per cent stocking and balsam fir its maximum at 75 per cent. However, most of the balsam fir and white spruce material is between the ages of 45 and 65 years, and therefore these values can be considered to apply only to this range of ages.

In the application of the yield tables degree of stocking is obtained from the strip-survey tallies after they have been worked up. For

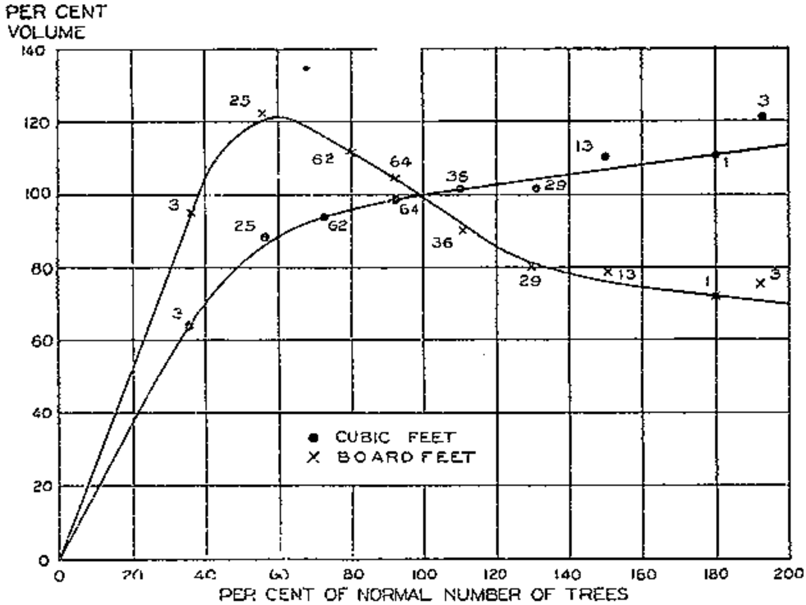
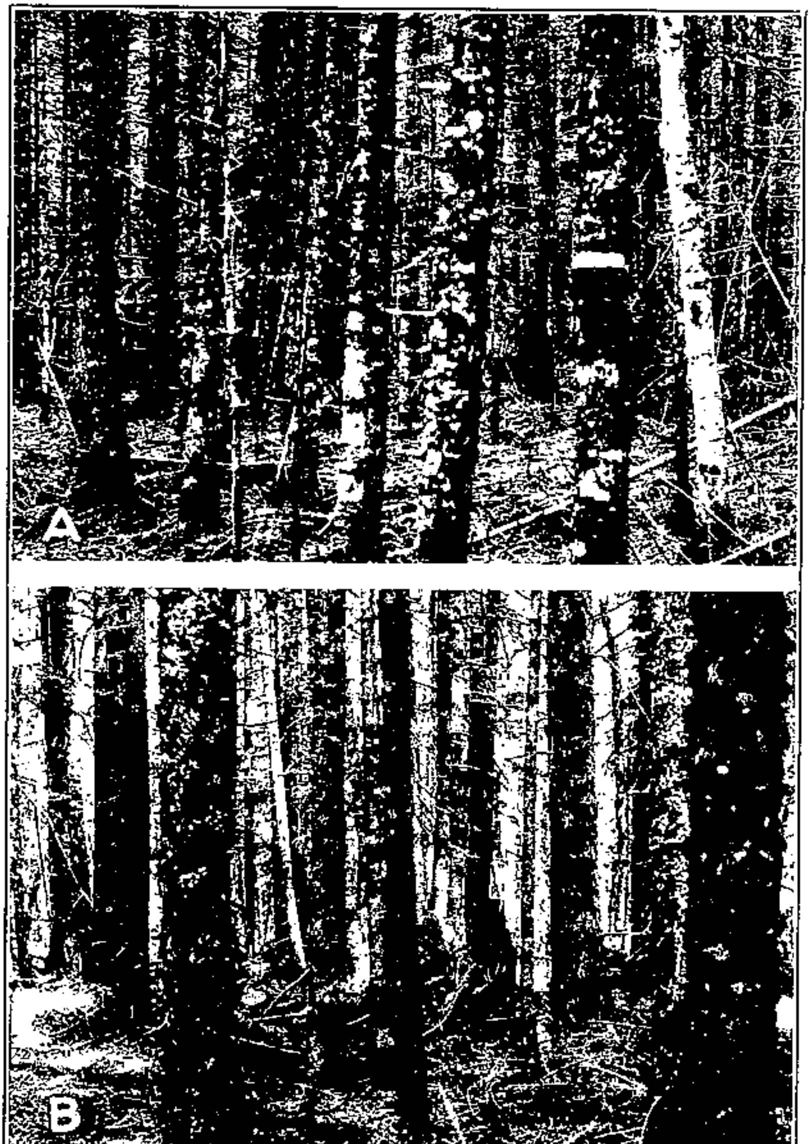


FIGURE 3.—Red spruce. Relation between percentages of normal number of trees and of normal volume

each subdivision of the stand by age, site, or stocking, the total basal area for the average acre is computed. This value divided by the normal value of the yield table for the site and age in question gives the degree of normality. For instance, if for a stand 65 years old, site index 50, the total basal area per acre amounts to 190 square feet, the degree of normality or the grade of stocking is 190 divided by 224 (fig. 4), or 85 per cent. This computed grade of stocking can then be used for all future predictions, the normal yields at any time in the future development of the stand being reduced by 15 per cent to obtain the predicted yield. This estimate is conservative, since it allows no growth toward normality, although such growth undoubtedly takes place in any understocked stand, especially if understocking is characterized by evenness of distribution of the trees. There is no doubt that understocked stands will approach



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RED SPRUCE ON POOR SITES

A.—The 90-year-old suppressed stand of red spruce on an unfavorable swampy site in northern New Hampshire has about 1,000 trees to the acre.
B.—This 85-year-old stand is on an unfavorable but less swampy site in southern Maine.

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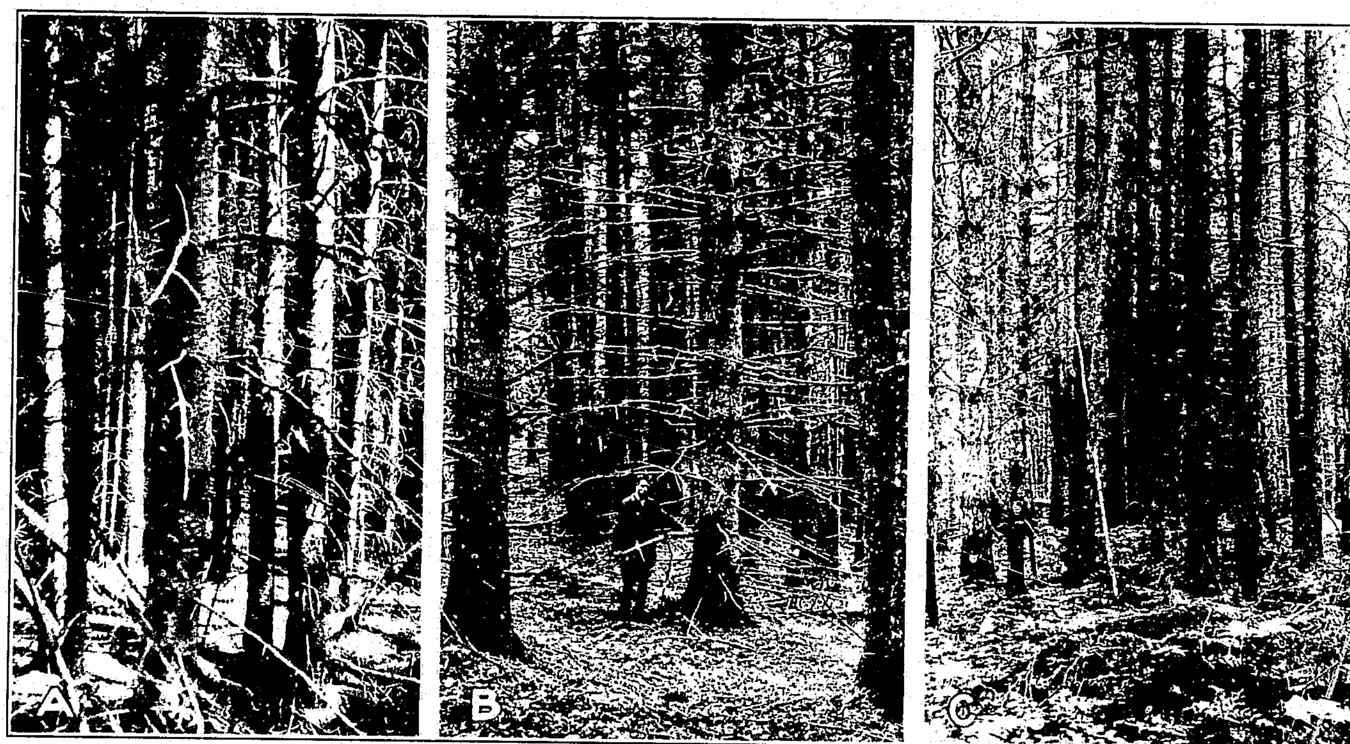
FAVORABLY STOCKED, WELL-PRUNED RED SPRUCE ON GOOD SITES

A 70-year-old stand on an old pasture in the White Mountains (A), favorably stocked; an 85-year-old stand on a good site in northern New Hampshire (B), heavily stocked, and with a natural pruning well advanced; and a heavily stocked stand in central New Hampshire 85 years old (C), having good natural pruning.



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TOO OPEN, BADLY PRUNED STANDS OF SPRUCE AND FIR

A mixture of young balsam fir and spruce (45 years) showing a great quantity of dead unpruned limbs.

The effect of very wide spacing on limbiness and diameter growth of red spruce in a 75-year-old stand in western Maine.

The presence of much herbage is indicative of too open stocking. This stand in western Maine is 60 years old, but has not pruned well.

a fully stocked condition with advance in age, but only by subsequent study of permanent sample plots can the rate of approach be satisfactorily determined.

TABLES FOR TOTAL STAND; ALL TREES ABOVE 0.6-INCH DIAMETER BREAST HIGH

BASAL AREA

The total basal area in square feet per acre is given in Figure 4 and Table 2 for the whole range of sites and ages. The average site index 50, starting with 22 square feet at 20 years, increases rapidly up to 60 years, and then increases steadily but at a less rapid rate to 250

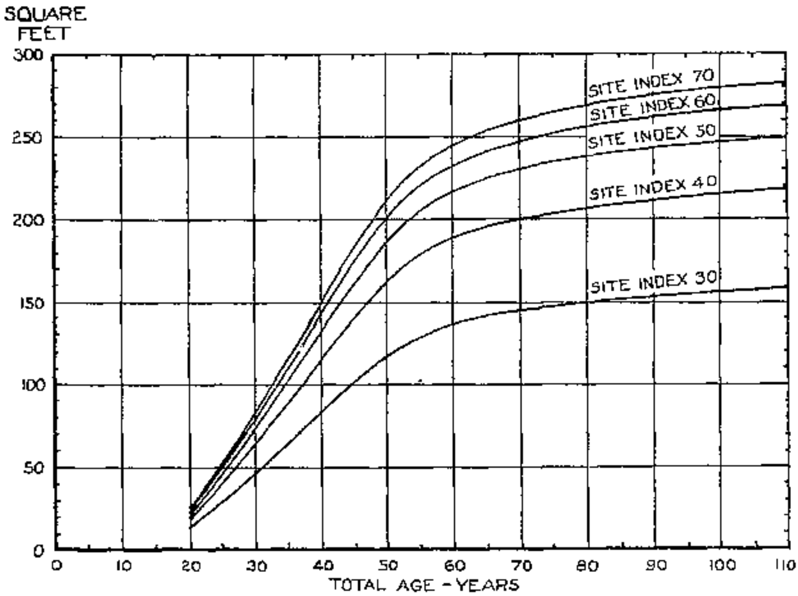

FIGURE 4.—Red spruce. Total basal area per acre

square feet at 110 years. With increase in site the distances between the site curves lessen.

TABLE 2.— *Red spruce: Total basal area per acre, including all trees above 0.6 inch diameter breast high*

Total age	Site index 70	60	50	40	30
	Basal area				
Years	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*
20	25	24	22	19	14
30	82	78	73	64	46
40	149	142	132	115	83
50	210	200	186	162	117
60	245	233	217	189	137
70	260	247	230	200	145
80	269	256	238	207	150
90	275	261	243	211	153
100	279	266	247	215	156
110	282	269	250	218	158

NUMBER OF TREES

In Figure 5 and Table 3 the total number per acre of trees 0.6 inch and more in diameter breast high is given. Site index 50, starting with 3,690 trees at 20 years, decreases rapidly up to approximately 60 or 70 years, and then slowly to 628 trees at 110 years. The great increase in number of trees with decrease in site index is strikingly apparent.

