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THE GROWTH OF HEMLOCK BEFORE AND AFTER RELEASE FROM SUPPRESSION

BY

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INTRODUCTION

In the autumn of 1924 the Harvard Forest marked for cutting a lot owned by the New England Box Company which contained a stand unusual in northern Massachusetts. It was composed of dense, almost pure, white pine and hemlock with very little ground cover or advance growth hardwood. The composition ranged from pure hemlock to nearly pure pine. But of special interest was the fact that the entire area was thickly sprinkled with old pine stumps which clearly testified that years before a heavy softwood cut had been made on the same area. Now as a general rule the forests which have followed nineteenth century softwood logging operations have resulted both in a conversion and a marked deterioration of type. But here softwood had followed softwood, and furthermore the new stand had both a large volume and excellent form. What was the history which had caused this anomaly?

It was in answer to this question that the present study was undertaken. Almost as soon as the first hemlocks had been felled, it was noticed that at the center of every stump there was a core of wood from one to five inches in diameter which frequently had taken one hundred or more years to grow. At the outside of this core there was a very abrupt change in growth rate, and for a period of years rings from one-eighth to one-fourth of an inch thick were found. Coinciding in point of time with this acceleration in growth were old scars, evidently caused by logging. The obvious explanation was that a previous stand had been cut, and the consequent infusion of light had released the long stunted hemlocks from suppression.

Fig. 1. BUTT CUT ON 188 YEAR OLD HEMLOCK SHOWING RATE OF GROWTH BEFORE AND AFTER RELEASE FROM SUPPRESSION

It took 108 years to grow three inches in diameter while under suppression (see location of knife), and after release only eighty years to grow to the present diameter of twenty inches. An old logging scar may be seen near the knife handle. Checks are due to the drying out of the log.

Photograph by A. C. Cline

As the work on the history of the old operation progressed, an interesting correlation with rainfall was apparent. Certain characteristic differences in the response of hemlock to the release also were noted. These matters were deemed worthy of further analysis, and consequently it was determined to broaden the scope of the study and consider the general subject of the growth of released hemlock in northern Massachusetts.

The conclusions reached in this report are based on an analysis of 784 hemlocks located in twenty-six different stands. About sixty per cent of the trees were examined on the stump, while the remainder were studied by increment borings at stump height, considered as nine inches. All but one of the stands were located in northern Worcester County, Massachusetts. This single exception was in Potter County, Pennsylvania, where thirty hemlocks were bored. Their characteristics were apparently similar to those of the Massachusetts trees. The results of this study should be considered of local significance, at least until such time as further research may prove them to be of wider applicability.

I desire to express my deep gratitude to several people for their help and coöperation. Professor R. T. Fisher suggested the study, has given much valuable advice in regard to the presentation of the material, and has made numerous improvements in the manuscript. Mr. A. C. Cline has given many helpful suggestions and much encouragement. To Mr. P. R. Gast I am especially indebted for aiding me to interpret some biological facts, and for teaching me the application of the statistical method to the data collected. I am also much obliged to Messrs. Arthur Davis, Fred Goulet, and Otis Goulet for their coöperation while felling timber. It was necessary to study the stumps on several sample plots while the timber was being cut. The three choppers went to considerable trouble to avoid dropping trees on me while I was engaged in this work.

