HARVARD FOREST

BULLETIN NO. 7

RICHARD T. FISHER, *Director*

Quality and Growth of White Pine as Influenced by Density, Site, and Associated Species

BY

E. E. TARBOX

WITH FIELD ASSISTANCE BY

P. M. REED

HARVARD FOREST, PETERSHAM, MASS.

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PREFACE

In the practice of forestry two objects are of primary concern to the forest manager — to keep down the cost of starting a crop, and to raise the quality (and hence the value) of the final product. The present study analyzes the factors which, in the natural or untreated second growth stands of white pine, influence form and the percentage of clear lumber in the log. The systematic correlation of log (or tree) quality with manufactured prices is difficult to state in unqualified terms, but as a range in price of $10 to $15 per thousand from stands of the same age and size is possible, the importance of controlling form is obvious. In many cases the profit and loss of the forest investment may depend upon it.

R. T. Fisher.

SUMMARY OF CONCLUSIONS

Pure Pine

I. That density of stocking has little or no direct influence upon length of internode (current height growth).

II. That in any stand of pure pine whose crowns have closed by the time it has reached twenty years of age, there is a constant relation between the average knot size in the first twelve-foot log and number of trees per acre.

III. That, for a given site, the quality of the yield is determined by the time required for the crowns of a young stand to meet and form a complete crown canopy.

IV. That in densely stocked stands on Site I yields are reduced appreciably by crown friction.

Pine and Hemlock

I. That the highest quality of lumber is secured from a pine-hemlock stand where the number of pines per acre does not exceed the number given in the yield table, at any given age.

II. That the quality which pine attains is due to partial suppression during the first forty or fifty years of life, and to the marked tolerance of the hemlock as compared with the pine.

Pine and Hardwoods

I. That with well-stocked stands, the quality of the lumber produced on this type is better than that secured from most pure pine stands.

QUALITY AND GROWTH OF WHITE PINE

INTRODUCTION

FACTORS OF QUALITY IN LUMBER

THE chief source of white pine lumber in New England at present is the second growth stands which originated for the most part on abandoned farm lands. Most of such stands claimed the land about the time of the Civil War, and may be considered as transition types. These stands are almost always cut at some time between the ages of fifty and seventy years, and as a result there is hardly ever any clear lumber obtained, except possibly a little in an unusually good butt log. Whereas the virgin timber was sawed into square edge boards and dimension stock, the present practice is to saw the logs through and through into "waney-edged" lumber. The demand for second growth pine came about because of the exhaustion of the supply of virgin timber, and because new industries developed which could make use of the inferior product of our second growth forests. Today, the heavy construction timbers and clear lumber of the Southern pineries and West Coast fill the place formerly held by virgin New England pine, while our second growth goes largely into manufactured products, chiefly boxes, sash and blind, match stock, toys, and woodenware.

Quality, as defined in grading rules, is not recognized in the present-day marketing of second growth pine. Nevertheless, quality is required in a greater or less degree by the industries named above, and size and number of knots per board are still the governing factors. At present, the varying prices which are paid for logs or lumber of differing quality are the result of agreement between the buyer and seller, who base the price on their knowledge of the manufactured value of the product. Manufacturers requiring short lengths wholly free from knots secure it by sawing out the whorls of knots from the boards. Since, on second growth pine, the limbs nearly always extend out to, or through, the bark, boards sawed from such timber contain clear material only between the yearly whorls of limbs, and the smaller the knots in the whorls, the less is the percentage of waste in the boards. Thus the factors governing height growth and natural pruning (or the rate at which side branches die) will control the ultimate quality of the lumber.

The purpose of this study is to correlate height growth and natural pruning with (1) site, (2) density, and (3) associated species and stand form. Three types were chosen for analysis, the principal ones in which pine occurs — (1) Pure white pine, (2) Pine and Hemlock, and (3) Pine and Hardwoods. The field data were gathered on or near the Harvard Forest in northern Worcester County, Massachusetts.

PURE PINE TYPE

FIELD WORK

The study of pure pine was limited to even-aged fully stocked stands. Any stand was considered fully stocked which had a complete crown canopy, regardless of the number of trees per acre. Stands containing other species or having openings in the crown canopy were rejected in the selection of material. Plots were taken in all possible situations ranging from ridge tops to valleys, and age classes from twenty to seventy years were represented. The areas studied were all one tenth or one fifth of an acre, except for the youngest age class, in which it was possible to find larger areas with a complete crown canopy. Only areas were taken on which there was little or no irregularity in the distribution of the trees. Seventy-two plots were taken in the towns of Petersham, Barre, Dana, Greenwich, Athol, Orange, and Royalston, Massachusetts, and Richmond, New Hampshire.

On each plot the following measurements were taken on dominant trees only:

1. Diameters at breast height recorded in inch classes.

2. The number of internodes in the first two twelve-foot logs. In the younger age classes only twelve feet of the bole was taken, because beyond that height the limbs were usually still alive and growing.

3. The average knot size for the first one or two twelve-foot logs in each tree. With the form used for tallying data, the number of internodes and the average knot size could be read from the sheet for any desired tree.

4. The ages of three trees of average diameter which were dominant in the stand determined by an increment borer. The total height of these average trees, and also the height to the first green limb. The crown radii of the three average trees, obtained either by actual measurement on the ground of four different radii of each tree, or by pacing. The four measurements taken were then averaged, and the result was considered the true crown radius of the tree.