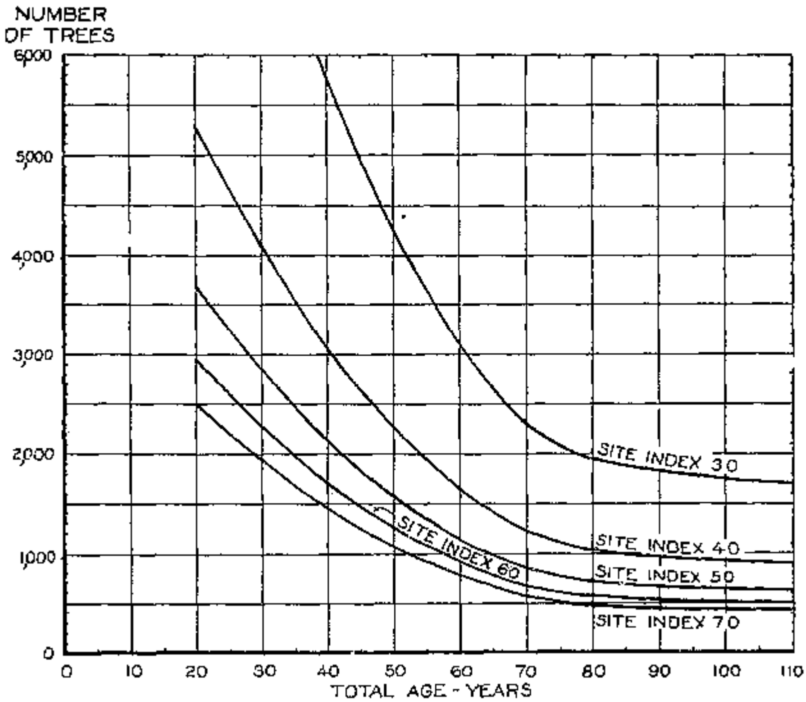

FIGURE 5.—Red spruce. Total number of trees per acre. All trees above 0.6-inch diameter at breast height are included

TABLE 3.—*Red spruce: Total number of trees per acre above 0.6 inch diameter breast high*

Total age (years)	Site index				
	70	60	50	40	30
	Number of trees				
20	2,495	2,935	3,690	5,285	6,945
30	1,925	2,265	2,845	4,075	7,670
40	1,440	1,695	2,130	3,055	5,745
50	1,065	1,250	1,575	2,255	4,240
60	782	920	1,155	1,655	3,115
70	575	676	849	1,215	2,290
80	486	572	710	1,030	1,940
90	458	538	676	969	1,825
100	440	518	650	932	1,755
110	425	500	628	900	1,695

SIZE OF THE AVERAGE TREE

The size of the average tree can be expressed either by the basal area of the average tree in square feet or by the diameter in inches corresponding to this basal area. (Fig. 6 and Table 4.) Since diameter is of more direct use, this criterion is the one presented. Trees of site index 50 have an average diameter breast high of 1 inch at 20 years, which increases steadily to 80 years, and from then on less rapidly to 110 years, reaching 8.5 inches. Were the size of the

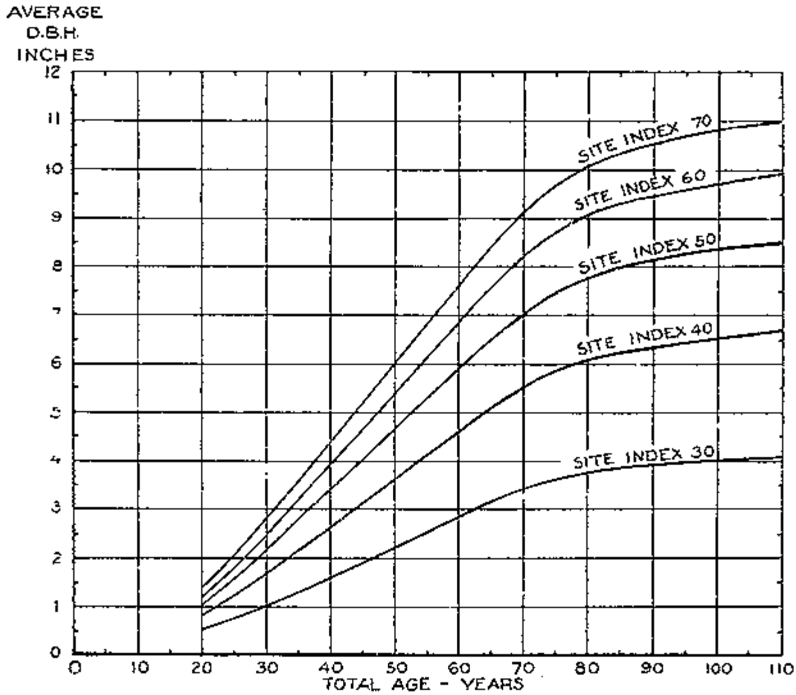

FIGURE 6.—Red spruce. Breastheight diameter of average tree

average tree expressed in basal area, the distance between the site curves would be quite regular. If the average diameter of stand were computed by averaging all the diameters of the stand, instead of being derived from basal area, the values would be from 0.2 to 0.4 inch lower than those given in the tables.

TABLE 4.—*Red spruce: Size of average tree in terms of breastheight diameter*

Total age	Site index 70	60	50	40	30
	Diameter, breast high				
Years	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	1.4	1.2	1.0	0.8	0.5
30	2.8	2.5	2.2	1.7	1.0
40	4.4	3.9	3.4	2.6	1.6
50	6.0	5.4	4.7	3.6	2.2
60	7.6	6.8	5.9	4.6	2.8
70	9.1	8.2	7.0	5.5	3.4
80	10.1	9.1	7.8	6.1	3.8
90	10.5	9.4	8.1	6.3	3.9
100	10.8	9.7	8.4	6.5	4.0
110	11.0	9.9	8.5	6.7	4.1

HEIGHT OF AVERAGE TREE

Although, of the average-height values, that of the dominants and codominants (Table 1), is the most important, the average height of the whole stand (fig. 7, Table 5) is of some interest. This height is the height of the tree of average basal area. All trees of the stand

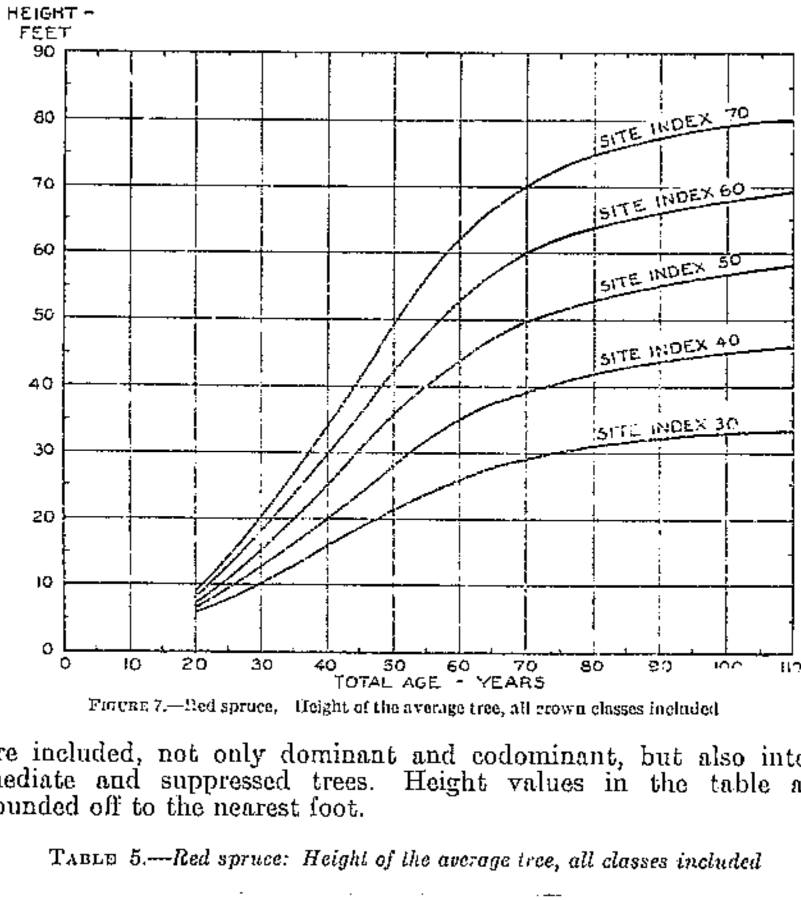

FIGURE 7.—Red spruce. Height of the average tree, all crown classes included

are included, not only dominant and codominant, but also intermediate and suppressed trees. Height values in the table are rounded off to the nearest foot.

TABLE 5.—*Red spruce: Height of the average tree, all classes included*

Total age	Site index 70	60	50	40	30
	Height				
Years	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
20	9	8	7	7	6
30	20	18	15	13	10
40	34	30	25	20	16
50	49	42	36	28	21
60	62	53	44	35	26
70	70	60	50	39	29
80	75	64	53	42	31
90	77	66	55	44	32
100	79	68	57	45	33
110	80	69	58	46	33

CUBIC-FOOT VOLUME

Figure 8 and Table 6 present the total cubic-foot yields of the stand inside bark, including stump and top, but without butt swell. These volumes are the so-called "normal volumes" as defined by C. E. Behre in his work on the conformity of the taper of various species to a mathematical taper curve (*44, 45, 46*). All cubic-foot volumes mentioned in this bulletin are of this character. To include bark, the cubic-foot yields should be increased by 12 per cent, which is an approximate average value, probably affected somewhat by the size of the trees. To include butt swell, a further addition of 2.6 per cent is necessary. Butt swell is correlated somewhat with the average size of the trees ranging from 1 per cent for the smaller diameters to 5 per cent for the larger diameters.

At 20 years site index 50 has the small volume of 120 cubic feet, which after a short period of development increases rapidly to the 50-year point, and thereafter less rapidly, until by 90 years only small gains are made.

TABLE 6.—*Red spruce: Total cubic-foot volume inside bark per acre, butt swell not included*

Total age	Site index 70	Site index 60	Site index 50	Site index 40	Site index 30
	Volume				
Years	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
20	200	160	120	80	50
30	1,060	860	660	500	280
40	2,850	2,350	1,800	1,350	750
50	5,350	4,430	3,510	2,550	1,400
60	7,210	6,030	4,780	3,490	1,930
70	8,430	7,020	5,590	4,050	2,200
80	9,150	7,610	6,060	4,400	2,450
90	9,580	7,970	6,340	4,600	2,560
100	9,870	8,210	6,520	4,740	2,640
110	10,100	8,410	6,680	4,860	2,700

TABLES FOR TREES IN AND ABOVE THE 4-INCH DIAMETER CLASS

Tables for partial stands are derived from the values of the total stand. Tables 7, 8, 9, 10, 11, and 13 give, respectively, total basal area in square feet per acre, number of trees per acre, average diameter, total and merchantable cubic-foot volumes, and cord volumes for all trees in the stand in and above the 4-inch d. b. h. class, or the equivalent of possible pulpwood in fully stocked second-growth stands.

To obtain merchantable volumes, percentage reductions were applied to total cubic-foot volume. Table 12 presents these percentages of the total volume between 1-foot stump and 3-inch top inside bark for trees of various diameters and heights. By taking into consideration the size of the average tree these values can be transformed to age and site percentages and can then be applied to total cubic-foot volume (Table 10) to get an approximation of the merchantable cubic-foot volume. (Table 11.) The reduction percentages are computed for form class 75, which is the class within which the majority of the second-growth red spruce stands fall.

CORD VOLUME

By applying the factor 95 to the peeled cubic-foot volumes of Table 11, the cord volumes of Table 13 are obtained. This is on the assumption that 95 cubic feet of wood is equal to 1 cord, a relation of course not altogether constant for various-sized bolts or bolts of other than 4-foot lengths, but sufficiently indicative, since no satisfactory converting factors for stands of different average sizes are available. The fact that volume with bark of a single tree may average 12 per

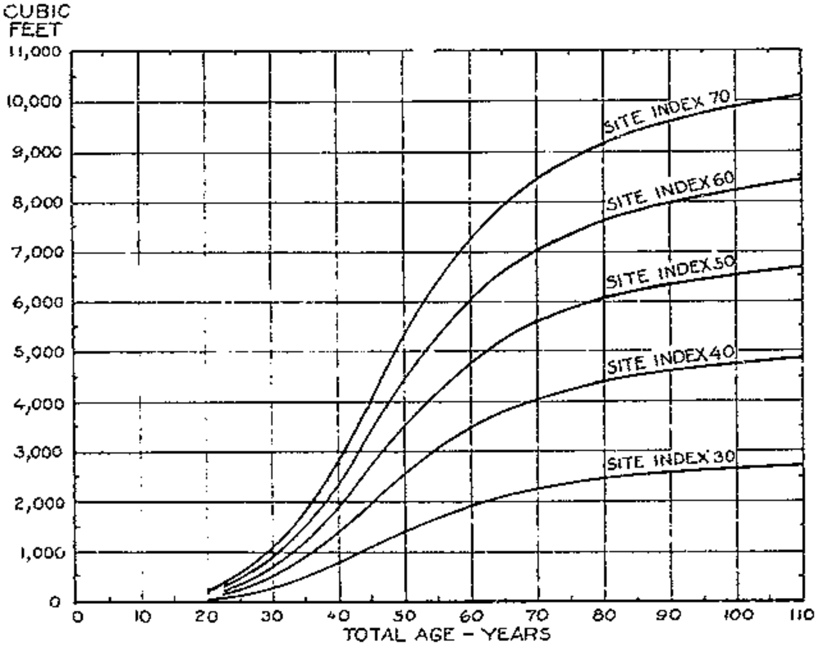

FIGURE 8.—Red spruce. Total cubic-foot volume inside bark, per acre

cent above the peeled volumes does not mean that cord volumes with bark should be 12 per cent higher. With the inclusion of bark, more roughness must be expected; the bolts of such cordwood will consequently fit less closely than the peeled bolts. The amount of increase in volume is therefore larger than 12 per cent. What the actual increase is can only be guessed, but a reasonable guess is 15 per cent. The cord volume of Table 13 may thus be increased by 15 per cent to obtain approximate cord volume with bark.

TABLE 7.—*Red spruce: Total basal area per acre of all trees in and above the 4-inch diameter class*

Total age	Site index 70	60	50	40	30
	Basal area				
Years	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*
30	45	38	26	14	-------
40	127	111	88	59	17
50	206	189	164	120	46
60	244	231	213	165	77
70	260	246	228	191	100
80	269	256	237	203	113
90	275	261	242	208	119
100	279	266	246	213	125
110	282	269	250	216	128

TABLE 8.—*Red spruce: Number of trees per acre in and above the 4-inch diameter class*

Total age (years)	Site index 70	60	50	40	30
	Number of trees				
30	404	363	264	143	-------
40	835	760	703	535	175
50	927	923	1,007	993	460
60	760	868	960	1,044	660
70	569	666	811	973	760
80	482	560	715	912	815
90	456	533	665	882	845
100	439	515	640	855	870
110	425	497	623	840	881

TABLE 9.—*Red spruce: Average breast-high diameter of all trees in and above the 4-inch diameter class*

Total age	Site index 70	60	50	40	30
	Diameter, breast high				
Years	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
30	4.5	4.4	4.3	4.2	-------
40	5.3	5.1	4.8	4.5	4.2
50	6.4	5.9	5.5	4.9	4.3
60	7.7	7.0	6.3	5.4	4.6
70	9.2	8.2	7.2	6.0	4.9
80	10.1	9.1	7.8	6.4	5.0
90	10.5	9.5	8.2	6.6	5.1
100	10.8	9.7	8.4	6.8	5.1
110	11.0	10.0	8.6	6.9	5.2

TABLE 10.—*Red spruce: Total cubic-foot volume inside bark per acre of all trees in and above the 4-inch diameter class*

Total age	Site index 70	Site index 60	Site index 50	Site index 40	Site index 30
	Volume				
Years	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
30	670	470	290	125	----------
40	2,580	2,070	1,430	800	195
50	5,280	4,280	3,250	2,100	670
60	7,240	6,020	4,700	3,250	1,240
70	8,430	7,020	5,590	3,930	1,750
80	9,150	7,610	6,060	4,350	2,060
90	9,550	7,970	6,340	4,570	2,200
100	9,870	8,210	6,520	4,730	2,310
110	10,100	8,410	6,680	4,850	2,390

TABLE 11.—*Red spruce: Merchantable cubic-foot volume per acre of trees in and above the 4-inch diameter class; 1-foot stump allowance, 3-inch top inside bark*