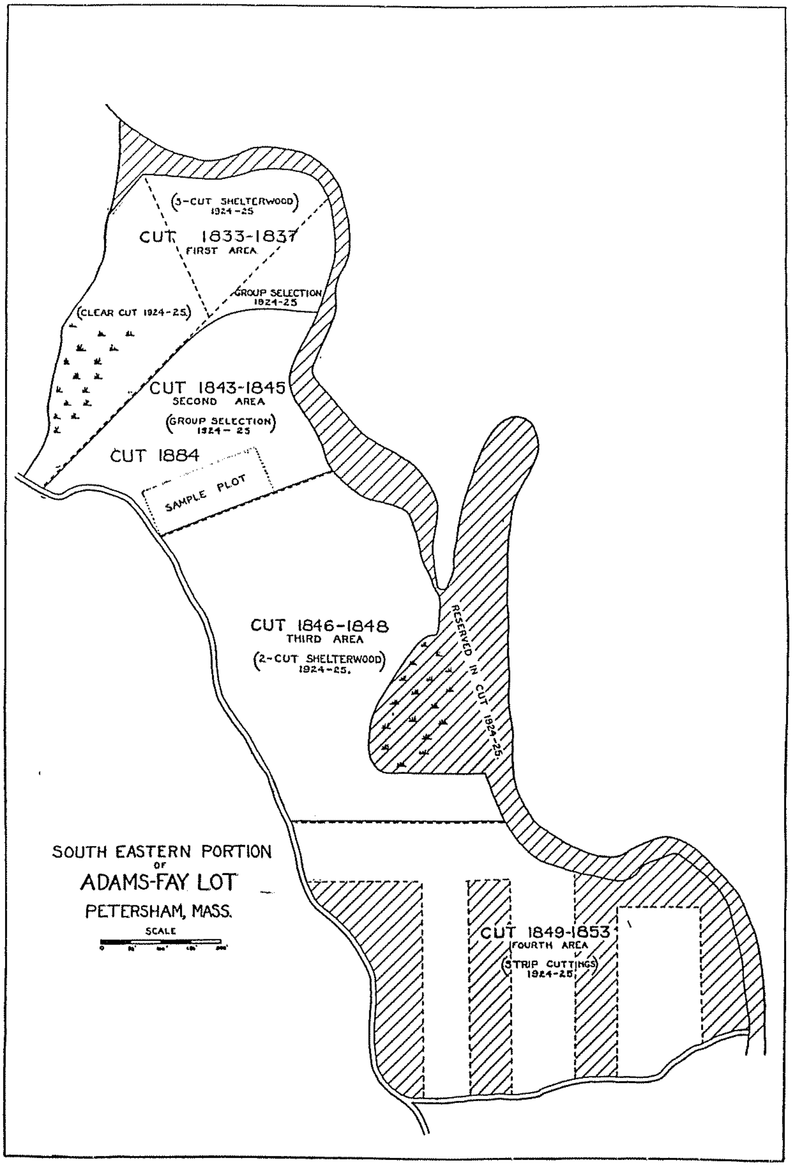

Fig. 2. A SKETCH MAP OF THE SOUTHERN PART OF THE ADAMS-FAY LOT SHOWING THE LOCATION OF THE OLD CUTTINGS DATING FROM 1833 TO 1853 AND ALSO THE RECENT CUTTING MADE BY THE HARVARD FOREST

HISTORY OF TYPICAL HEMLOCK STANDS ON THE ADAMS-FAY LOT

THE history here considered commenced 272 years ago, at the time of the inception of the oldest element in the stand of 1924. In 1652, a year before Cromwell became Lord Protector of England, and thirty years before William Penn crossed the Atlantic, a hemlock seed germinated in the dense shade of the virgin forest and a tree commenced its long life of suppression. The history of the stand previous to 1822 can only be conjectured. The forest probably consisted principally of white pine, with considerable hemlock, and a sprinkling of chestnut, beech, yellow birch, and red oak. It was no doubt autochthonous in character. When one element dropped out, either the surrounding trees seeded in the spot or advance growth reproduction replaced the dead tree. But only the most shade-tolerant species could possibly survive with the slight amount of light which penetrated the canopy. Therefore, the understory consisted chiefly of that extremely shade-enduring species, hemlock, which, though it grew on the average about an inch in a century, was nevertheless able to maintain life. It was only when some natural catastrophe made a small opening in the forest that the trees had an opportunity to grow to a large size. No doubt the majority died after years of stunted existence. Frequently in larger openings the less tolerant white pine would seed in and overtake the slower growing hemlock. Then another period of suppression would ensue.

Aside from natural openings, it is doubtful if there was any break in the canopy of the old forest until about 100 years ago. In 1822, ninety years after the first settlement in Petersham, choice trees were felled in nine or ten different localities. This is indicated by the fact that in exactly the same year trees scattered throughout the area show signs of accelerated growth. Windfall might be assumed to be the cause, but there is no evidence of it on the ground.

Fig. 3. THE FIRST AREA ON THE ADAMS-FAY LOT

This area had been cut lightly in 1833–1837, leaving a dense growth of suppressed hemlock saplings. Hemlock predominates in the present hemlock-pine mixture.

Photograph by P. R. Gast

Systematic logging of the area commenced in 1833 and culminated in 1854. It can be followed step by step through the record of recovery from suppression which is written plainly in the centers of the old hemlocks. The cutting began in the northern end of the lot and by 1837 about 2½ acres had been lumbered. For these five years there is a steady record of progression, but following 1837 comes an abrupt break and no further indication of cutting until 1843. This five year hiatus checks up perfectly with the economic history of the country. Following the panic of 1837 business throughout the nation was greatly retarded for half a dozen years, and prices were so low that many industries suspended activities altogether. It is safe to assume that the operator of the Adams-Fay Lot was one of those who, unable to find a market for their product, ceased to produce it for a period.