5. Notes on the soil composition, the silvical condition of the stand, and its topographic location.

RELATION OF DENSITY TO HEIGHT GROWTH

Within very wide limits density apparently has no influence upon current height growth. The following figures, typical of the whole, show that length of internode is independent of number of trees per acre. A young age class is used because in such a stand there is as yet little or no reduction in the number of trees present at the time of origin.

TABLE I. HEIGHT GROWTH AND NUMBER OF TREES PER ACRE

SITE II. AGE CLASS, 20–30 YEARS

Plot No.	Density Trees per Acre	Average Length of Internode in First 12-Foot Log
38	520	.97′
21	700	1.29′
11	850	.99′
43	1120	1.17′
19	1940	1.27′
10	1940	1.05′
69	2360	1.00′
5	3156	1.06′

Growth in height (or expressed differently, length of internode) is determined by the quality of site (see Table XI). The unqualified statement must not be made however that density has no effect upon height growth. Indirectly it does. The white pine weevil is an insect which causes a large amount of damage to pure white pine stands wherever they are found extensively. H. B. Pierson in his bulletin ("*Control of the White Pine Weevil by Forest Management*," Harvard Forest Bulletin No. 5, Harvard Forest, Petersham, Mass.) finds as one of the conclusions of his study that "weevil injury is largely overcome by a density of stand which does not allow for the spreading and forking of the trees." This statement has been verified by observations made during the course of the present study. Also, in more dense stands, the percentage of original injury seems to be less. Therefore, even though density itself does not influence height growth and thus better the quality of the lumber produced, it is of great importance that stands be of sufficient density in order that the damage caused by the weevil's attack may be lessened.

EFFECT OF DENSITY UPON KNOT SIZE

For a given site, the length of time that it takes for the crowns of a stand of pine seedlings to meet and form a complete crown canopy determines knot size. When the crowns of the trees meet the lowest side branches cease to grow due to the absence of sufficient light. As growth continues in the stand, the side branches of adjacent trees continue to meet higher up the tree. They also die. With this process of meeting and dying going on year after year, the living crown is forced higher and higher up the tree, and the result of the process is clear length of bole.

In a densely stocked young stand the crowns will meet sooner than they will in a stand less densely stocked, assuming that the possibility of growth is the same. This means that in a dense stand the side branches will die small, while in a less dense stand they will be larger at death, and the increase in size is inversely proportional to the density. If the density of the stand is so low that the crowns of the trees never meet, the side branches will continue to live and grow as long as the tree lives. A single pine growing in the open exemplifies this condition.

The accompanying table shows the influence of density upon knot size. The results shown were obtained by plotting average knot size over numbers of trees per acre, and drawing a curve through the points. Plots in the 20–30 year age class were used in making the curve, because, in a stand at that age, most of the trees which were there originally are still standing. The results show that up to 20–30 years, there is a constant relation between knot size and number of trees per acre.

It will be seen also that while the number of trees per acre diminishes by a constant, the corresponding increase in average knot size is not constant. All stands used in constructing this table had a closed crown canopy, and the average figures for knot size given in the table are fixed.

That is to say, the limbs measured were dead, so that the knot size will neither increase nor decrease during the remainder of the life of the stand.

TABLE II. RELATION BETWEEN NUMBER OF TREES PER ACRE AND KNOT SIZE

SITE II. AGE CLASS, 20–30 YEARS

Number of Trees per Acre	Average Knot Size Inches
3000	.33
2500	.37
2000	.43
1500	.53
1000	.65
500	.79

A similar curve constructed for age class 40–50 years showed no such correlation. A stand at twenty years of age may have 2500 trees per acre. By the time this stand has reached the age of sixty years, the number of trees per acre may be reduced to 300. In this case many trees have died and disappeared which served their purpose in pruning the remaining stand. Now consider a stand which at twenty years of age contained only 1500 trees per acre. At sixty years this stand may contain as few trees per acre as the first stand, assuming the same site, but the knot size would be much larger, due to the fact that it had fewer trees per acre at the early age as shown in Table II. Chapman says in this connection in his *Forest Mensuration*, page 392, "It has been found that in stands originally stocked with only a part of the normal number of trees for smaller ages, as the age of such stands advances and the number of trees required in a stand of maximum or normal density decreases, the poorly stocked stand tends to approach and to equal the yield per acre of the stand which has been normally stocked throughout its life." And again he says on page 395, " . . . since naturally stocked areas tend constantly to pass from a condition of under-stocking to one of over-stocking."

Table III illustrates this absence of correlation in the older age classes between numbers of trees per acre and average knot size.

TABLE III. NUMBER OF TREES PER ACRE AND KNOT SIZE

SITE II. AGE CLASS, 40–50 YEARS

Based on 9 plots

Number of Trees per Acre	Average Knot Size Inches
700	.72
500	1.11
410	.87
340	1.50
320	.82
300	1.06
250	1.20
240	1.15
190	1.21

The average size of the knots in a stand of pine is thus determined by the time it takes the crowns to meet. If it is desired that the land produce pine of the best quality obtainable for the type, then every effort must be made to secure a dense and uniform reproduction. This will lead to an early dying out of the side branches which would otherwise persist and lower the quality of the lumber. When the abandoned fields of this region began to seed in to pine after the Civil War, natural circumstances decided whether the resulting young stands should be sparse or dense. More often than not these stands were understocked, and remained so until they reached maturity. The results are shown in the many poor knotty and crooked logs which are drawn to the sawmills today.