Total age	Site index 70	Site index 60	Site index 50	Site index 40	Site index 30
	Merchantable volume				
Years	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
30	500	340	210	88	----------
40	2,100	1,650	1,110	600	138
50	4,780	3,770	2,760	1,670	480
60	6,850	5,550	4,200	2,750	940
70	8,100	6,620	5,150	3,470	1,400
80	8,880	7,280	5,700	3,920	1,670
90	9,300	7,650	6,000	4,160	1,800
100	9,570	7,870	6,100	4,310	1,900
110	9,800	8,050	6,350	4,440	1,900

TABLE 12.—*Red spruce: Merchantable cubic-foot volume percentages of total cubic-foot volume of single trees, over a range of diameters and heights; 1-foot stump allowance, 3-inch top inside bark; for form class 75*

Diameter breast-high outside bark	Height of tree: 20 feet	30 feet	40 feet	50 feet	60 feet	70 feet
	Merchantable volume					
Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
4	68	68	68	68	68	80
5	80	81	82	83	84	85
6	86	87	88	89	90	91
7	88	90	91	93	93	94
8	89	91	93	94	95	95
9	90	92	93	94	95	96
10	90	92	94	95	96	96
11	91	93	94	95	96	97
12	91	93	95	96	96	97
13	91	93	95	96	97	97
14	91	93	95	96	97	97

TABLE 13.—*Red spruce: Volume in cords per acre of all trees in and above the 4-inch diameter class, obtained by applying conversion factor of 95 to Table 11*

Total age	Site index				
	70	60	50	40	30
	Volume				
Years	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*
30	5.3	3.6	2.2	0.9	------
40	22.7	17.4	11.7	6.3	1.5
50	50.3	39.7	29.1	17.6	5.1
60	72.1	58.4	44.2	28.9	9.9
70	85.3	69.7	54.2	36.5	14.7
80	93.5	76.0	60.0	41.3	17.6
90	97.9	80.5	63.2	43.8	18.9
100	100.7	82.8	65.2	45.4	20.0
110	103.2	84.7	66.8	46.7	20.9

TABLES FOR TREES IN AND ABOVE THE 7-INCH DIAMETER CLASS

Tables 14, 15, 16, and 17 give, respectively, for the partial stand containing all trees belonging to the 7-inch diameter class and larger, the basal area, number of trees, average diameter, and board-foot volume by the International rule with ⅛-inch saw kerf. Site index 30, producing a very negligible board-foot volume, if any, is omitted entirely. Like the 4-inch tables, these 7-inch tables, with the exception of the board-foot yields, are derived from the total-stand values. Figure 9 presents the board-foot yields graphically. No allowance for cull is included in these volumes. Site index 50 begins to have

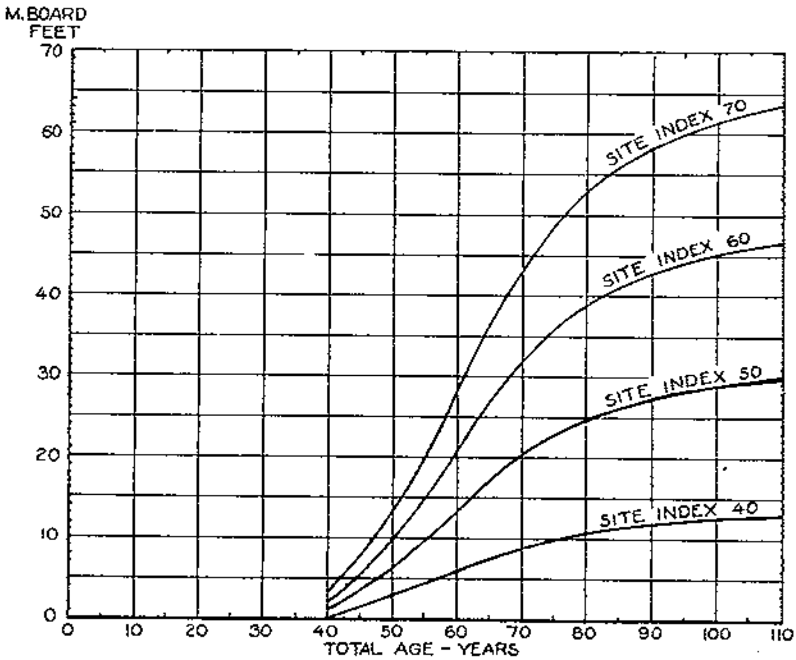

FIGURE 9.—Red spruce. Total board-foot volume per acre by the International rule, ⅛-inch saw kerf

board-foot volume at the age of 40 years and attains its maximum rate of increase between the ages of 60 and 70. In the later years, as in the early years, rate of increase in volume is definitely determined by site quality.

TABLE 14.—*Red spruce: Total basal area per acre of all trees in and above the 7-inch diameter class*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Basal area			
Years	*Square feet*	*Square feet*	*Square feet*	*Square feet*
40	41	28	15	
50	119	92	61	26
60	199	166	117	61
70	242	215	172	97
80	260	238	198	122
90	270	247	211	134
100	275	254	218	142
110	270	259	224	150

TABLE 15.—*Red spruce: Number of trees per acre in and above the 7-inch diameter class*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Number of trees			
Years				
40	130	92	49	
50	340	276	169	85
60	485	446	335	192
70	468	480	441	290
80	445	463	467	350
90	426	455	473	376
100	415	450	474	391
110	408	443	474	402

TABLE 16.—*Red spruce: Average breast-high diameters of all trees in and above the 7-inch diameter class*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Diameter, breast high			
Years	*Inches*	*Inches*	*Inches*	*Inches*
40	7.6	7.5	7.5	
50	8.0	7.8	7.7	7.5
60	8.7	8.3	8.0	7.6
70	9.7	9.1	8.5	7.9
80	10.5	9.7	8.8	8.0
90	10.8	10.0	9.0	8.1
100	11.0	10.2	9.2	8.2
110	11.2	10.3	9.3	8.3

TABLE 17.—*Red spruce: Board-foot volume per acre of trees in and above the 7-inch diameter class*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Volume			
Years	*Board feet*	*Board feet*	*Board feet*	*Board feet*
40	3,300	2,200	1,200	
50	13,300	9,900	6,200	2,800
60	28,400	20,800	13,300	5,800
70	43,200	31,800	20,300	8,800
80	52,900	38,900	24,800	10,800
90	58,300	42,800	27,400	11,900
100	61,500	45,100	28,800	12,600
110	63,600	46,600	29,800	13,000

TABLES FOR DOMINANTS AND CODOMINANTS

A few tables of the dominant and codominant stand are of interest, since the trees which constitute this partial stand form the main canopy and have the best growth.

In Tables 18, 19, and 20 are given the values for basal area, number of trees, and average diameter for this partial stand. Heights have already been given in Table 1 and Figure 2.

TABLE 18.—*Red spruce: Total basal area per acre of all dominant and codominant trees*

Total age	Site index 70	Site index 60	Site index 50	Site index 40	Site index 30
	Basal area				
Years	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*
20	17	17	15	13	10
30	58	55	51	45	32
40	110	104	95	82	58
50	161	152	139	117	82
60	203	187	169	140	97
70	232	211	186	153	105
80	250	228	200	163	109
90	261	237	207	167	112
100	268	244	212	171	114
110	274	249	218	175	116

TABLE 19.—*Red spruce: Number of trees per acre in the dominant and codominant classes*

Total age (years)	Site index				
	70	60	50	40	30
	Number of trees				
20	920	1,070	1,330	1,900	3,580
30	780	895	1,100	1,510	2,760
40	675	765	905	1,220	2,120
50	595	655	760	980	1,665
60	515	560	635	795	1,270
70	445	477	530	645	975
80	410	438	485	580	855
90	398	428	472	565	820
100	390	420	465	555	795
110	385	415	460	540	780

TABLE 20.—*Red spruce: Average breast-high diameter of all dominant and codominant trees*

Total age	Site index				
	70	60	50	40	30
	Diameter, breast high				
Years	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
20	1.8	1.7	1.4	1.1	0.7
30	3.7	3.4	2.9	2.3	1.5
40	5.5	5.0	4.4	3.5	2.2
50	7.1	6.5	5.8	4.7	3.0
60	8.5	7.8	7.0	5.7	3.7
70	9.8	9.0	8.0	6.6	4.4
80	10.6	9.8	8.7	7.2	4.8
90	11.0	10.1	9.0	7.4	5.0
100	11.2	10.3	9.2	7.5	5.1
110	11.4	10.5	9.3	7.7	5.2

INCREMENTS AND ROTATIONS

Figures 10, 11, and 12 give graphically the mean annual and the 10-year periodic annual increments for total cubic-foot volume, merchantable cubic-foot volume, and board-foot volume computed directly from Tables 6, 11, and 17. For length of rotation the culmination of mean annual growth is chosen. This is also the age of intersection of the curves for periodic annual and mean annual growths.

The best rotation for total cubic-foot production is, therefore, 65 years total age; the rotation for pulpwood production varies with site—66 years for site index 70, 68 years for site index 60, 70 years for site index 50, 73 years for site index 40, and 79 years for site index 30. The rotation for quantity board-foot production is 82 years. Quality production is not considered; to produce the maximum amount of good-quality lumber the rotation would undoubtedly have to be greatly lengthened, since natural pruning does not take place at an early age.

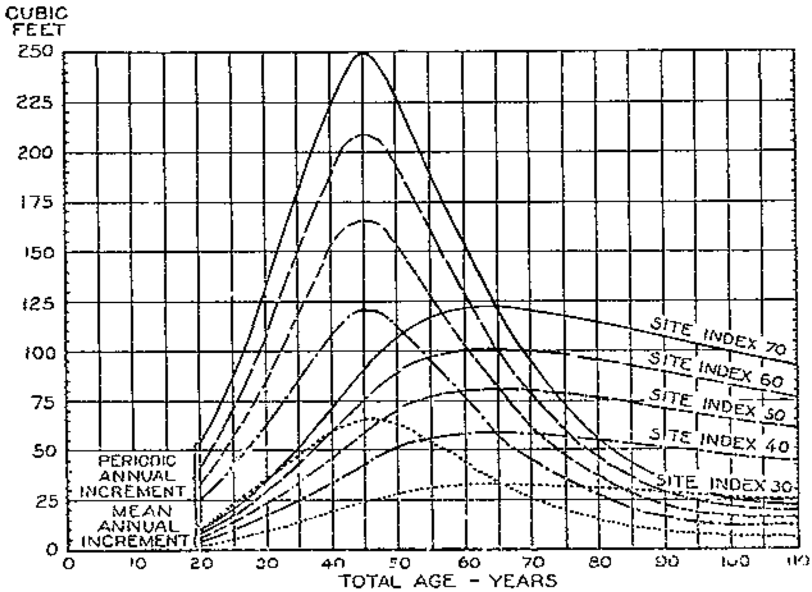

FIGURE 10.—Red spruce. Periodic and mean annual increments for total cubic-foot volume

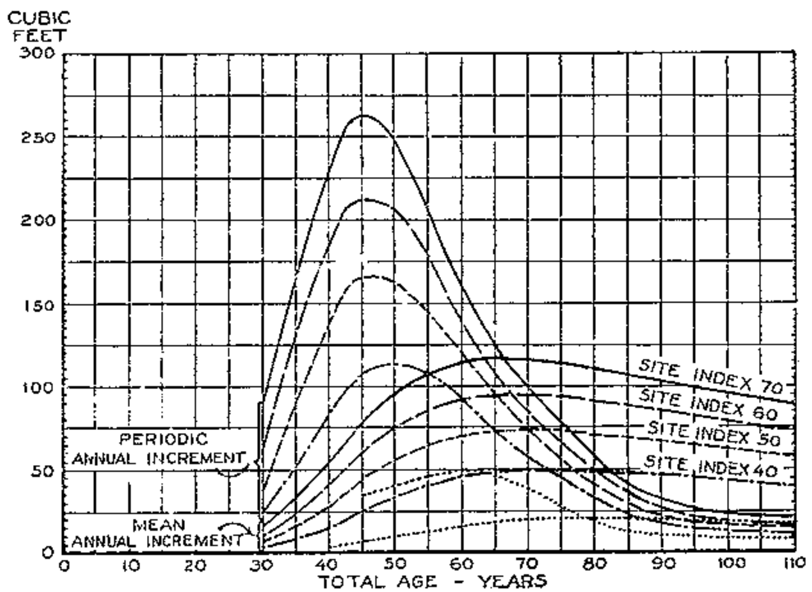

FIGURE 11.—Red spruce. Periodic and mean annual increments for merchantable cubic-foot volume of all trees 4 inches in diameter at breastheight and larger

STAND TABLES

Until recently stand tables have had but a small place in yield studies. The present tendency is to observe the conformity of diameter distribution in a stand to the normal distribution obtained from the Gauss curve of error or the law of probabilities. Attempts to fit the distribution of trees in second-growth red spruce stands to these normal distributions result in failure, since the smaller diameters always have a pronounced tendency to include disproportionately large numbers of trees. This is to be expected with a tolerant species such as red spruce, which can endure a suppressed state much longer than many other species.

Although the species does not conform to the symmetrical distribution, its distribution of diameters can be computed in a simple way by means of Figure 13. The bottom scale indicates the diameter classes in a stand. On the vertical scale may be read the percentages

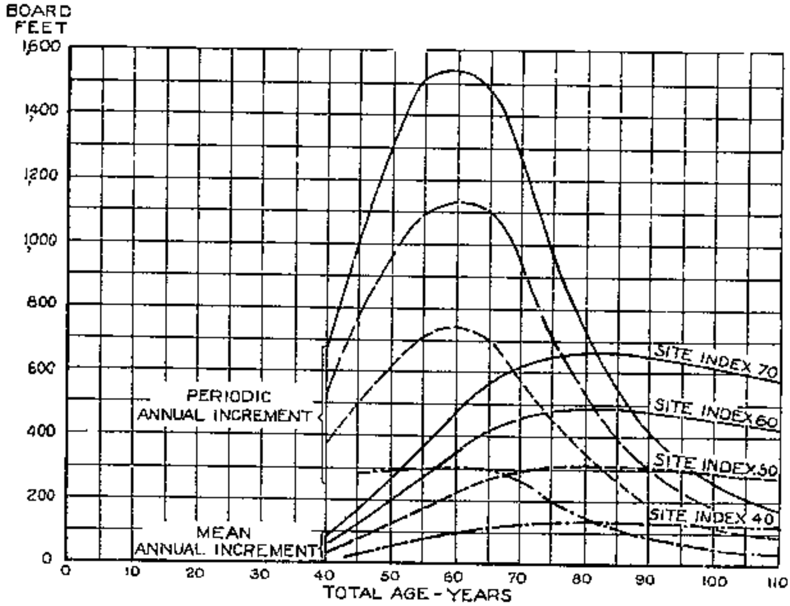

FIGURE 12.—Red spruce. Periodic and mean annual increments for total board-foot volume

of total numbers of trees in and below the range of diameter limits of the stand tally. The diagonals represent the distribution of trees by diameters in stands with average stand diameters ranging from 3 to 15 inches. The average diameter of the stand is found by dividing the total basal area by the total number of trees and then converting the resultant average basal area to diameter in inches. The point where a diagonal crosses a diameter class line gives the percentage of total number of trees in and below that diameter class. For illustration, let a certain site and age class of the tables be taken, for instance site 50, age 70, for which the average diameter according to Table 4 is 7 inches. The diagonal 7 is therefore first chosen, and the diameter classes which it crosses are listed. Next, at each diameter class the percentage of total number of trees is read. The total number of trees, which for this site and age class is 849 (Table 3), is multiplied by each of the percentages. The total number of trees in each class is then determined by subtracting each value from the total in the next larger class. In this way a stand table is obtained. The basal areas may be computed and the results compared with those in Table 2. Table 21 is a sample computation for age 70 and site class 50.