By 1843 the effects of the panic had almost disappeared in the new boom of prosperity, and so the lumbering of the Adams-Fay Lot was resumed where it had been abandoned. However, for three years the cutting was lighter than at any other time during the operation. As a result, over half the area was left covered with groups of thrifty pines. In 1846 the logging assumed a more severe character. Three years later everything down to six inches in diameter appears to have been either harvested or destroyed, while the greater part of the hemlock understory was killed. By 1853 the south end of the lot was reached, and the next year the quarter-century old operation was completed with the removal of scattered merchantable trees which were still left standing throughout the area.

By this time the method used in logging was to clearcut all the merchantable material, the severity of lumbering varying with the market conditions. The insignificant hemlock understory which was all that remained on most of the area was never considered. The many scars from the old logging which show plainly in the hearts of the present trees tell clearly that the old lumbermen regarded them

Fig. 4. THE PORTION OF THE SECOND AREA ON THE ADAMS-FAY LOT WHICH WAS CUT IN 1843–1845

The present stand had its origin in the suppressed hemlocks released by the cutting of 1843–1845.
This photograph was taken just after marking for a group selection cutting in 1924.

Photograph by P. R. Gast

simply as bothersome brush. In one place on the north end the course of the old skid road can still be traced by the marks where the little trees had been barked eighty years before. Today these hemlocks constitute the major part of an excellent stand. Truly, "the stone which the builders rejected is become the chief cornerstone."

For a quarter of a century the lot was undisturbed by man, and grew so rapidly that another harvest was made in 1884. The felling was carried on in that stand cut between 1843 and 1845, the one which had been lumbered most lightly in the first operation. According to the sawyer a yield of about 20,000 board feet per acre was obtained, consisting entirely of white pine. The result of this operation, like the earlier one, was greatly to stimulate growth in the remaining trees.

For forty years nothing was done to the lot save the occasional removal of a dead tree for fuel. In the fall of 1924 a one hundred per cent cruise was made. Decided differences in composition were found which divided the lot into four distinct areas. (See Fig. 2.)

The first, which ninety years before had been cut relatively lightly and left with a dense growth of small hemlock, in 1924 contained a mixture of hemlock and white pine, with the former greatly predominating in volume. Both species were of high quality.

On the second area, groups of almost merchantable pine were left in the cutting of 1843–1845. When these were cut in 1884 the tendency toward a group selection form was accentuated. As a result, the almost pure hemlock stand of 1924 contained two sharply defined divisions. The one had its origin in the suppressed hemlocks released from 1843 to 1845, the other in the understory which recovered after the operation of 1884.

The third area, which had a less dense understory of hemlock, was cut over more heavily. Consequently much white pine seeded in, and by 1924 it contained a fairly uniform mixture of white pine and hemlock.

Fig. 5. THE THIRD AREA ON THE ADAMS-FAY LOT

The present stand, photographed just after marking for a shelterwood cutting, is a fairly uniform mixture of white pine and hemlock, resulting from the cutting of 1846–1848, in which a thin understory of hemlock was left. Owing to the severity of the cutting, pine seeded in and now forms the bulk of the stand.

Photograph by P. R. Gast

The fourth area, which had been very heavily logged seventy years before, destroying most of the hemlock reproduction, in 1924 had an overstory of almost pure white pine. Underneath the main canopy was a subordinate stand of hemlock which had started about the same time as the dominant trees. These formed a very minor part of the merchantable material.

Table 1, worked up from the cruise data, shows the volume of the hemlock and pine by stands in 1924. Only trees five inches and more in diameter are included in this total. In addition to the two major species there was a sprinkling of soft maple, yellow and black birch, chestnut, beech and red oak.

TABLE 1

STAND VOLUMES ON THE FOUR AREAS OF THE ADAMS-FAY LOT

Date of Original Cut	Area Acres	Volume per Acre in Bd. Ft. Hemlock	Pine	Total
1833–1837	2.49	19.5M	7.5M	27.0M
1843–1845	2.63	15.5M	2.5M	18.0M
1846–1848	2.96	10.0M	16.0M	26.0M
1849–1853	4.43	4.0M	24.5M	28.5M

The hemlocks on the Adams-Fay Lot were between 70 and 272 years old. The larger trees had undergone a period of suppression varying from 20 to 175 years. The pine had all seeded in at the time of the first cut or later, so none was over 100 years old. The same was true of the hardwoods, except for a half dozen beeches, red oaks, and chestnuts, which ranged up to 150 years in age. Despite its earlier start the hemlock, on the whole, was smaller than the pine, but of much better quality.