Old fields and, to a limited extent, cutover areas are still being seeded in to pine. Unless a fully stocked stand of reproduction is secured by proper silvicultural operations, or unless the present insufficient stocking is filled out by planting, mature stands of the next rotation will be no better than those of the present. There must be no delay in remedying an understocked condition, for it is in the first ten years of a stand's life that a foundation is laid for future quality.

DENSITY AND CROWN FRICTION

Some of the old field stands of pure pine were densely stocked in youth and have remained so throughout their lives. In such stands the competition for light and growing space is much keener than in stands less densely stocked. This condition, at the start, is very beneficial in improving the quality of the stand, and in lessening the severity of the weevil damage, as has been previously stated. But in later life, although there may be, apparently, more than enough trees to make a fully stocked stand, the individual crowns often fall far short of forming a closed canopy. Since there is a common opinion that second growth pine almost stops growing at about fifty to sixty years old, all measurements taken on such stands were segregated and studied separately. The results of the separate study were compared with those secured from stands which did not show the condition above noted.

First, it was found that diameter growth falls off early, and at a surprising rate. This loss in growth rate begins when the stands are about thirty years old and forty feet in height. Since diameter growth is a function of crown volume, the small diameter growth must be due to the smallness of the crowns. Chapman says in his *Forest Mensuration*, page 352, par. 273, that "rate of growth of the individual or average tree is profoundly influenced by the number of trees in the stand."

Continued observation of these stands, made at times when there was considerable wind, showed why the crowns, and consequently the growth rate, were so small. The trees in a dense Site I stand have relatively small diameters, while their height growth is at least equal to the height growth in a less dense stand. Therefore such stands are more easily swayed by the wind than a less dense stand which is also Site I, or in a Site II stand which is not so tall. The friction or rubbing between the swaying crowns of the various trees breaks off the terminal buds from the side branches and checks the crown growth. If this condition continues, the crowns become smaller and smaller, until the trees of the stand have what is locally known as "umbrella tops."

The photograph shown (Fig. 3) was taken looking up into the crown canopy of a stand showing the condition under discussion. The wearing away of the lateral branches has continued until the crowns of the different trees no longer touch by several feet, and a great deal of available growing space is going to waste. When the wind blows, however, the crowns will sway in a circle or parabola, and continue to rub against each other.

The curves of diameter growth (Fig. 7) present a comparison between Site I and Site II where the crowns are normal, and Site I where crown friction is present. These curves are the averaged result of one hundred and fifty-five borings taken in all stands which have been measured. It will be seen that once crown friction has made itself felt, diameter growth falls far below even the rate for Site II stands.

The need for early thinnings is thus clearly shown. Densely stocked stands in the younger age classes are necessary in order that quality be produced and weevil damage lessened. If stands are allowed to remain densely stocked much after thirty years, crown friction greatly reduces the yield. Since the foundation for quality can be laid only during the youth of the stand it seems logical that some of these trees should be removed after the need for them has passed. If stands of pine are thinned so that their crowns do not rub, and so that there is continually room for expansion, there is no reason why a good growth rate cannot be maintained to an age far beyond that at which it is now commonly supposed to fall off. Today, in many localities, small quantities of logs are readily salable to manufacturers, provided they are landed beside a road where a truck can pick them up. This makes it possible for pine owners, both large and small, to go into a tract of timber and cut without necessarily stripping the land.

It has been definitely shown at the Harvard Forest on sample plots where thinnings have been made and permanent records kept that the rate of growth is much better than in similar stands where no cuttings have been made, and that the increase in increment amounts to from 15 to 20 per cent.

The foregoing discussion applies almost wholly to stands found on Site I. But few stands on Site II show crown friction, because at a given density diameters are greater in proportion to heights.

YIELD TABLE

In order to test still further the effect of density on yield, the volumes found on the seventy-two plots were expressed in the form of a yield table. Two site classes only were used, as the variation in height growth did not warrant the use of three. The figures represent the average maximum yield obtainable in unthinned natural stands. The table shows that on Site II at sixty-five years, the yield exceeds that of Site I. This is explained by the crown friction which occurs as described above in densely stocked Site I stands. The findings from the study of crown friction and the results obtained in making the yield table seem to furnish conclusive evidence regarding the effect of overstocking on growth rate in Site I stands.

Board-foot volumes computed from Table No. 10 — Volume Table for White Pine. Published in "*Forest Mensuration*" by the Commonwealth of Massachusetts, Division of Forestry.

Cubic-foot volumes computed from Table No. 12 — White Pine, Southern New Hampshire. Published in "*The Woodman's Handbook,*" U. S. Department of Agriculture, Forest Service, Bulletin No. 36.

TABLE IV. WHITE PINE YIELD TABLE. NORTHERN WORCESTER COUNTY, MASSACHUSETTS

SITE I

Age	Trees per Acre	D.B.H.	Basal Area	Aver. Height Dominants	Volume Cu. Ft.	Volume Bd. Ft.	Board Feet C.A.I.	Board Feet M.A.I.
20	2000	3.5″	130	25	....	6,400	320	320
25	1460	4.3″	145	32	2770	10,400	800	416
30	1070	5.3″	162	40	3620	15,500	1020	517
35	820	6.3″	176	48	4470	21,200	1140	606
40	660	7.3″	190	55	5390	27,800	1320	695
45	560	8.1″	198	61	6120	34,000	1240	755
50	480	8.9″	206	65	6680	39,700	1140	794
55	420	9.6″	212	70	7350	45,000	1060	818
60	370	10.3″	216	75	7980	49,700	940	828
65	335	11.0″	220	79	8620	53,400	740	821
70	310	11.5″	225	82	9060	56,600	640	808