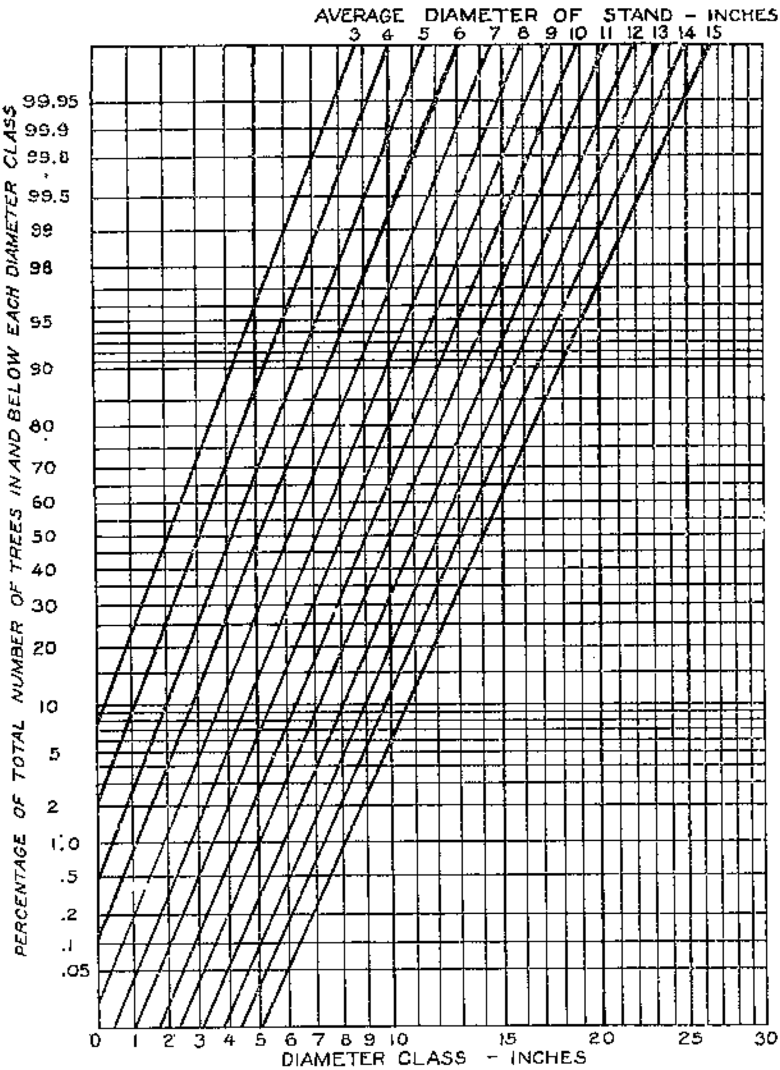

FIGURE 13.—Basis for red spruce stand tables

From Tables 2, 8, and 15, the normal values for basal area, number of trees 4 inches and over, and number of trees 7 inches and over are found to be, respectively, 230, 811, and 441, to which the derived values of Table 21 correspond closely.

TABLE 21.—*Sample computation for stand table, illustrating the use of Figure 13 for age 70, site index 50, at which average breast-high diameter of stand is 7 inches and total number of trees 849*

Diameter breast high	Trees below given diameter class	Trees below given diameter class	Trees in diameter class [1]	Basal area in diameter class
Inches	*Per cent*	*Number*	*Number*	*Square feet*
1	0.2	2	2	
2	1.2	10	8	0.2
3	4.5	38	28	1.4
4	13.0	110	72	6.3
5	27.5	233	123	16.7
6	47.5	403	170	33.3
7	67.5	573	170	45.4
8	83.0	705	132	46.1
9	92.0	781	76	33.6
10	96.8	822	41	22.3
11	98.9	840	18	11.9
12	99.64	846	6	4.7
13	99.9	848	2	1.8
14	99.98	849	1	1.1
Total			849	224.8

[1] Number of trees 4 inches and over, 811; 7 inches and over, 446.

VOLUME TABLES

A multitude of volume tables exist for red spruce; they are expressed in varying units for many localities and conditions. Very few, however, would be applicable to a yield study for the whole region, and in addition, none of them are expressed in terms of the International rule. For this reason new volume tables based on the form-class system as developed by Behre (*44, 45, 46*) were prepared for use in this study. Tables 22, 23, and 24 contain the normal total cubic-foot volumes of trees and Tables 26, 27, and 28 the board-foot volumes by the International rule (⅛-inch kerf) for form classes 65, 70, and 75. Normal volume may be defined as the volume of a tree the taper of which is expressed by Behre's formula for tree taper. As applied, it is the total volume of a tree inside bark, not including butt swell. The diameters of the tables are so-called normal breast-high diameters, which are the diameters of bodies of the ideal taper expressed by the formula. A reduction is therefore needed for each species to give the amount of bark thickness and butt swell, since these are considered to be the two important factors in making species tapers nonconformable to the theoretical taper. Table 25 gives the actual and normal diameters for red spruce, white spruce, and balsam fir.

TABLE 22.—*Form-class volume table for total cubic feet: Form class 65*

Normal diameter breast high (inches)	Total height, feet													
	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	Normal volume,[1] cubic feet													
1	0.066	0.077	0.087	0.099	0.112	0.123								
2	.263	.307	.350	.397	.447	.493	0.541							
3	.590	.689	.786	.890	1.00	1.11	1.22							
4	1.05	1.22	1.40	1.58	1.76	1.97	2.16	2.35	2.55					
5	1.64	1.91	2.18	2.48	2.79	3.07	3.37	3.67	3.98					
6	2.36	2.76	3.14	3.57	4.01	4.43	4.86	5.29	5.74	6.15	6.59	7.02	7.45	7.88
7	3.22	3.76	4.28	4.86	5.47	6.03	6.62	7.21	7.81	8.41	9.01	9.50	10.2	10.8
8		4.91	5.60	6.35	7.15	7.89	8.66	9.42	10.2	11.0	11.7	12.5	13.3	14.0
9			7.09	7.99	9.00	10.0	10.9	11.8	12.9	13.8	14.8	15.8	16.8	17.7
10			8.74	9.92	11.2	12.3	13.5	14.7	15.9	17.1	18.3	19.5	20.7	21.9
11				12.0	13.5	14.8	16.3	17.7	19.3	20.7	22.1	23.6	25.1	26.4
12				14.3	16.1	17.7	19.5	21.2	23.0	24.6	26.4	28.1	29.8	31.6
13					18.9	20.7	22.7	24.8	27.0	28.9	30.8	33.0	35.0	36.9
14					21.9	24.2	26.5	28.9	31.3	33.6	35.9	38.2	40.6	43.0
15					25.1	27.8	30.3	33.0	35.8	38.4	41.0	43.9	46.6	49.0
16					28.6	31.6	34.6	37.7	40.8	43.8	46.9	50.0	53.1	56.1
17						35.5	38.9	42.4	46.0	49.4	52.8	56.4	59.8	63.1
18						39.9	43.8	47.7	51.7	55.5	59.4	63.3	67.2	71.0
19						44.4	48.7	53.0	57.5	61.8	66.1	70.6	74.8	79.0
20						49.3	54.1	58.9	63.8	68.5	73.3	78.1	82.9	87.7
21						54.3	59.6	64.9	70.1	75.4	80.7	86.2	91.3	96.7
22						59.7	65.5	71.3	77.2	82.9	88.7	94.5	100	106
23						65.2	71.4	77.7	84.3	90.8	96.9	103	110	116
24						71.0	77.9	84.8	91.9	98.7	106	112	119	126

[1] Total cubic-foot volume without butt swell.

TABLE 23.—*Form-class volume table for total cubic feet: Form class 70*

Normal diameter breast high (inches)	Total height, feet													
	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	Normal volume,[1] cubic feet													
1	0.068	0.081	0.093	0.106	0.119									
2	.273	.323	.374	.426	.478	0.530								
3	.610	.730	.842	.966	1.07	1.19	1.31							
4	1.09	1.29	1.49	1.70	1.90	2.11	2.32	2.53	2.74					
5	1.70	2.02	2.33	2.65	2.98	3.30	3.63	3.96	4.28					
6	2.45	2.90	3.36	3.83	4.29	4.76	5.24	5.71	6.18	6.65	7.12	7.60	8.07	8.54
7	3.34	3.96	4.58	5.21	5.85	6.49	7.13	7.77	8.41	9.05	9.69	10.4	11.0	11.6
8		5.17	5.97	6.81	7.64	8.48	9.32	10.2	11.0	11.8	12.7	13.5	14.4	15.2
9			7.58	8.63	9.68	10.7	11.8	12.8	13.8	15.0	16.0	17.1	18.2	19.2
10			9.32	10.6	11.9	13.2	14.6	15.9	17.2	18.5	19.8	21.2	22.4	23.8
11				12.8	14.4	16.0	17.6	19.1	20.7	22.3	23.9	25.6	27.1	28.7
12				15.3	17.2	19.1	21.0	22.8	24.7	26.6	28.5	30.5	32.3	34.2
13					20.1	22.3	24.5	26.7	29.0	31.0	33.3	35.7	38.8	40.0
14					23.4	26.0	28.5	31.1	33.7	36.2	38.8	41.5	44.0	46.6
15					26.8	29.7	32.7	35.6	38.5	41.3	44.4	47.6	50.3	53.1
16					30.6	33.9	37.3	40.6	44.0	47.3	50.6	54.2	57.4	60.7
17						38.0	42.0	45.7	49.5	53.1	57.1	61.2	64.9	68.3
18						42.9	47.2	51.4	55.7	59.9	64.1	68.0	72.8	77.0
19						47.6	52.7	57.2	61.9	66.5	71.5	76.5	81.4	85.5
20						53.0	58.2	63.5	68.7	73.9	79.2	84.6	89.9	95.1
21						58.2	64.3	70.0	75.7	81.2	87.6	93.5	99.9	105
22						64.1	70.5	76.8	83.2	89.5	95.8	102	109	115
23						69.9	77.4	84.0	90.8	97.5	105	113	119	126
24						76.4	83.9	91.4	99.0	107	114	122	129	137

[1] Total cubic-foot volume without butt swell.

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TABLE 24.—*Form-class volume table for total cubic feet: Form class 75*

Normal diameter breast high (inches)	Total height, feet													
	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	Normal volume,[1] cubic feet													
1	0.072	0.086	0.099	0.114	0.128									
2	.287	.342	.398	.455	.512	0.569								
3	.645	.768	.894	1.02	1.15	1.28	1.42							
4	1.15	1.36	1.59	1.82	2.04	2.27	2.50	2.73	2.97					
5	1.70	2.13	2.48	2.84	3.20	3.55	3.92	4.27	4.63					
6	2.58	3.07	3.58	4.10	4.60	5.12	5.64	6.15	6.67	7.19	7.71	8.22	8.74	9.26
7	3.51	4.10	4.87	5.58	6.27	6.97	7.69	8.38	9.00	9.80	10.5	11.2	11.7	12.5
8		5.47	6.37	7.29	8.20	9.11	10.0	11.0	11.9	12.8	13.7	14.7	15.6	16.4
9			8.07	9.24	10.4	11.5	12.7	13.9	15.0	16.2	17.4	18.6	19.7	20.9
10			9.95	11.4	12.8	14.2	15.7	17.1	18.5	20.0	21.4	22.9	24.3	25.8
11				13.8	15.5	17.2	19.0	20.7	22.5	24.2	25.9	27.7	29.4	31.2
12				16.4	18.4	20.5	22.6	24.6	26.7	28.8	30.8	33.0	35.0	37.1
13					21.7	24.0	26.5	28.9	31.4	33.8	36.1	38.6	41.1	43.4
14					25.1	27.9	30.8	33.6	36.4	39.2	42.0	44.9	47.7	50.6
15					28.8	32.0	35.3	38.4	41.8	44.9	48.0	51.3	54.7	58.0
16					32.8	36.4	40.2	43.8	47.5	51.2	54.9	58.6	62.3	66.0
17						41.1	45.4	49.3	53.6	57.7	61.9	66.0	70.3	74.3
18						46.1	50.9	55.5	60.1	64.8	69.4	74.2	78.8	83.6
19						51.3	56.9	61.8	67.1	72.1	77.5	82.6	88.1	93.0
20						56.9	62.8	68.5	74.2	80.0	85.7	91.7	97.3	103.0
21						62.8	69.5	75.5	82.1	88.2	94.8	102	108	115
22						68.9	76.0	82.9	89.8	96.9	104	111	118	125
23						75.4	83.5	90.8	98.5	106	113	122	129	137
24						82.0	90.5	98.7	107	115	123	132	140	149

[1] Total cubic-foot volume without butt swell.

TABLE 25.—*Normal diameters of red spruce, white spruce, and balsam fir. (Actual breast-high diameters minus bark thickness and butt swell)*

Actual diameter breast high	Red spruce, normal diameter	White spruce, normal diameter	Balsam fir, normal diameter
Inches	*Inches*	*Inches*	*Inches*
1	0.94	0.93	0.95
2	1.86	1.87	1.89
3	2.79	2.80	2.84
4	3.70	3.73	3.78
5	4.62	4.66	4.73
6	5.52	5.60	5.68
7	6.42	6.53	6.62
8	7.32	7.46	7.57
9	8.23	8.40	8.51
10	9.13	9.33	9.46
11	10.03	10.26	10.41
12	10.93	11.20	11.35
13	11.84	12.13	12.30
14	12.74	13.06	13.24
15	13.64	14.00	14.19
16	14.54	14.93	15.14
17	15.44	15.86	16.08
18	16.35	16.79	17.03
19	17.25	17.73	17.97
20	18.15	18.66	18.92
21	19.05	19.59	19.87
22	19.95	20.53	20.81
23	20.86	21.46	21.76
24	21.76	22.39	22.70
Basis (trees)	650	337	346

The heavy lines indicate the extent of the basic data.