Scattered throughout the Northeast are countless sites which have been seriously injured by logging. That the productivity of the Adams-Fay Lot did not deteriorate may be primarily attributed to two factors. The first, which is beyond the control of man, is the soil, which is so light and sandy as to preclude serious competition from hardwoods.

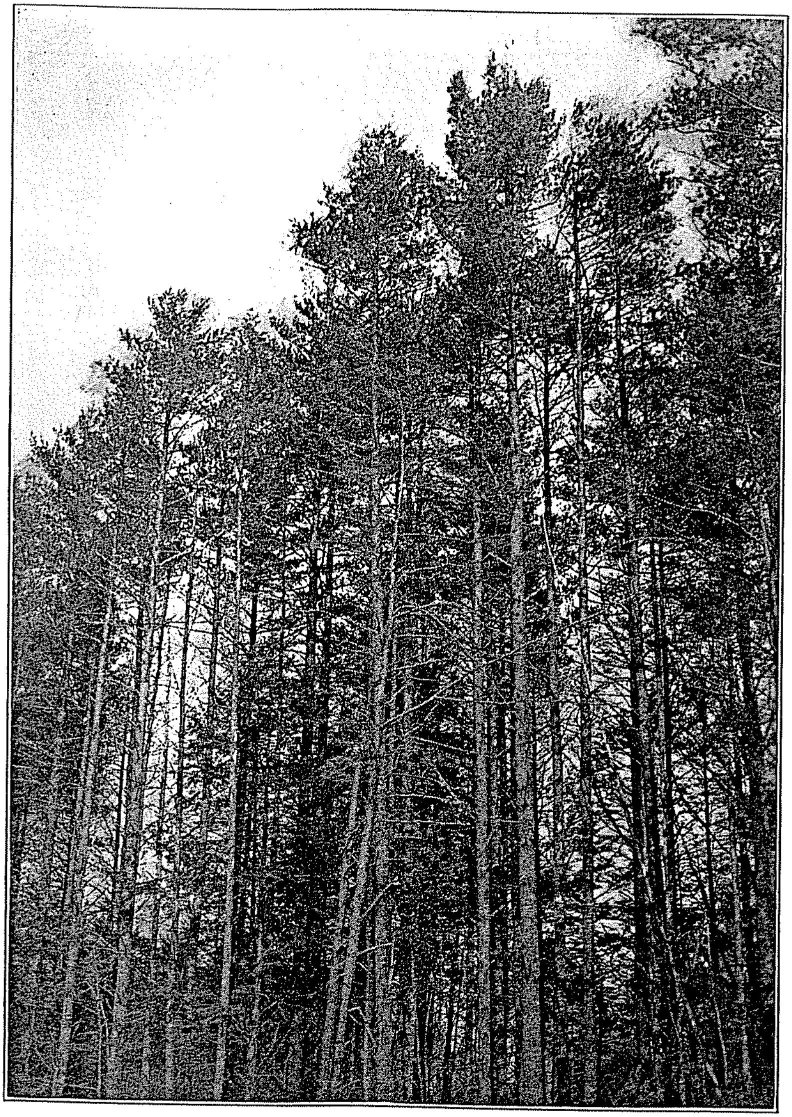

FIG. 6. THE FOURTH AREA ON THE ADAMS-FAY LOT

The present two-storied stand of pine over hemlock resulted from the severe cutting of 1849-1853 in which most of the hemlock reproduction was destroyed and the area made suitable for the seeding in of pine.

Photograph by A. C. Cline

On heavy lands the advance growth hardwood which is commonly present under old stands, takes possession of the site as soon as the mature crop is cut and chokes out any coniferous reproduction.[1] The second factor which helped to produce such an excellent new crop was controllable by man. In contrast to present-day operations the early logging on the Adams-Fay Lot left a good stocking of young growth, which not only formed the basis of an excellent future stand, but also guarded the soil from deterioration. The history of the stand shows, first, that suppressed hemlock will recover to make rapid growth and a high grade of lumber; and second, that the key to successful silviculture on light, sandy soils lies in the maintenance of a protective cover.