SITE II

Age	Trees per Acre	D.B.H.	Basal Area	Aver. Height Dominants	Volume Cu. Ft.	Volume Bd. Ft.	Board Feet C.A.I.	Board Feet M.A.I.
20	2200	3.2″	120	21	....	4,500	225	225
25	1620	3.9″	132	27	2430	8,000	700	320
30	1230	4.7″	148	34	2830	12,500	900	417
35	950	5.7″	168	41	3785	17,500	1000	500
40	750	6.8″	188	47	4650	23,400	1180	585
45	600	7.9″	206	53	5465	29,500	1220	655
50	500	9.0″	222	58	6290	36,000	1300	720
55	440	9.8″	232	63	7095	42,500	1300	773
60	380	10.8″	240	67	7860	48,400	1180	806
65	340	11.5″	246	72	8585	53,500	1020	823
70	315	12.1″	250	76	9315	57,400	780	820

PINE AND HEMLOCK TYPE

FIELD WORK

White pine shows excellent quality where the individual tree is shut off from contact with others of the same species by intervening hemlocks. As the number of pines in the mixture increases beyond a certain point the quality decreases, until in the pure stands of pine we find the poorest quality of lumber produced. Therefore in order to provide rigid control for the study of pine-hemlock stands, it was decided to consider only those specimens of pine which were completely surrounded by hemlocks. When a pine was located which was surrounded by hemlocks the distances from the pine to the boles of the surrounding trees were measured, and also to the margins of the crowns of these trees on the side farthest away from the pine. By drawing these measurements to scale in the notebook, the plots were reproduced just as they occurred in the woods, with the crown areas sketched on the sheets.

For tree measurements, the diameter at breast height, total height, height to first green limb, crown radius, number of internodes per twelve or twenty-four feet, and average knot size were taken for each pine. The age of each pine and usually of two hemlocks on the plot were found with an increment borer. The clear length of each hemlock was recorded. If any small dead trees occurred on the plots, these were recorded in a separate column. All cores taken in making borings for age were saved, and used in constructing curves of growth. The borings were taken at approximately one foot from the ground, and total age was found by adding to the ring count the age of a seedling one foot high.

FORM AND COMPOSITION

The composition of unmanaged pine-hemlock stands varies greatly from those which contain mostly hemlock to those in which the pine element predominates. The quality of the pine and its yield per acre vary according to the mixture. In all, forty-three plots were secured. In a few cases, in the oldest age classes, a plot was taken which had two pines in the center instead of one. The stands on these plots varied in age from twenty-eight to ninety years, and were so distributed that each age class was almost equally well represented. The pines were straight, clean-boled, and free from injury in the older age classes, and in the younger age classes, as from twenty to fifty years, showed promise of developing into trees similar to the older ones. Up to the age of about fifty years the forest has the form of an even-aged stand, but from that age on the pine outgrows the hemlock to such an extent that a two-storied forest is established. The under story is a dense canopy formed by the shade-enduring crowns of the hemlocks, while the upper story is made up of the thrifty crowns of the scattered pines. Each pine crown is free from contact with that of its nearest neighbor, due to the presence of the intervening hemlocks.

Some idea of the exceptional quality of the trees may be had when it is said that in only two of the plots did the average knot size of the pines reach three quarters of an inch on the first two twelve foot logs. On most of the pines fifty years of age and upward, the first log length of the bole was absolutely free from all limbs. When pine of this sort is compared with pine growing in pure stands, it shows what great influence hemlock has on pine in improving quality.

THE IDEAL STAND

If it is possible to find here and there in a stand of pine and hemlock a pine of perfect quality which has grown entirely surrounded by hemlocks, it is within the range of possibility to assume that with proper management a pine-hemlock stand could be developed in which the trees per acre of each species were so controlled as to numbers and position that there would be many more pines in the stand, each surrounded by hemlocks. Thus each hemlock would multiply its usefulness by serving a pine on each side, while in the present wild stands a hemlock usually has a pine on one side only, and in most cases hemlocks are adjacent to other hemlocks. In other words, it should be possible to increase the amount of pine in a pine-hemlock stand to a point where there will be a maximum yield of pine of the best quality.

A pine-hemlock stand such as that described in the last paragraph is only an ideal, but so is the normal forest. The perfect combination of proper numbers and spacing of trees to the acre could never be attained, but it could be approached. There are considerable areas of land in this region which grow hemlock, and which will continue to do so. The amount of pine mixed with this hemlock is generally small, and is present in the stand by chance rather than design. When the fact is considered that hemlock is growing on sites to which it is well suited, and that pine of excellent quality can be grown with the hemlock, it would seem a paying investment to increase the amount of pine in the mixture.

LIFE HISTORY AND ITS RELATION TO QUALITY

In the pine-hemlock stands examined for this study, the hemlock was always older than the pine. The difference in age might vary from two or three years to as many as twenty-five or thirty. On all the plots taken the ages of the pine and hemlock were compared, and the average difference was found to be seven years. This means that the hemlock was already established on the land when the pine was seeded in, and served to show how such stands originate.