TABLE 26.—*Form-class volume table for board feet by the International rule, ⅛-inch saw kerf: Form class 65*

Normal diameter breast high (inches)	Total height, feet										
	30	35	40	45	50	55	60	65	70	75	80
	Normal volume, board feet										
7	11	15	18	21	25	28	31				
8	16	21	25	30	35	40	44	49	53		
9	21	28	34	41	47	53	59	65	71		
10	28	36	45	53	62	70	77	84	92	101	110
11	34	44	56	66	78	88	98	108	118	127	139
12	40	54	68	81	95	108	121	133	145	158	172
13		64	81	97	114	130	144	160	175	190	207
14		75	96	115	135	153	170	190	210	228	246
15			112	134	157	178	199	222	245	266	287
16			130	155	180	205	230	257	283	307	333
17				170	207	235	263	293	322	350	379
18				204	230	267	298	331	363	395	429
19					264	299	334	372	408	444	485
20					294	333	373	414	455	497	540
21					325	369	414	460	506	552	600
22					356	406	457	508	550	610	662
23					386	444	500	558	615	672	731
24					413	485	546	611	674	737	800

TABLE 27.—*Form-class volume table for board feet by the International rule, ⅛-inch saw kerf: Form class 70*

Normal diameter breast high (inches)	Total height, feet										
	30	35	40	45	50	55	60	65	70	75	80
	Normal volume, board feet										
7	12	16	20	24	28	33	37				
8	18	23	28	34	40	46	51	56	61	67	
9	25	32	39	46	54	61	69	76	83	91	
10	34	42	51	60	70	80	89	98	106	115	
11		51	63	75	87	99	111	123	134	146	158
12		60	75	90	105	120	135	150	165	180	195
13			90	109	127	144	162	180	198	216	235
14			107	129	150	170	191	213	235	257	279
15			125	150	174	198	223	248	273	299	324
16			145	174	202	230	259	287	315	344	373
17				199	231	263	296	328	360	393	425
18				226	263	299	335	372	408	445	480
19					294	334	375	416	458	500	541
20					326	372	418	463	510	557	603
21					357	409	460	511	564	618	671
22					388	444	503	561	620	680	739
23					419	482	548	613	678	742	807
24					450	510	590	663	735	806	877

TABLE 28.—*Form-class volume table for board feet by the International rule, ⅛-inch saw of: Form class 75*

Normal diameter breast high (inches)	Total height, feet										
	30	35	40	45	50	55	60	65	70	75	80
	Normal volume, board feet										
7	14	18	23	28	33	38					
8	21	27	33	40	46	52	58	65	71	77	
9	29	37	46	54	61	69	78	87	96	105	
10	40	50	60	70	80	90	100	110	120	132	
11			73	87	99	113	125	139	151	165	179
12			87	105	120	136	153	170	184	202	219
13			103	125	144	163	182	202	220	240	262
14			122	146	170	192	215	238	260	283	308
15			143	170	197	223	250	278	305	331	358
16			166	196	227	258	288	320	351	382	413
17				223	258	294	330	366	403	438	473
18				252	291	332	374	415	457	498	539
19					325	372	418	464	511	558	606
20					363	414	464	515	568	620	674
21					400	460	515	568	624	682	740
22					435	508	567	625	687	749	809
23					470	557	620	684	749	813	879
24					503	610	678	747	816	882	950

The computation of separate tables for each species is made unnecessary by the use of the procedure described below and illustrated in Figure 14. This method has been tried out thoroughly and has been found to be entirely practical and easily applicable after the first principles are mastered.

The values of Table 24 are plotted on logarithmic coordinate paper. The 10 by 10 inch, 1-cycle paper is the most convenient size for this work. Normal diameters are read along the base, starting with 1 inch at the left and proceeding to 10 inches at the right, then returning to the left end, starting with 10 inches and ranging to 100 inches at the extreme right. The vertical axis represents cubic-foot volumes with similar ranges. The volumes of each height class fall in a straight line. In addition the lines are parallel to one another. With this mode of form-class volume table, the volume lines can be easily drawn in by pointing off the intercepts on any of the graduations and drawing in the lines with a slope of 2 to the base. If logarithmic paper of several cycles were used these lines would be continuous, but with 1-cycle paper, such as is used here, the lines are interrupted.

As an example, take the line for height 60 which starts at the base at 2.5 inches and runs diagonally to the top to 8 inches; starts again at the base at 8 inches and runs out at the right edge at 10.87; and begins at the left edge at 10.87 and runs out at the top at 25 inches. The next step is to impose upon the diagram (see the scale at the bottom and top of fig. 14) the diameter reductions for the species. (Table 25.) Then, over the respective reduced diameters and at the proper height lines, the volumes for the corresponding species, diameters, and heights can be read. In the figure, for purpose of illustration, broken lines connect several actual diameters. The location of the decimal point is obtained by comparison with the original table and after a little practice can be easily remembered. Figure 14 is for illustration only. When the data are to be applied, finely graduated logarithmic paper should be used.

The total volume of any number of trees of any one diameter and height is read directly from the graph. On the left of Figure 14 there is a scale with the same divisions as the main diagram. Such a scale should be prepared on a separate strip, preferably xylonite, by tracing the original.

As a specific example, it is desired to obtain the volume of 20 red spruces 7 inches d. b. h., height 43 feet. Over the diameter 7 inches, as reduced for red spruce, the position of height 43 between the 40-foot and 45-foot lines is approximated by eye. Now place the vertical scale on the chart with one of the ends at this point, so that the "2" (representing here 20 trees) falls somewhere on the chart. In this instance the upper end is used. Running along the vertical scale to point 2 read off the volume value and place the decimal point. The result is 112 cubic feet, ascertained, in this way, by a single reading. The principle involved is that of the slide rule.

Board-foot volume tables (Tables 26, 27, and 28) are treated in an exactly similar fashion. These volumes were drawn up according to the International rule for ⅛-inch saw kerf, allowing 1 foot for stump, using 16.3-foot logs scaled as 16-foot logs, and an odd length section to a 5-inch top inside bark.

The value of the average form class or form quotient of a stand is necessary in using these tables.[4] Form class or form quotient is the quotient obtained by dividing the diameter at half the height above breastheight by the diameter at breastheight. Form point is defined as that point in the crown which can be considered the center of wind stress. It will be more or less the geometrical center of the crown.

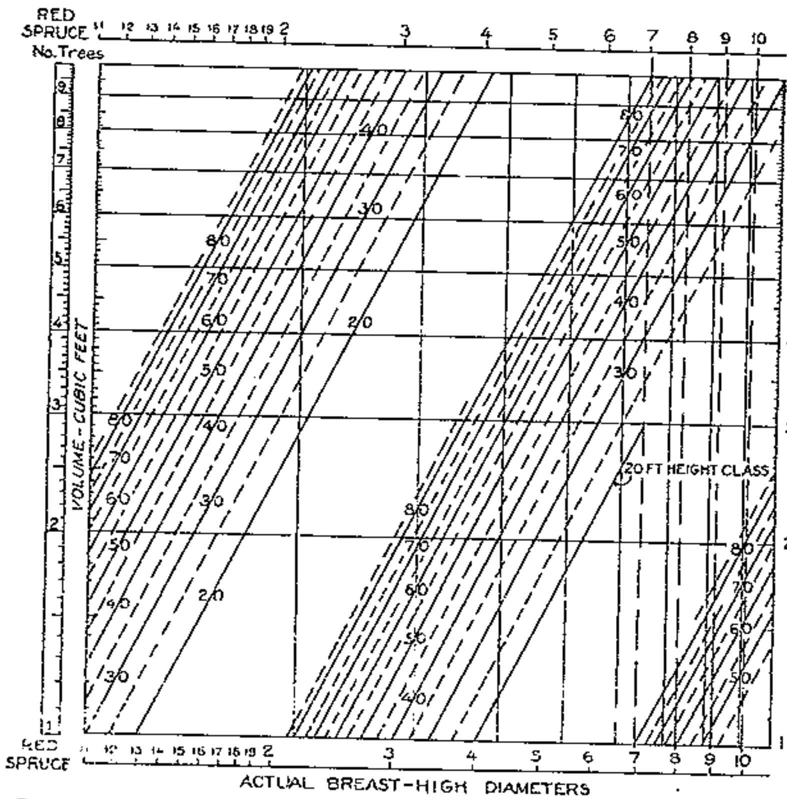

FIGURE 14.—Normal volume table for total cubic-foot form class 75, plotted on logarithmic paper and adapted to red spruce

Form-point height is the percentage of the total height at which this point occurs. In Figure 15, the relation between form-point height and form class is expressed by regression lines. (See p. 30.) In the field measurements the form-point heights of a number of the dominants and codominants (about 20 in a stand) are taken and averaged. The form class corresponding to this average height is read from the chart and the volume table nearest in form class is then used.

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[4] The relation of form-point height and form quotient has been studied by C. E. Behre, and the preliminary results are given here. Later modifications and refinements will undoubtedly be made, but the present conclusions are sufficiently accurate.

For fully stocked second-growth red spruce stands, form class 75 was the one which occurred most commonly, and form class 70 occurred occasionally. Balsam fir and white spruce stands, however, averaged 70, occasionally falling off to 65. The lowering of form class within a species is ordinarily connected with open stocking or young age.

YIELDS OF MIXED STANDS

The effect of mixtures of white spruce and balsam fir on the yields of red spruce is not quite as definite as may be supposed. A detailed statistical analysis failed to bring out any definite relation with any

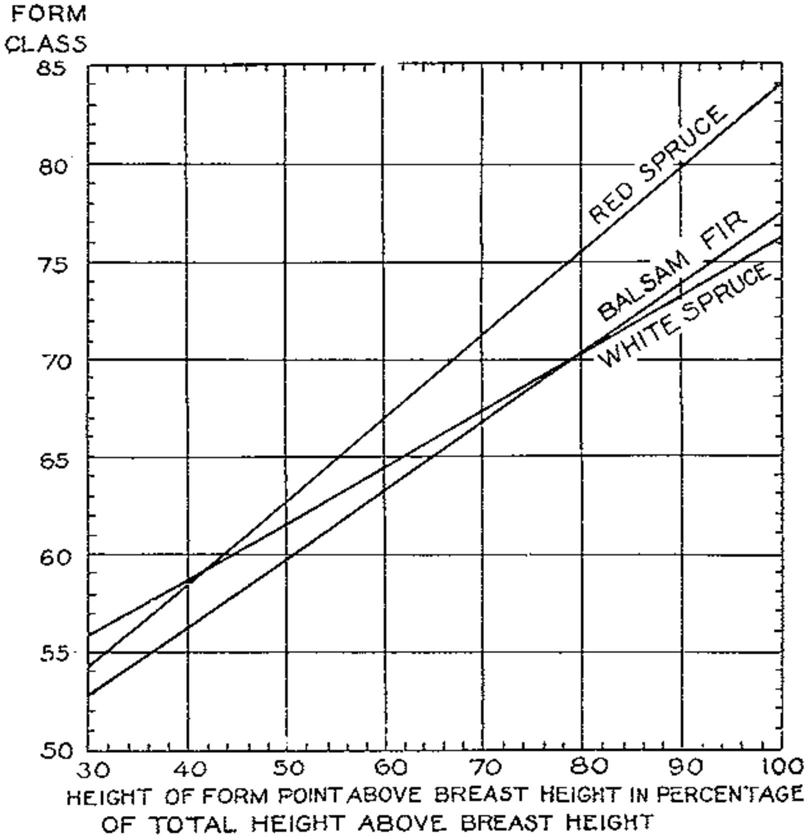

FIGURE 15.—Relation between form-point height and form class, expressed by regression lines

of the factors considered. As it is, some of the plots which were used as a basis for the fully stocked red spruce tables, chiefly of the younger ages, were somewhat mixed. All indications lead to the conclusion that the tables presented apply equally well to stands which have moderate amounts of white spruce and balsam fir in them.

The composition found may vary from 100 per cent red spruce through all grades to 100 per cent balsam fir or 100 per cent white spruce. In the same stands, the average dominant and codominant red spruce was found to be on the whole 10 per cent shorter in height than the average dominant and codominant balsam fir and 4 per cent shorter than average dominant and codominant white spruce. However, in mixed stands of balsam fir and white spruce alone, these species averaged the same height. Therefore, since among the plots measured such mixtures were much more common than the mixtures of red spruce and white spruce and since the mixtures of red spruce and balsam fir were also very common, it can be concluded that the heights of the average dominant and codominant balsam fir and white spruce should be reduced 10 per cent to obtain the equivalent red spruce height.

When the stands are predominantly balsam fir or white spruce, the trends of growth have been found to be significantly different from

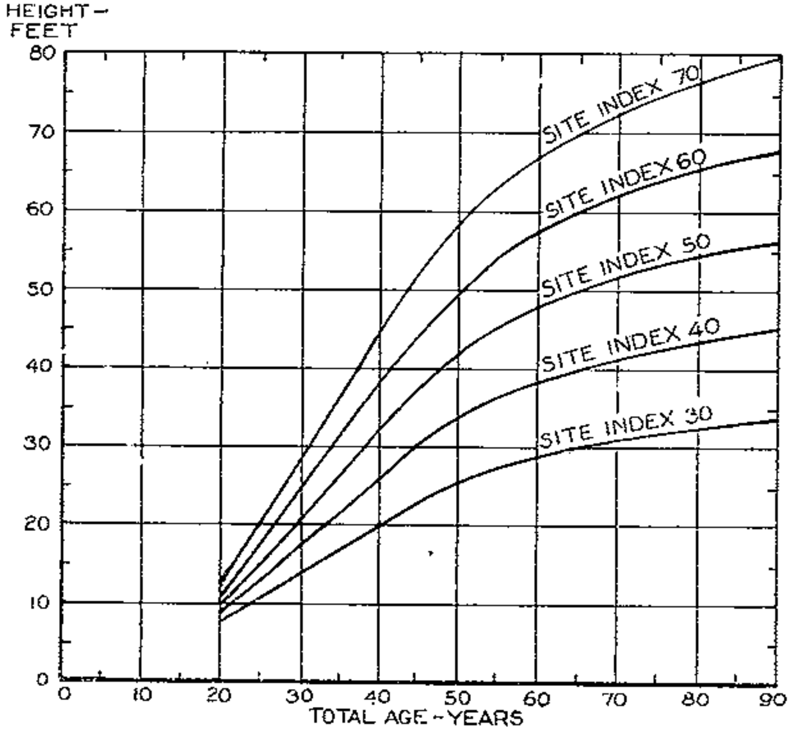

FIGURE 16.—White spruce site index based upon the height of the average dominant and codominant tree

that of red spruce. For this reason tables for total basal areas, number of trees, average tree diameter, and board-foot volume have been drawn up for stands chiefly composed of either of these species. The small number of these plots does not permit the more detailed analysis made for red spruce.