Young hemlock can often be found growing in a pine-hemlock stand as an under story. It may be very young, or it may be as old as twenty-five or thirty years, and stunted by lack of sufficient light. This fact accounts for the variability of the hemlock in age. If the mature stand which is cut contains this young hemlock advance growth, much of it will live, and together with what reproduction comes from seed in the litter, form the new stand. Any pine which enters into the new stand is seeded in from the mature trees in the cut stand, or else from pine on an area adjacent to the cutting. Unless the mature stand is cut in a pine seed year the percentage of pine in the new crop is more than apt to be small, and this is the condition found in practically all existing stands.

The heights of all pine and hemlock of different age classes were plotted on cross section paper, and curves of average height were drawn. Then the average curves for both species were plotted on the same sheet, the hemlock curve being corrected for the average difference in age. These curves (Fig. 8) show that until the age of thirty-six years is reached the pines are not as tall as the hemlocks. The hemlocks do not actually overtop the pines, but so shade them that only the top of the crown receives direct sunlight. Consequently the side branches die while very small, and their death is hastened by the fact that the hemlock is so tolerant of shade as compared with the pine. When the pines once get their crowns above the general level of the hemlock crown canopy the rate of height growth is increased. The early shading of the pines, however, has resulted in killing off the side branches on at least the first fifteen feet of the bole. After the pine crowns have expanded in the full sunlight, the rate of height growth of the hemlocks slows down considerably. As the hemlock continues to grow slowly in height, the upper portion of the pine boles is thoroughly pruned.

Curves of diameter growth were plotted on cross section paper from the cores obtained by boring on each plot. These curves were for growth at the stump, and were corrected for breast height by means of stump taper tables constructed for both pine and hemlock from measurements taken in a mixed stand. The results check well with those for height growth. Pine passes hemlock in height at thirty-six years of age, and in diameter at forty-two years, showing how it responds to an increase in the amount of light received. The slow growth of the pines in diameter during the early age classes, combined with an early dying of the lower side branches, greatly improves the quality of the final yield. When height and diameter growth are accelerated because of the release of the pines from the shade of the hemlocks, each succeeding year's layer of wood is either wholly clear, or marred only by small pencil knots.

YIELD OF PINE IN PINE-HEMLOCK STANDS

In the discussion of the ideal stand it was stated that the number of pine in a managed pine-hemlock stand might be increased so as to contain the maximum number of pine, that is, as many per acre as possible with each pine entirely surrounded by hemlocks. Curves showing the average diameter at breast height and average height of pine at different ages have already been constructed. In order to work out the yield of the ideal or normal number of pine in a mixed stand, it is necessary only to know the number of pine per acre which such a stand should contain at different ages. Such a table could be used in predicting the yield of the pine in any pine-hemlock stand as long as the number of pines per acre did not exceed the normal number given in the table. Whether the stand under consideration contained only a few pine or the normal number would make no difference; the growth of the individual pines would be the same because in either case each pine is a unit completely surrounded by hemlocks.

As a means of finding out the numbers of trees per acre at different ages, crown areas and diagrams were used. The area of each of the plots was known, the area of the pine crown on each plot, and the number of hemlocks. So, for every plot, the area of the pine crown was set down opposite the age, and the average hemlock crown area was determined by dividing the total hemlock crown area by the number of hemlocks on the plot. From the results obtained curves were drawn of crown area over age for both pine and hemlock. These curves showed that the pine crowns pass those of hemlock in area at the age of forty-nine years. This result links up well with the results obtained from the curves of height and diameter growth which were previously given.

From these curves of crown area values were read off at five-year intervals, ranging from twenty through to ninety years. Next, one sixteenth and one quarter acre areas were laid off to scale on paper, and on these were drawn, also to scale, the crowns of an ideal pine-hemlock stand. As many pine as possible were drawn in, with each pine surrounded by hemlocks. This fulfilled the requirement of the ideal stand previously discussed. One sixteenth acre areas were used for the twenty to fifty year age classes, and the one quarter acre areas for age classes fifty to ninety years. Where the pine crowns overtopped the hemlocks under actual field conditions, they were so drawn in the diagrams. When the diagrams were completed, the numbers of trees per acre of pine and hemlock for each age class could be computed by making a count of the crowns on each diagram, and reducing this count to an acre basis. With the number of trees per acre, average diameter at breast height, and average height known for all age classes, the yield per acre can be computed.

While no such ideal stand exists, the effort was made to furnish an idea of how much pine might be expected from one, so as to furnish a comparison with the yield obtainable in a pure pine stand. The growth measurements were all obtained from actual pine-hemlock stands, and the only artificial factor assumed was the number of trees per acre. After making due allowance for partial overtopping by hemlock, the pine's height growth indicates Site II for the stands here considered. Below is the yield table worked out as above described.

This table represents the growth of the maximum number of pines possible in a mixed stand of pine and hemlock, where every pine is surrounded by hemlocks. It should not be used to predict the yield of groups of pine in a hemlock stand, but only of pines growing singly; because the growth rate differs under the two conditions. Nor should it be used in pine-hemlock mixtures which contain more pines per acre than given in the table.

TABLE V. YIELD TABLE FOR PINE AND HEMLOCK
NORTHERN WORCESTER COUNTY, MASSACHUSETTS

SITE II

Age	Average D.B.H.	Trees per Acre	Basal Area	Mean Height	Volume Cu. Ft.	Volume Bd. Ft.
20	3.1″	1025	53	10	....	....
25	3.8″	715	56	16	....	....
30	4.5″	525	58	21	....	....
35	5.2″	400	59	27	920	4,000
40	5.9″	300	61	33	990	4,800
45	6.6″	265	63	40	1362	6,890
50	7.4″	225	67	47	1629	9,090
55	8.4″	190	73	54	1973	11,550
60	9.3″	170	80	60	2353	14,365
65	10.3″	150	87	64	2700	16,950
70	11.2″	135	92	68	3037	19,305
75	12.1″	125	100	71	3405	21,390
80	12.8″	118	105	73	3665	23,350
85	13.3″	113	109	75	3875	24,970
90	13.7″	109	112	78	4110	26,530

PINE AND HARDWOOD TYPE

FIELD WORK

The pine and hardwood stands used in this study originated on cutover lands, and are consequently even-aged. The type as here considered is confined to the better soils. The best quality of pine is found where it is entirely surrounded by hardwoods of about the same height. For this reason the method of field work used was the same as with the pine-hemlock type; that is, plots were selected consisting of a pine having better hardwoods (transition type) on all sides. On each plot the age, total height, clear length, average knot size, and number of internodes in the first one (or two) twelve-foot log lengths were measured. A hardwood on the plot of seedling or seedling sprout origin was then selected, and its age and height were also determined. These measurements on the plots showed the pine's quality, and its age and height growth as compared with the age and height growth of the neighboring hardwood. In order to obtain a larger number of height growth figures, the height and age of a pine and a better hardwood were found and compared wherever two such trees occurred side by side. No quality measurements were taken on the pine in such cases.

FORM AND COMPOSITION

During the first twenty years of the life of a pine-hardwood stand, the hardwoods grow much faster in height than the pine. In this period many of the pine which originally formed a part of the stand are overtopped and killed. By the time the age of thirty years is reached the remaining pine have increased their rate of height growth and are rapidly overtaking the hardwoods. At the age of about forty-five years the pine passes the hardwoods in height and from then on is slightly in the lead. The hardwoods are mainly of sprout or seedling sprout origin, and this fact largely accounts for their vigorous height growth during the early life of the stand.

The composition of the pine-hardwood type shows great variation, not only in different stands, but at different periods in the life of a single stand. The percentage of pine in any young mixture varies with the past history of the land, and the character of the surrounding forest. The percentage of pine which will survive in any young stand containing a given amount at the beginning depends mainly upon the character of the soil, and the origin and abundance of the hardwoods with which it has to compete. The better hardwoods in the type are chiefly red oak, white ash, hard maple, black birch, and paper birch. Red maple is always present in varying quantities. In the young age classes other inferior species such as gray birch and pin cherry are usually present, but these seldom survive.

knots to be found in pure pine, pine and hemlock, and pine and hardwoods. The 40 to 50 year age class is used because all stands studied at the age had an average clear length greater than two twelve-foot logs. According to observations made in the field, there are an average of five limbs put forth in each yearly whorl of the tree. Therefore this table shows in general the number of nodes in the first two twelve-foot logs of each of the different types, or the number of knots which will be found in any board sawed from these logs. It must be borne in mind in this connection that the limbs of pure pine and pine in hardwood almost always extend out through the bark, while in pine and hemlock this is not always the case.

TABLE VI. NUMBER OF NODES IN THE FIRST TWO TWELVE-FOOT LOGS

By Types

Based on 6525 trees

Age	Pure Pine Site I	Pure Pine Site II	Pine and Hemlock Site II	Pine and Hardwoods Site I
40–50	17	19	26	20

Tables VII, VIII, IX, and X show a general comparison among the three types.

TABLE VII. HEIGHT TO FIRST GREEN LIMB IN FEET

By Types

Based on 159 plots

Age	Pure Pine Site I	Pure Pine Site II	Pine and Hemlock Site II	Pine and Hardwoods Site I
20–30	21′	12′	11′	10′
30–40	27′	18′	15′	15′
40–50	35′	27′	24′	25′
50–60	45′	42′	32′	33′
60–70	51′	42′	30′	45′
70–80	64′	..	36′	..
80–90	..	..	41′	..

TABLE VIII. AVERAGE KNOT SIZES IN INCHES

By Types

Based on 159 Plots

Age	Pure Pine Site I and II		Pine and Hemlock Site II		Pine and Hardwoods Site I	
20–30	.55″	12′ log	.3″	12′ log	.41″	12′ log
30–40	.90″	24′ "	.32″	12′ "	.44″	12′ "
40–50	1.00″	24′ "	.50″	24′ "	.55″	24′ "
50–60	.95″	24′ "	.40″	24′ "	.60″	24′ "
60–70	1.20″	24′ "	.32″	24′ "	.64″	24′ "
70–80	1.00″	24′ "	.42″	24′ "	....	
80–90	....		.55″	24′ "	....	

TABLE IX. DIAMETER GROWTH AT BREAST HEIGHT

By Types

Based on Dominant Trees on 120 Plots

Age	Pure Pine Site I	Pure Pine Site II	Pine and Hemlock Site II
20	3.5″	3.2″	3.1″
25	4.3″	3.9″	3.8″
30	5.3″	4.7″	4.5″
35	6.3″	5.7″	5.2″
40	7.3″	6.8″	5.9″
45	8.1″	7.9″	6.6″
50	8.9″	9.0″	7.4″
55	9.6″	9.8″	8.4″
60	10.3″	10.8″	9.3″
65	11.0″	11.5″	10.2″
70	11.5″	12.1″	11.2″
75	....	....	11.9″
80	....	....	12.7″
85	....	....	13.3″
90	....	....	13.9″

TABLE X. HEIGHT GROWTH

By Types

Based on 300 Trees

Age	Pure Pine Site I	Pure Pine Site II	Pine and Hemlock Site II	Pine and Hardwoods Site I
20	25′	21′	10′	17′
25	32′	27′	16′	24′
30	40′	34′	21′	30′
35	48′	41′	27′	37′
40	55′	47′	33′	44′
45	61′	53′	40′	50′
50	65′	58′	47′	57′
55	70′	63′	54′	63′
60	75′	67′	60′	69′
65	79′	72′	64′	75′
70	82′	76′	68′	82′
75	..	..	71′	..
80	..	..	73′	..
85	..	..	75′	..
90	..	..	78′	..