In general the same qualifications and definitions hold true for the white spruce and balsam fir tables that are given for the respective red spruce tables. Site is indicated in these two sets of tables by the species in question and not by the equivalent red spruce site.

Figure 16 and Tables 29, 30, 31, 32, 33, and 34 present for white spruce the values for site indices or heights of the dominants, total basal areas per acre, total number of trees per acre, size of the average tree, yields of the stand in total cubic feet, and yields of the stand in board feet by the International rule, ⅛-inch saw kerf. Figure 17 and Tables 35, 36, 37, 38, 39, and 40 give similar balsam fir values. Site 30 is left out in most of the tables for neither species ranges commonly below site 40.

White spruce and balsam fir are evidently both unsuited to maintaining a complete crown canopy. Balsam fir stands especially seem to break up after the early ages have been passed. In the collection

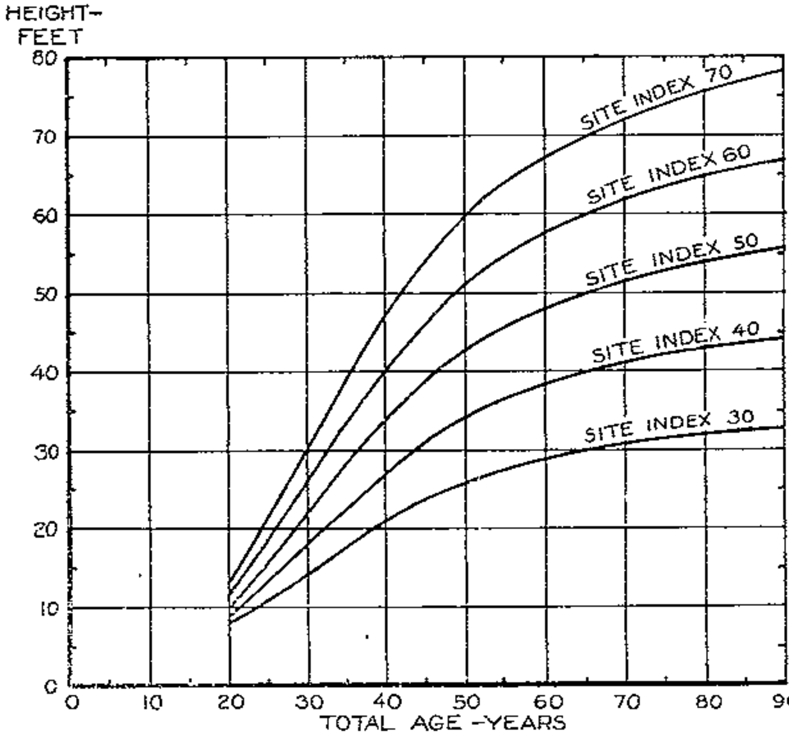

FIGURE 17.—Balsam fir site index based upon the height of the average dominant and codominant tree

of material for the tables, stands with complete canopies were desired. Consequently there is the chance that these tables do not represent the best conditions for growth, but rather an overstocked condition, resulting in poor individual tree development. Sufficient satisfactory material was lacking from which to draw more definite conclusions.

If the volume increments for the white spruce tables and the balsam fir were computed and graphed in figures similar to Figures 10 and 12, it would be found that the rotation for total cubic feet for white spruce is 58 years and that for balsam fir 55 years, and that the rotations for board-foot volume are, respectively, 78 and 82 years.

TABLE 29.—*White spruce: Site index based upon the height of the average dominant and codominant tree*

Total age	Site index 70	60	50	40	30
	Height				
Years	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
20	12	11	10	9	8
30	28	25	21	18	14
40	45	38	32	26	20
50	58	50	42	34	26
60	67	58	48	38	29
70	72	62	52	41	31
80	76	66	54	44	32
90	80	68	56	45	34

TABLE 30.—*White spruce: Total basal area per acre of all trees above 0.6-inch diameter breast high*

Total age	Site index 70	60	50	40
	Basal area			
Years	*Square feet*	*Square feet*	*Square feet*	*Square feet*
20	24	22	19	17
30	90	86	70	71
40	180	172	158	140
50	210	209	192	172
60	232	222	204	183
70	238	228	210	187
80	241	230	212	180
90	243	232	213	191

TABLE 31.—*White spruce: Total number of trees per acre above 0.6-inch diameter breast high*

Total age (years)	Site index 70	60	50	40
	Number of trees			
20	3,370	4,470	5,880	7,530
30	2,170	2,880	3,780	4,840
40	1,320	1,800	2,360	2,980
50	790	1,090	1,420	1,820
60	540	720	945	1,210
70	420	570	750	905
80	365	500	655	845
90	345	470	615	785

TABLE 32.—*White spruce: Breast-high diameter of average tree*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Diameter breast high			
Years	*Inches*	*Inches*	*Inches*	*Inches*
20	1.1	1.0	0.8	0.6
30	2.8	2.3	2.0	1.6
40	5.0	4.2	3.5	2.9
50	7.1	5.9	5.0	4.2
60	8.9	7.5	6.3	5.3
70	10.2	8.6	7.2	6.0
80	11.0	9.2	7.7	6.4
90	11.4	9.5	8.0	6.7

TABLE 33.—*White spruce: Total cubic-foot volume per acre of all trees above 0.6 inch diameter breast high*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Volume			
Years	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
20	170	143	106	90
30	1,060	890	715	540
40	3,430	2,860	2,310	1,750
50	5,550	4,640	3,750	2,840
60	6,860	5,740	4,630	3,510
70	7,680	6,420	5,180	3,920
80	8,240	6,880	5,560	4,210
90	8,700	7,280	5,880	4,450

TABLE 34.—*White spruce: Board-foot volume per acre of all trees in and above the 7-inch diameter breast-high class, by the international rule, ⅛-inch saw kerf*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Volume			
Years	*Board feet*	*Board feet*	*Board feet*	*Board feet*
40	4,200	2,950	1,720	460
50	18,800	13,100	7,650	2,060
60	35,200	24,500	14,300	3,850
70	47,200	33,000	19,200	5,150
80	54,700	38,200	22,200	5,900
90	60,700	42,300	24,700	6,650

TABLE 35.—*Balsam fir: Site index based upon the height of the average dominant and codominant tree*

Total age	Site index				
	70	60	50	40	30
	Height				
Years	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
20	13	12	10	9	8
30	30	26	22	18	14
40	47	40	34	27	21
50	60	51	43	34	26
60	67	58	48	38	29
70	72	62	52	41	31
80	76	65	54	43	32
90	78	67	56	44	33

TABLE 36.—*Balsam fir: Total basal area per acre of all trees over 0.6 inch diameter breast high*

Total age	Site index			
	70	60	50	40
	Basal area			
Years	*Square feet*	*Square feet*	*Square feet*	*Square feet*
20	21	20	18	16
30	99	93	87	78
40	180	170	158	143
50	221	209	194	175
60	238	226	210	189
70	248	234	217	196
80	253	240	223	201
90	259	245	227	205

TABLE 37.—*Balsam fir: Total number of trees per acre above 0.6 inch diameter breast high*

Total age (years)	Site index			
	70	60	50	40
	Number of trees			
20	2,510	3,540	4,980	7,280
30	1,745	2,460	3,460	5,060
40	1,135	1,605	2,260	3,300
50	755	1,000	1,490	2,180
60	555	780	1,095	1,600
70	465	652	920	1,340
80	420	595	835	1,225
90	400	560	790	1,160

TABLE 38.—*Balsam fir: Breast-high diameter of average tree*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Diameter breast high			
Years	*Inches*	*Inches*	*Inches*	*Inches*
20	1.2	1.0	0.8	0.6
30	3.2	2.6	2.1	1.7
40	5.4	4.4	3.6	2.8
50	7.3	6.0	4.9	3.8
60	8.9	7.3	5.9	4.7
70	9.9	8.1	6.6	5.2
80	10.5	8.6	7.0	5.5
90	10.9	9.0	7.3	5.7

TABLE 39.—*Balsam fir: Total cubic-foot volume per acre of all trees above 0.6 inch diameter breast high*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Volume			
Years	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
20	165	135	110	80
30	1,455	1,210	960	720
40	3,940	3,270	2,600	1,940
50	5,910	4,920	3,920	2,910
60	7,100	5,900	4,700	3,500
70	7,760	6,450	5,140	3,820
80	8,270	6,870	5,480	4,080
90	8,700	7,230	5,760	4,290

TABLE 40.—*Balsam fir: Board-foot volume per acre of all trees in and above 7 inch diameter breast-high class, by the International rule, ⅕-inch saw kerf*

Total age	Site index 70	Site index 60	Site index 50	Site index 40
	Volume			
Years	*Board feet*	*Board feet*	*Board feet*	*Board feet*
40	5,850	4,150	2,430	720
50	18,500	13,150	7,700	2,280
60	31,000	22,000	12,900	3,820
70	40,900	29,100	17,000	5,040
80	48,200	34,200	20,000	5,930
90	53,800	38,200	22,400	6,620

MATERIAL AND TECHNIC EMPLOYED IN YIELD STUDY

DISTRIBUTION OF PLOTS

The geographical distribution of all the plots of this yield study has been mentioned previously and is shown in Figure 1. Table 41 gives the distribution of the 201 plots used for normal red spruce yield tables in respect to locality, site, mixture, size, age, and number of trees on the plot. Eighty-one per cent of them lie between the ages of 45 and 84 years, 88 per cent between site indices 40 and 59, and 79 per cent are practically pure red spruce.

TABLE 41.—*Distribution of plots used for fully stocked red spruce tables*

State	Plots	Site index groups	Plots	Mixture	Plots	Size	Plots	Total age	Plots	Live trees per plot	Plots
	Number	*Indices*	*Number*		*Number*	*Acres*	*Number*	*Years*	*Number*	*Number*	*Number*
Maine	77	30 to 39	10	Practically pure red spruce	159	Less than 0.1	3	25 to 34	2	50 to 74	26
New Hampshire	82	40 to 49	59	With balsam fir	28	0.10	102	35 to 44	10	75 to 99	35
Vermont	42	50 to 59	118	With white spruce	12	0.11 to .20	68	45 to 54	23	100 to 149	55
		60 to 69	14	With white spruce and balsam fir	2	0.21 to .30	17	55 to 64	48	150 to 199	40
Total	201					0.31 to .40	3	65 to 74	54	200 to 249	26
		Total	201	Total	201	0.41 to .50	8	75 to 84	38	250 to 299	10
								85 to 94	15	300 to 349	3
						Total	201	95 to 104	9	350 to 399	5
								105 to 115	2	450 to 499	1
								Total	201	Total	201

PLOT MEASUREMENTS

In the determination of the size of the plots, an attempt was made to include a minimum of 100 trees. However, as evenness of stocking was another factor to be considered, this minimum number of trees had to be disregarded in about 30 per cent of the plots. It was preferable to have a small, evenly stocked plot than a large plot with pronounced irregularities, abnormalities, or holes. Horizontal measure was used throughout in laying out the plots.

The method of collection of the data followed the customary routine. Briefly stated, the notes gathered on each plot covered location, size, description, tree tallies, heights, form-point heights, increment borings, and, for some of the plots, sample trees.

ALLOWANCE FOR ABNORMALITIES DUE TO DAMAGE BY SPRUCE BUD WORM

Over large areas of Maine and northern New Hampshire the damage done to spruce and fir by the spruce bud worm during the period 1910–1915 was extensive, and because of the character of the damage sample plots taken in such regions were abnormal. Wherever the attack was made practically every tree was affected; if it was not killed, at least its diameter growth was reduced, temporarily if not permanently. It was necessary, therefore, in the computation of the yields of these plots to take into account the reduction of diameter growth as well as the loss in tree numbers. Field tallies included estimates of death due to bud worm, and increment-core measurements gave the effect on diameter growth. For each affected plot the diameters were revised so that the reduction in diameter due to the damage was eliminated and the tallies were corrected so as to include trees which were killed by the bud worm and which might have lived had they not been attacked. This was necessarily a procedure to be carried out on the individual plot, as the figures for diameter reduction and death were extremely variable. Badly affected stands were not considered at all. Altogether about 60 of the plots chosen showed bud-worm damage, and very few of them could be included in the red spruce tables because of their composition or because of understocking.

METHOD OF CONSTRUCTION OF TABLES AND CHARTS, AND THEIR LIMITATIONS

CURVE CONSTRUCTION

Since the methods employed in the office work follow essentially the procedure set forth by Donald Bruce (*47*) in an article entitled "A Method of Preparing Timber Yield Tables," they will be outlined only briefly. The aim of the procedure is to obtain a set of tables which check with each other and with their own material at the same time. For example, the curves for total basal areas, number of trees, and size of the average tree should check with each other. In addition, each curve should fit its plotted points. In this study all the plots between site indices 45 and 54 were used as a basis for the original curve of trend with age, called the graduating curve. The graduating curves of groups of factors which should check with each other were fitted together and with their own points at the same time. Following this, first estimates for plots of all sites were made from the graduating curve, and these, grouped and averaged by site classes, gave a means for obtaining correct spacing of the curves for all the site classes represented. The spacings between sites were also made to check among the various groups or curves.

The curves for all site classes were next drawn in by anamorphosis, so that each curve maintained the trend of the graduating curve. A second estimate for all plots was made based upon these final site curves, the computed difference between the estimated total and the actual total giving a gross error of the estimate.

The deviations of the individual plots from the principal curves, such as the curves for total basal area, number of trees, total cubic feet, and total board feet were computed in percentages. The average of these percentage deviations, neglecting the algebraic sign, gave the average error, which when multiplied by 1.253 gave an approximation of the standard error. All plots which had deviations more than twice the standard error in basal area were discarded, which necessitated a slight readjustment of the curves.