FIG. 1. WHITE PINE STAND FULLY STOCKED
Showing straight stems and small knots
Photographed by A. C. Cline

Fig. 2. WHITE PINE STAND POORLY STOCKED
Showing crooked stems and large, persistent branches
Photographed by A. C. Cline

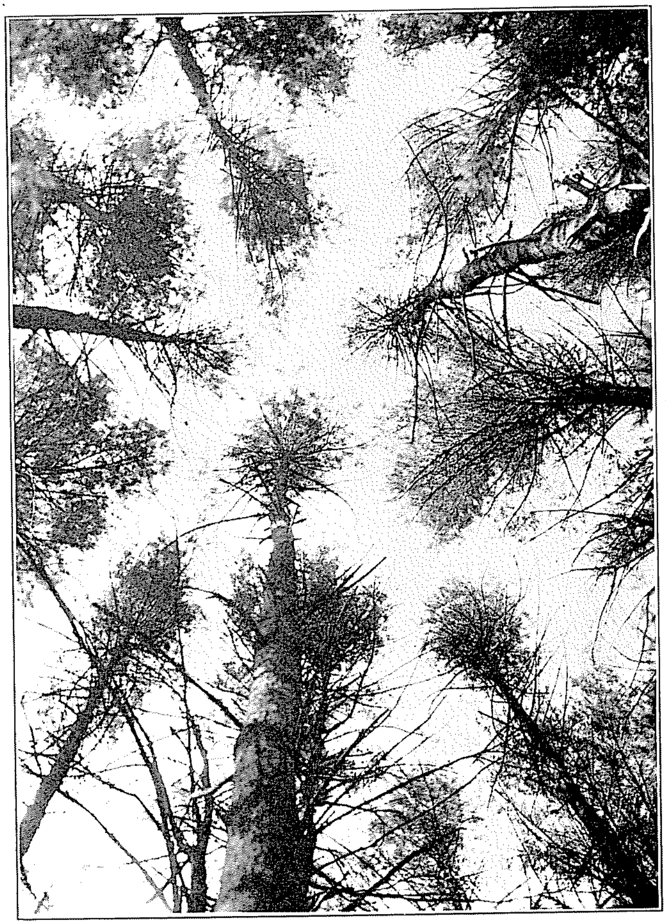

Fig. 3. CROWN FRICTION

Showing the effect of wind upon the crowns of a pure Pine stand which is now 60–70 years old and 70–75 feet high. Site I

Photographed by A. C. Cline

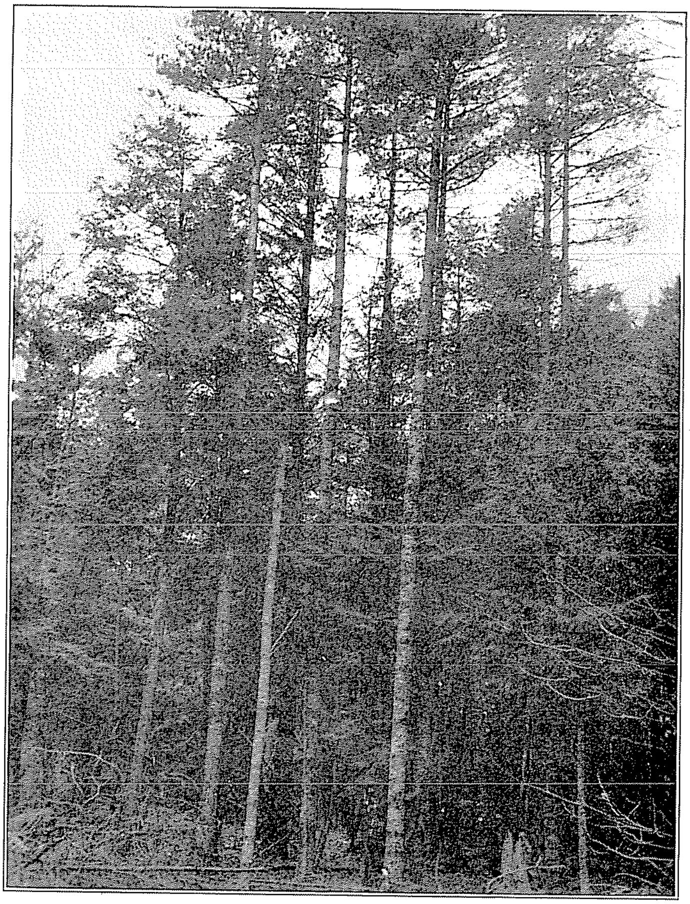

Fig. 4. TWO-STORIED STAND OF PINE AND HEMLOCK
The heavy shade of the Hemlocks kills off the side branches of the more intolerant Pine and improves its grade
Photographed by A. C. Cline

FIG. 5. PINE GROWING AMONG HARDWOODS
In an untreated stand many Pines die as compared with the number that survive
Photographed by E. E. Tarbox