Other sets of curves besides those mentioned above were balanced. Basal area per acre, height of the average dominant and codominant, and total cubic-foot volume were so balanced that a computed forest form-factor curve took a smooth trend, the forest form factor being derived from the equality that basal area × height × forest form factor equals cubic volume. Were it not for the system of volume computation used in this study, an alternative set of check curves might have been those for size of the average tree, height of the average tree, volume of the average tree, number of trees, and total cubic-foot volume. This would assume that the same table of volumes and the same curve of heights were used for all species on each plot. In this study the volume table indicated by the average form-point height of the plot and species in question was used for obtaining the total plot volume. This meant that each of the three species, red spruce, white spruce, and balsam fir, was treated separately. Since mixture of species and lowering of form class of red spruce usually occurred in the lower age classes, it is in these ages that the total cubic-foot curves will vary somewhat from the desired check. A fourth check set composed of curves of total cubic feet, ratio of board feet to cubic feet, and total board-foot volume was used to obtain the proper trend of the board-foot curve.

A summary of the average errors and the aggregate or gross errors of the total estimates is given in Table 42 for the three species. The white spruce errors are based upon use of the white spruce tables (Tables 29–34) and the balsam fir errors on the balsam fir tables. (Tables 35–40.) The errors involved in applying the red spruce tables to white spruce and balsam fir are not given.

TABLE 42.—*Average errors and aggregate errors of several of the tables*

Item	Average error for—			Aggregate error for—		
	Red spruce	White spruce	Balsam fir	Red spruce	White spruce	Balsam fir
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Basal area	9.4	10.5	9.7	−0.22	−0.23	−0.87
Number of trees	22.4	20.2	18.0	+.60	+2.01	+.58
Total, cubic-foot volume	10.0	10.5	10.0	−.12	+.52	+.46
Total, board-foot volume	21.2	28.6	25.1	−.69	+2.13	+.60

The aggregate error of the total estimate stated in Table 42 indicates the difference between the sum of the estimated values of all the plots interpolated for age and site and the sum of the actual values of all the plots. For instance, under red spruce and opposite basal area, −0.22 per cent means that the sum of estimated basal areas of the plots used as basis for the red spruce tables is 0.22 per cent lower than the sum of the actual basal areas of these plots. To a certain extent a list of average and aggregate errors indicates the fit of a set of data to their curves. The weakness of the white spruce material is quite evident in that several of the percentage errors are relatively

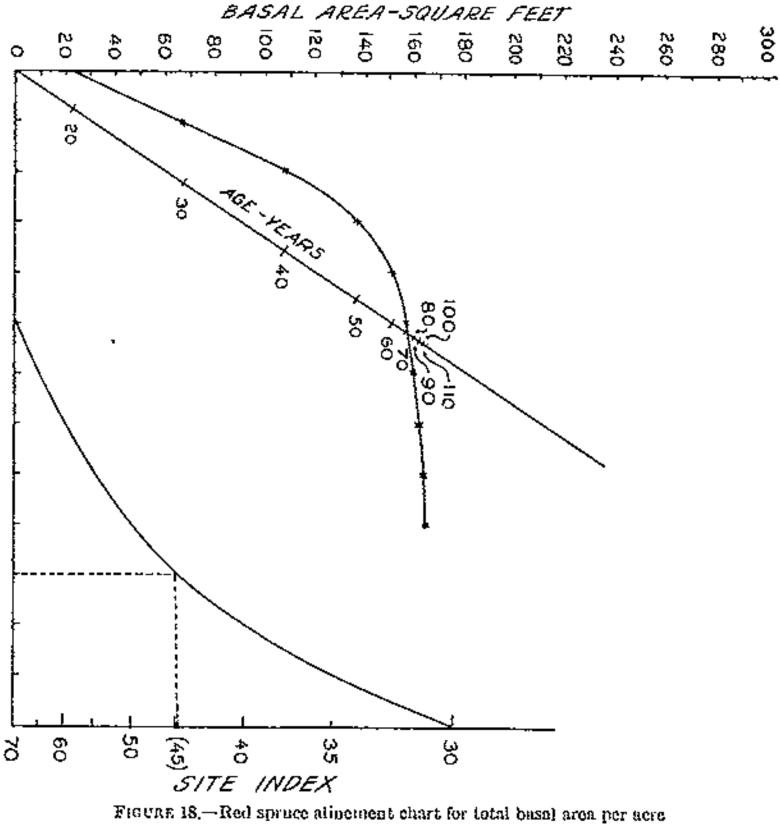

FIGURE 18.—Red spruce alinement chart for total basal area per acre

high. Further refinement of curve fitting and computation is of little use, since the plots are few in number and variable in their values.

PRESENTATION OF DIAGRAMS BY ALINEMENT CHARTS

Sets of curves which have been derived by anamorphosis can be easily replaced by alinement charts. Figure 18 illustrates the total basal area curve for red spruce in this form.

The total basal area is first laid off on the left-hand vertical scale in equal graduations. At a convenient distance to the right another vertical scale is erected upon which are marked the site-index graduations that represent the proportionate spacing of the site curves.

In this case, they can be obtained by dividing the total basal-area values for any age by the first of these values. For instance, for 110 years these values are 282, 269, 250, 218, and 158 for the five sites, and the divisor is 282. The quotients derived are 1.000, 0.954, 0.887, 0.773, and 0.560. On the right-hand vertical axis the base is marked site 70. Above this at 1.000 − 0.954, or 0.046 units, site 60 is placed. At 1.000 − 0.887, or 0.113 units, site 50 is placed, and so on for the remaining sites. The unit used should be large enough to give well-spaced graduations.

The age graduations must next be determined. For this purpose, for each age place a straightedge between site index 70 and its corresponding basal area. Repeat this process for the same age with site 30. The intersections of the two lines are the positions for the age graduations in question. The intersections will be found to lie in a straight line radiating from the origin of basal-area axis.

The curved lines shown in Figure 18 are merely for obtaining finer age or site graduations, and are obtained by plotting the age or site graduations at equal horizontal intervals and drawing a curve through the plotted points. Subdivision of the equal horizontal intervals into 10 parts, and projection of these subdivisions vertically up to the curve and from this point horizontally to the age or site axis give the finer graduations desired on the axis.

Similar presentations can be made for tables for total number of trees, diameter of average tree, total cubic-foot volume, and total board-foot volume.

STAND TABLES

The method of computing stand tables as outlined in the first section of this bulletin was made necessary by the character of stem distribution in red spruce stands. As mentioned previously a common method of studying the distribution of trees in diameter classes is to compare it to a normal distribution as obtained by use of the Gaussian curve or law of probabilities. If the comparison is sufficiently close, the character of this distribution can be very simply stated by giving only the average diameter of the stand and the standard deviations of the diameters from this average. However, red spruce does not have this conformity. To use a mathematical expression, it has a skewed distribution. In Figure 13 an effort was made to present in a simple manner a series of such skewed distributions through the range of average diameter classes.

For the preliminary steps only those plots were taken which were practically 100 per cent pure red spruce and which in addition had no abnormalities in stocking such as holes or exceptionally large trees. These plots were grouped into classes, based on the diameter of the average tree. In each group the number of trees in each diameter class was found and cumulative sums were built up to a complete total for that group. The percentages of these cumulative sums over the group totals were then computed (Table 43) and plotted on arithmetic-probability paper. When the plotted points were connected by straight lines, readings of diameters made at certain percentage points such as 99.9, 99, 90, 75, 50, 25, and 2 were the basis for a new plotting on ordinary coordinates with average diameter of the stand as the horizontal scale and diameter class as the vertical scale. Straight lines were drawn, one through all the 99.9 per cent points, one through all the 99 per cent points, etc. When these curved values were read and plotted on logarithmic-probability paper it was found that by the addition of 20 to the diameter classes the straight lines of Figure 13 were formed with practically no deviation. Figure 13 is a section of logarithmic-probability paper with the diameter units 20 to 50 enlarged and numbered 0 to 30 to represent the actual diameter classes.

TABLE 43.—*Basic data for red spruce stand tables*

Diameter class (inches)	Average diameter of stand (inches)												
	2.38	3.88	4.67	5.68	6.35	7.16	7.73	8.22	8.78	9.37	9.72	10.25	10.9
	Percentages of total number of trees up to and including diameter class												
1	41.0	9.7	4.2	0.62									
2	70.0	28.0	14.1	2.9	0.44	0.34	0.46	0.22	0.85			1.16	
3	87.5	52.8	35.8	13.8	4.5	2.3	1.83	1.21	2.7			1.16	
4	96.3	74.1	57.5	33.8	18.5	9.7	6.5	3.0	5.0	0.13	0.22	1.16	
5	98.7	87.9	75.5	54.3	39.0	25.6	16.5	11.7	11.4	5.4	3.7	2.33	
6	100.0	96.5	88.5	73.5	59.7	45.4	33.5	26.2	20.0	12.9	11.1	2.33	1.7
7		98.5	95.1	88.1	78.5	66.0	51.3	43.1	35.0	29.2	25.0	14.0	1.7
8		99.28	98.5	94.5	91.5	82.7	70.1	60.9	51.0	45.3	37.0	27.7	19.7
9		99.84	99.46	98.00	97.1	91.0	83.6	77.5	68.0	60.2	54.0	43.0	35.3
10		100.0	99.89	99.75	98.8	96.5	93.3	88.3	82.0	73.5	70.0	64.0	49.3
11			99.94	100.0	99.57	98.59	97.4	94.7	92.4	86.7	80.5	76.7	61.5
12			100.0		99.92	99.57	99.22	98.1	95.6	92.5	87.7	88.4	76.1
13					100.0	99.87	99.80	99.39	98.0	95.0	95.0	91.9	85.0
14						99.92	100.00	99.92	99.23	97.6	97.9	96.5	91.9
15						100.0		99.96	99.83	98.03	98.89	97.7	95.6
16								100.0	100.0	99.37	98.89	98.84	97.4
17										99.37	100.0	98.84	98.0
18										99.63		100.0	98.9
19										100.0			99.4
20													100.0
Basis, number of plots	3	7	11	14	17	21	22	21	11	5	2	1	2

VOLUME TABLES

The form-class system of normal volume tables has several advantages, a number of which have already been stated or hinted at. This subject has been studied intensively, but as the results have not reached final form at the time of preparation of this bulletin, modifications and improvements of the results adopted in this work may be expected later. These will, however, increase the applicability and accuracy of the system, and will not affect to any appreciable degree the total volumes of stands as given.

The total cubic-foot volume tables were checked for the three species with the results stated in Table 44.

TABLE 44.—*Total cubic-foot volume table check*

Datum	Red spruce	White spruce	Balsam fir
	Per cent	*Per cent*	*Per cent*
Difference between table volumes and normal volumes [1] [2]	−0.81	−1.68	−0.61
Difference between actual volumes and normal volumes [3]	+2.63	+2.61	+1.36
Average error of table volumes about normal volumes	4.7	4.6	4.2
Basis, number of trees	608	200	306

[1] "Table" volume is the estimated volume from the table interpolating for 1-foot-height class, 1-inch diameter and one unit-form class.
[2] "Normal" volume is the volume of actual scale reduced for butt swell and bark.
[3] "Actual" volume is the volume including butt swell, but not bark.

For red spruce the sums of volumes as determined from the tables underrun the sums of scaled normal volumes by 0.81 per cent; the actual volume of trees, including butt swell, overruns the normal volume not including butt swell by 2.63 per cent; and the average error of the normal volumes from the table is 4.7 per cent. White spruce and balsam fir have similar checks. The average errors are apparently small. To be made comparable to average error obtained by other systems of volume tables, several modifications must be made. In application to stand tallies only one average form class is used for each. By investigation Behre found that the range of form quotients or form classes of the individual trees of a stand have a standard deviation of 4.5 units, which he further showed to be equivalent to 6.75 per cent of volume. The standard error corresponding to the average error of 4.7 per cent of the check on the volume tables (Table 44) is 5.88 per cent. In combining these two standard deviations of 6.75 and 5.88 per cent by the rule of the square root of the sum of their squares, this result is obtained—

$$\sqrt{(6.75)^2+(5.88)^2}=8.95 \text{ per cent}$$

This is equivalent to an average error of 7.16 per cent, which Behre concludes is well below the minimum of 10 per cent, temporarily set up as a standard in volume-table work.

Figure 15 is supported by the data of 670 red spruce, 337 white spruce, and 346 balsam fir. The form-point height and the form class of each were measured and the correlations between them investigated. Table 45 presents the results concisely.

TABLE 45.—*Correlation computations supporting Figure 15 on relation between form point and form quotient*

Species	Basis, number of trees	Coefficient of correlation	Error of estimate of individual trees	Error of estimate of stand form quotient with 20 trees
			Form quotient units	*Form quotient units*
Red spruce	670	0.7020±0.0196	5.40	1.57
White spruce	337	.7394± .0247	5.07	1.52
Balsam fir	346	.5800± .0356	4.38	1.40

Figure 15 gives, as already mentioned, only the regression lines. There is undoubtedly some curvilinearity in the upper portions, evidences of which will be strengthened by more material in the course of the form-class volume-table study. The significance of correlation coefficients is mentioned in the following pages. The error of estimates of individual trees means that single quotient units will have a standard error of so many form-quotient units. If 20 trees in a stand are taken to obtain the average form quotients of a stand the standard error of this average is indicated in the last column of the table. This was obtained by summing the square of error of estimate of single trees and the square of the standard deviation of form quotients in a stand, formerly stated to be 4.5, then dividing by the number of trees measured (assumed to be 20), and finally taking the square root of it all.

PREPARATION OF TABLES FOR PARTIAL STANDS

The preliminary step in the preparation of tables for separate parts of the total stand was to compute for each plot the percentages of basal area, number of trees, and volume for the partial stand; also the size of the average tree included in these portions of the stand. Then, regardless of site and age, these percentages and sizes were averaged in classes of average stand diameter, and plotted over these average diameters. Smooth curves were drawn through the plotted points. For each partial stand the curves for percentage of basal area, percentage of number of trees, and average size were drawn so as to balance with one another.

The fundamental assumption of this method is that the average diameter is the chief variable in determining the proportions of basal area, number of trees, and volume represented in any portion of the stand. In several other studies this assumption was found to be entirely sound. In the present study, however, too much faith must not be placed on the extreme values. That is to say, some of the results will not be very reliable when applied to site 30 and site 70 and to the very low ages of the other site classes. However, for the sites which are commonly found, and for the effective ages, the procedure is sound.

LIMITATIONS OF TABLES

The specific limitations of some of the tables and charts should be mentioned. For all the red spruce tables, the values for the low ages are weak. The material for stand ages under 35 years total age is very sparse. The material is also scant for the high ages, such as ages above 90 years, indicating accordingly a weakness in the curves at this age. As mentioned previously, the extreme sites 70 and 30 are very seldom found, but are included in the graph and tables in order to furnish a means of interpolation between the adjacent site classes.

STATISTICAL ANALYSIS OF RESULTS[5]

An attempt was made to study the interrelation of the various stand characteristics by statistical analysis. The characteristics or variables used were percentage of mixture (called composition), age, site, basal area, number of trees, cubic volume, and board-foot volume. For the last four the actual values were expressed as percentages of the tabular values interpolated in each case for the age and site of the particular plot. These percentages could be called normality percentages. The sites of the balsam and white spruce plots were reduced to equivalent red spruce site values and computations were made for these species similar to those for the red spruce from the red spruce tables. Multiple regression equations, correlations, and deviations of several orders were computed for a number of combinations of the variables. Only a few of these will be discussed. All plots above 30 years of age at breastheight (45 years total age), whether understocked, fully stocked, or overstocked, were used. For red spruce 257 plots were available, for balsam fir 137 plots, and for white spruce 98 plots.

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[5] For more detailed information as to methods, see *48, 49, 50, 52, 53, 54*.

A few words are needed in explanation of correlation coefficients. A correlation coefficient is a computed quantity giving the degree of relationship between two variables. A negative coefficient means that if one of the variables increases, the other decreases. A positive coefficient means that if one of the variables increases the other increases. The size of the coefficient indicates to a certain extent the amount of relationship, a zero coefficient indicating no correlation, and small coefficients signifying little or none. Not until the values approach 0.50 and are larger than three times their probable errors are they ordinarily assumed to have substantial importance. The greater the number of samples used in computing the coefficients, the more significant will these coefficients be.

As an indication of the fit of the curves to the basic material, the value of the correlation coefficients of several variables to age were considered. Coefficients of negligible amount with noncurvilinearity of residuals would indicate a good fit. With red spruce the test was satisfactory, as is seen in Table 46.

TABLE 46.—*Correlation coefficients of age with several stand factors*

Correlation between age and—	Red spruce	White spruce	Balsam fir
Normality per cent of board-foot volume	−0.06±0.042	−0.26±0.064	−0.25±0.054
Normality per cent of cubic-foot volume	− .07± .042	− .24± .064	− .17± .050
Normality per cent of number of trees	+ .09± .042	+ .18± .066	+ .07± .057
Normality per cent of basal area	− .10± .042	− .35± .060	− .23± .055
Normality per cent of site	− .03± .042	− .09± .068	− .32± .052

The coefficients for red spruce are insignificant and therefore the fit of the curves to the material is apparently good. For balsam fir and white spruce, the fit is not so good, the correlation coefficients exceeding three times their probable errors in numerous instances. The negative character of the coefficients indicates that the position of the curves in the younger ages for all factors except number of trees is probably a trifle low for these species or that in the higher ages it is a trifle high. The need is thus evident for separate tables for white spruce and balsam fir.

TABLE 47.—*Important correlation coefficients between various stand factors*

Correlation between normality percentages of—	Coefficients for—		
	Red spruce	White spruce	Balsam fir
Board-foot volume, number of trees	−0.40±0.035	−0.40±0.054	−0.48±0.044
Board-foot volume, cubic foot	.28± .039	.51± .050	.49± .044
Board-foot volume, basal area	.18± .041	.38± .058	.43± .047
Cubic-foot volume, basal area	.91± .007	.71± .034	.85± .016
Basal area, number of trees	.48± .032	.20± .062	.32± .052

The only important correlation coefficients between any two of the variables tested are those in Table 47, which bring out a number of interesting points. Although Figure 3 indicates a decided curvilinear tendency in the board-foot and number-of-trees relation, the coefficient of correlation has a significant value. If the correlation index, which is to the curved line what a correlation coefficient is to a straight line, were computed, a decidedly significant value could be expected. Board-foot volume and basal area seem weakly related. Curvilinearity may in this case hide the true trends. Basal area and cubic-foot volume are very closely related. For this reason the use of basal area as an index of normality of a stand which is recommended under the discussion of the application of yield is well substantiated, or at least for cubic-foot volumes. For board-foot volume it apparently will not serve so well, unless the curvilinear trend of board-foot volume with basal area be defined. Further study must be made of these factors.

The effect of percentages of mixture of the principal species was also investigated, but no important deductions could be made.

DETERMINING THE PERIOD OF DEVELOPMENT FROM GROUND TO BREASTHEIGHT

SEEDLINGS

The ages of the yield plots were determined by taking increment borings at breastheight. This procedure necessitated the determination of the number of years needed to develop from germination to a height of 4.5 feet. If at all possible, the effect of site on the length of the period would have to be included. For this purpose 218 red spruce seedlings, 95 white spruce, and 152 balsam fir seedlings were analyzed. The majority of these were taken from sites where full benefit of light was obtained, and if any shading or competition was at hand, notes were made to that effect. Of the total number, 168 of those reaching or exceeding 4.5 feet in height were red spruce, 79 were white spruce, and 134 were balsam fir. For these groups Table 48 gives the average ages at which stump heights of 1 foot and breastheight were reached.

TABLE 48.—*Number of years required for seedlings to attain heights of 1 foot and 4.5 feet*

Species	Age to 1 foot	Age, 1 foot to 4.5 feet	Total age to 4.5 feet
	Years	*Years*	*Years*
Red spruce	6.9	7.9	14.8
White spruce	6.2	7.3	13.5
Balsam fir	6.9	8.0	14.9

In each locality where seedlings were measured a notation was made of the site as obtained from an adjacent sample plot, if possible, or from a personal estimate of the character of the soil and the soil cover. The results were in a way disappointing for no distinct relation between age of reaching breastheight and site could be determined. At times, in fact, the measurements seemed to be contradictory. For developing seedlings it is apparent that site is much more specialized than for maturing trees. Each pebble, each bunch of grass, each depression may affect its development, so that full access to light alone is not the sole requirement. Large numbers of measurements are needed if any correlation of age with site is desired, as the differences caused by the obscure site factors are large. A single average value of 15 years for development from germination to 4.5 feet height was therefore tentatively taken for all sites.

The variation in height growth of seedlings on areas which have the gross characteristics of equality of site bears out the conclusion that the minor details of site affect seedling development greatly. One area in particular can be mentioned. It was an old pasture with a scattering of white spruce seedlings over the whole of it, and with no competing vegetation except heavy grass. The shortest seedling taken measured 1.5 feet in height and was 10 years old, the tallest was 9 feet in height and was 13 years old. Intermediate sizes showed an irregular variation between these heights. Usually there is a slight correlation between age and height of seedlings, which, however, is not at all commensurate with their respective differences in height development.

Further study will undoubtedly reveal differences in ages upon various sites, or reveal methods whereby the long period of initial development can be decreased. As soon as this is done the total age of the yield tables, which is now 15 years plus the breastheight age, can be easily corrected.

SAMPLE TREES

As the period of seedling development was much longer than that originally estimated, certain comparisons were made to check this value. The sample trees taken with the preliminary data furnish a partial comparison. Since measurements were made on these trees at 1-foot stump height and at breastheight, either by actual cutting or by increment borings, there was an approximated measure of development from stump to breastheight. For 84 red spruces this period was 5.3 years, for 42 white spruces 4 years, for 43 balsam firs 4 years. This is to be compared to the values 7.9, 7.3, and 8 of Table 48. The weight of numbers lies, however, with the seedlings; and since it is known that they were accurately taken, the age for development to breastheight must be judged from their measurements. On the other hand, the very apparent indications that this period can be less or can be made less by a little treatment or care of the soil should allow some flexibility in estimating total age.

PERMANENT SAMPLE PLOTS

A number of permanent sample plots were laid out in 1904 and 1906 in pure second-growth spruce stands at Corbin Park, near Newport, N. H. Since that time cuttings have disturbed several of them very seriously, so that some of the records do not go farther than 1915. Subsequent subdivisions had to be made in some of the plots because the conditions of stocking were judged to vary so widely that the growth in several portions of the same plot might be radically affected. Four of the plots were thinned.

Table 49 gives a list of the total cubic-foot volumes per acre of live trees on the five dates of measurement. Table 50 gives the periodic annual increments computed directly. Each period is assumed to be five years although the months of measurements vary enough to throw them out of an exact 5-year interval. However, total volume of live trees and periodic increments do not tell the whole story. Mortality is continually taking place among trees, and at times may involve a considerable volume, which decreases considerably the net increment of live trees. In this connection, if Table 51 is observed and the periods of large mortality are noted, it will be seen that the corresponding increment in almost every case is small if not negative.

TABLE 49.—*Statistics of permanent sample plots, located in a pure red spruce stand, Corbin Park, N. H.*

Plot No.	Total age in 1904	Site index	Size	Total volume per acre on— October, 1904		July, 1910	August, 1915		July, 1920		June, 1925
Unthinned:	*Years*		*Acre*	*Cubic feet*		*Cubic feet*	*Cubic feet*		*Cubic feet*		*Cubic feet*
711A	65	58	0.167	6,440		6,340	6,720		7,220		7,320
711B	65	56	.167	4,850		5,230	5,500		5,890		6,210
711C	65	48	.167	4,640		4,960	5,270		5,420		5,470
714A	65	56	.25	5,920		6,230	6,680		6,870		6,750
714B	65	54	.25	5,990		6,340	6,890		6,810		6,800
717A	65	50	.08	5,700		6,040	6,350		6,590		6,660
717B	65	51	.21	1,575		1,875	2,130		2,210		2,235
717C	65	50	.21	5,060		5,170	5,990		5,920		5,930
723	65	56	.5	4,230		4,550	5,040		5,400		5,550
762	60	55	.2	6,890		6,810	6,760				
				Before thinning	After thinning		Before thinning	After thinning	Before thinning	After thinning	
Thinned:											
720A	65	52	.333	4,840	4,050	4,570	4,760	3,880	4,350	4,120	4,270
720B	65	53	.167	5,190	4,450	4,980	5,310	4,200	4,780	4,770	4,890
726A	65	52	.4	4,400	3,700	4,160	4,600	3,830	3,990	3,820	4,290
761	60	53	.2	[1] 6,225	[1] 4,990	[1] 5,245		5,810			

[1] Measured in July, 1906, and June, 1911, instead of October, 1904, and July, 1910.

TABLE 50.—*Periodic annual increments per acre on permanent sample plots*

Plot No.	1904–1910	1911–1915	1916–1920	1921–1925
Unthinned:	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
711A	−20	76	100	20
711B	76	54	78	64
711C	64	62	30	10
714A	62	90	38	−24
714B	70	110	−16	−2
717A	50	62	48	14
717B	60	51	16	15
717C	22	164	−14	2
723	64	98	84	18
762	−16	−10		
Thinned:				
720A	101	38	94	30
730B	102	70	116	24
726A	92	88	32	94
761	51	113		

TABLE 51.—*Volume per acre in dead trees on permanent sample plots*

Plot No.	1904–1910	1911–1915	1916–1920	1921–1925
Unthinned:	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
711A	604	144	114	126
711B	108	84	42	0
711C	36	18	132	102
714A	332	48	128	356
714B	112	136	312	272
717A	75	50	25	325
717B	0	0	0	52
717C	76	10	243	224
723	8	34	36	182
762	185	295		
Thinned:				
720A	135	60	30	138
720B	72	66	12	138
726A	45	10	10	
761	150	30		

Tables 49 to 51, inclusive, indicate that the stand was at that age when, according to Figure 10, periodic increments are rapidly approaching low values and thinning becomes advisable. The thinnings carried out on four of the plots, as shown in the tables, with the grades of thinning given in Table 52, resulted in benefits more apparent than real. The gross average annual increments for plots 711A to 723 were found to be 72 and for plots 720A to 726A, 86; for the very dense plot 762 and its thinned neighbor plot 761 they were 35 and 100, respectively. In other words, in the first group of plots the thinnings did only a trifle more than utilize the volume of trees which would have died anyway. In the second group the benefit is much more real, since the gross increment is substantially increased. One must conclude, therefore, that in the first group the thinnings should have been heavier or more consistently repeated throughout the life of the stand.

TABLE 52.—*Grade of thinnings made on permanent sample plots* [1]

Plot No.	First period			Third period			Fourth period		
	Trees	Basal area	Cubic feet	Trees	Basal area	Cubic feet	Trees	Basal area	Cubic feet
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
720A	23	14	16	33	21	18	11	0	5
720B	16	14	14	32	22	21	2	1	0
726A	17	13	16	36	20	17	7	5	4
761	28	21	20						

[1] No thinning made in second period.

The set of permanent sample plots can also furnish interesting discussion of the yield tables and their application. In Table 53 there is an effort to translate a number of plot values in terms of percentages of yield-table values and by means of this to determine the reliability of the relation between the percentage of normal number of trees or basal area and that of volume. The ages and sites used are indicated for each plot in Table 49. Only the unthinned plots measured through the whole 20-year period will be considered.

TABLE 53.—*Comparisons of percentages of normal number of trees and basal area with regard to prediction of cubic-foot volume for a 20-year period*

Plot No.	Normal number of trees		Volume from Figure 3		Normal basal area		Normal volume		Differences between columns					
	1904	1925	1904	1925	1904	1925	1904	1925	4-8	5-9	4-9	6-8	7-9	6-9
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*						
711A	68	66	93	92	95	93	102	98	−9	−6	−5	−7	−5	−3
711B	46	53	77	84	78	85	80	86	−3	−2	−9	−2	−1	−8
711C	62	70	90	94	90	92	94	93	−4	+1	−3	−4	−1	−3
714A	96	94	100	99	98	96	98	94	+2	+5	+6	0	+2	+4
714B	100	103	100	100	97	100	104	99	−4	+1	+1	−7	+1	−2
717A	73	79	95	97	99	108	110	107	−15	−10	−12	−11	+1	−8
717B	16	22	30	41	27	30	29	36	+1	+5	−6	−2	0	−9
717C	65	72	92	95	94	97	97	96	−5	−1	−4	−3	+1	−2
723	46	59	77	88	84	85	81	89	−4	−1	−12	+3	−1	−5
Average error in terms of per cent of normal volume									5.2	3.6	6.4	4.3	1.4	5.1

Columns 2 and 3 of Table 53 give the percentages of the normal number of trees at the first and last measurement. Columns 4 and 5 give the corresponding percentage of volume as read from Figure 3. Columns 6 and 7 are the percentages of normal basal area and 8 and 9 of normal volume. Columns 10 to 15 give the difference of the several column values as indicated. The use of number of trees and the use of basal area as a measure of stocking and for prediction of future volumes can now be compared. According to these limited data, both methods give low estimates. Columns 10, 11, 13, and 14 give the relations of same years, but columns 12 and 15 consider respectively the prediction of volume after 20 years from the number of trees and the basal area at the beginning of the period. In this case the two methods result in strikingly similar values. The basal-area method, however, is the one more commonly used and is probably not affected so much by groupwise stocking of trees; it is therefore recommended until further investigation can disclose more satisfactory methods.

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