FIG. 6. PINES OVERTOPPED AND KILLED IN AN UNTREATED PINE-HARDWOOD STAND

This lot was cut during a pine seed year

Photographed by E. E. Tarbox

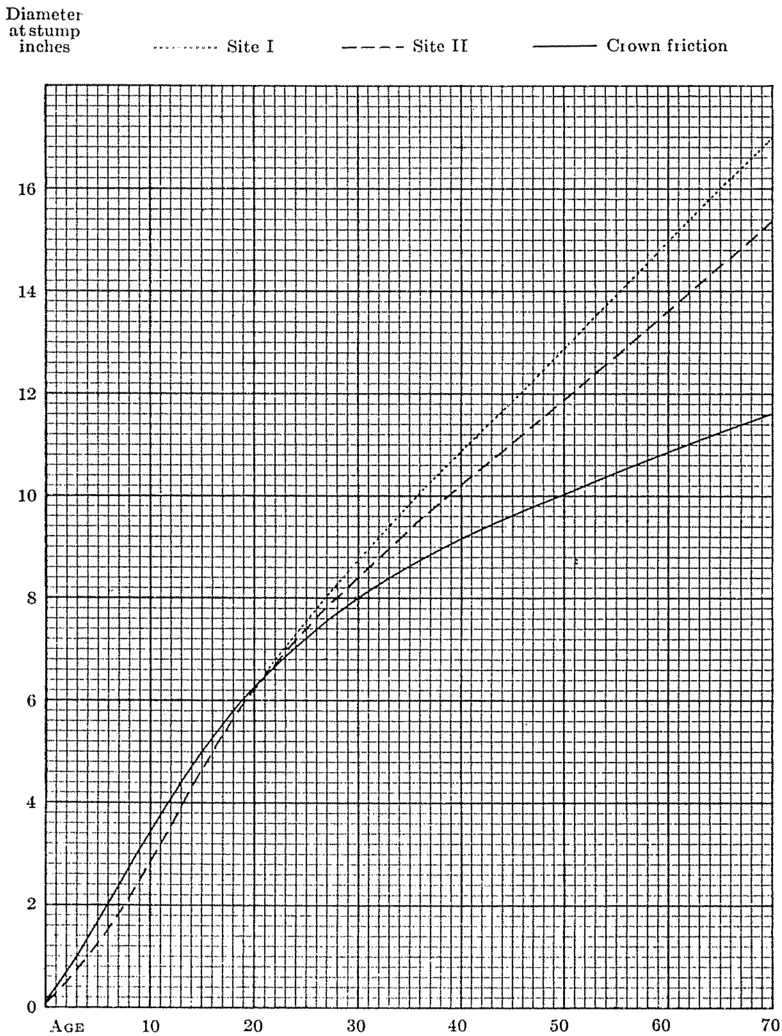

Fig. 7. EVEN-AGED PURE WHITE PINE
Showing the effect of crown friction on diameter growth
in densely stocked site I stands

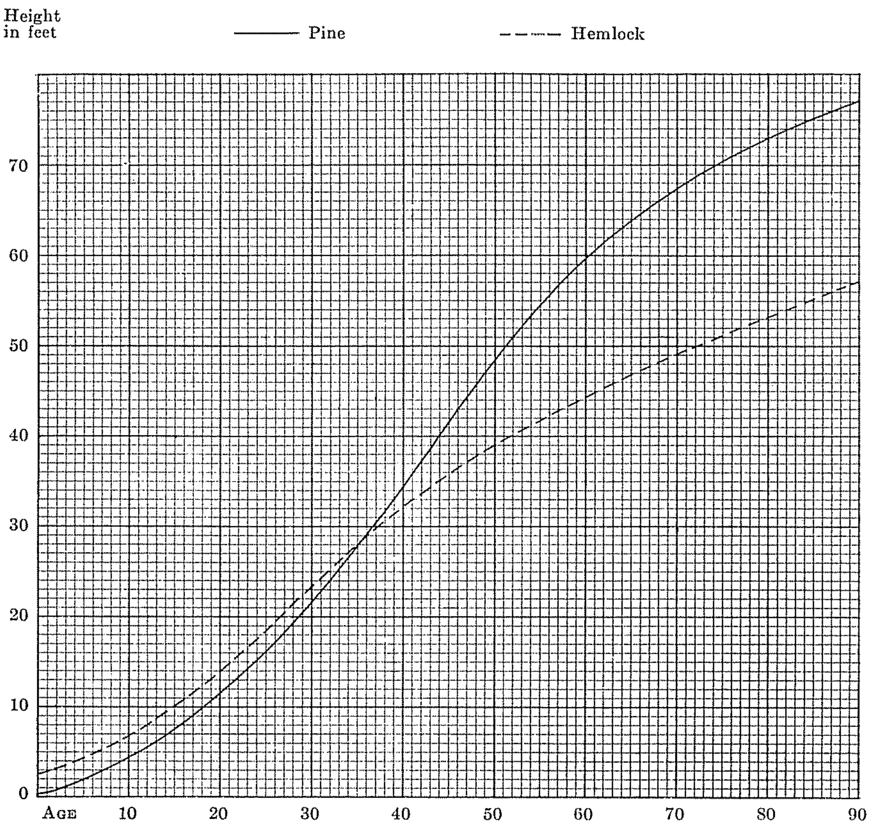

Fig. 8. HEIGHT ON AGE MIXED PINE AND HEMLOCK
Hemlock averages about seven years older than pine. Site II