EFFECT OF SUPPRESSION AND RELEASE ON HEMLOCK GROWTH

Comparison of Growth before and after Release

The common method of determining how well a tree recovers after being released from suppression is to find the ratio which exists between the growth before and after this release. However, it is not enough to consider the growth for one season or even one decade. A considerable span of years should be selected so that the effect of an abnormally dry or wet period immediately following the cutting will not impair the value of the data. Furthermore, by taking a long period it will be easier to determine what the real benefit of the liberation has been, since trees which make sensational growth for a few years and then decline rapidly will be given their permanent recovery value. In this study the average growth for four decades before and six decades after release has been determined. The basis for the figures obtained included 326 trees on 21 different areas. The results are shown in Table 2.

TABLE 2

BREAST HEIGHT DIAMETER GROWTH OF HEMLOCK BEFORE AND AFTER RELEASE

Growth Period	Decadal Breast Height Increment in Inches
31–40 years before release	.46
21–30 " " "	.34
11–20 " " "	.26
1–10 " " "	.24
1–10 " after "	2.12
11–20 " " "	1.94
21–30 " " "	1.66
31–40 " " "	1.36
41–50 " " "	1.08
51–60 " " "	.86

Total growth for forty years before release	1.30 inches
Total growth for forty years after release	7.08 inches
Ratio between growth before and after release	1–5½

Measurements in the field were made at stump height, and were then converted to a breast height basis by multiplying them with the ratio between breast height and stump diameters inside bark. Breast height diameters inside bark were calculated with the aid of Merrill and Hawley's table of average bark thickness.[2]

The increments before release show a steady decrease due to the increasing density of the suppressing overstory and the normal effect of age. After liberation there is also a regular decrease due to senility, and in certain cases a second suppression or a too dense stocking. A second release or a thinning would increase the growth rate, although it scarcely could reach the peak attained after the original cutting.

The average ratio between increments for forty years before and after the release of the hemlock is as 1 is to 5½. In other words a tree which had grown one inch in diameter for forty years before the overstory shading it was removed would be expected to increase 5½ inches during the next four decades. Merrill and Hawley[3] studying the effect of the cutting of a hardwood overstory on hemlock growth, found that the rate of growth after liberation was increased 2½ times. In the present study, however, white pine invariably formed the overstory. Due to the denser shade which it provided, it was natural that a greater recovery occurred when it was removed.

One result of the big increase in growth following releasing is to make it almost impossible to determine the relative age of hemlock by its diameter. As Frothingham[4] has remarked, trees of the same diameter may differ in age by more than a century. Very frequently the more aged tree is the smaller one. A 120 year old tree, suppressed forty years and free to grow eighty years, would have a diameter of twelve inches, using the ratio previously given in terms of inches. On the other hand, a 150 year old tree, suppressed 110 years, would have a diameter of only 8¼ inches. The example just cited is by no means unusual, and any number of similar instances were actually found. As an extreme case, a 272 year old tree was only 10 inches in diameter at breast height, while sixty feet away was an 18 inch, 100 year old specimen. Table 3 indicates the relationship between diameter and age among all the hemlocks on a 0.4 acre sample plot.

TABLE 3

RELATION BETWEEN DIAMETER GROWTH AND AGE IN HEMLOCK

D. B. H. Inches	No. Trees	Average Age	Maximum Age	Minimum Age
2	11	65	94	50
3	4	77	84	68
4	4	100	150	78
5	5	96	105	84
6	4	97	112	88
7	3	106	134	85
8	10	107	139	94
9	10	117	150	93
10	9	126	149	94
11	7	129	148	94
12	7	129	162	95
13	5	112	146	94
14	6	125	153	94
15	4	122	136	106
16	5	128	150	104
17	1	139	139	139
18	1	100	100	100
19	1	120	120	120
20	1	160	160	160
21	1	165	165	165

While there is in general a rising trend in age with increasing diameters, it would be impossible to predict the age of a given tree knowing only its girth. The mere fact that a fourteen inch tree is as young as a two inch one, and a nineteen inch tree younger than a four inch one indicates the absolute lack of correlation between age and diameter in trees which have been suppressed.

Height growth of hemlock was studied by age counts at the end of each log in forty trees. In addition, the ages of 100 suppressed seedlings under four feet in height were determined. These measurements were then plotted and curved, and the following table of average height growth by age was prepared.

TABLE 4

RELATION BETWEEN HEIGHT GROWTH AND AGE BEFORE AND AFTER RELEASE FROM SUPPRESSION

Age	Height	Age	Height	Age	Height
5	2″	35	4½′	80	49′
7	3″	40	6′	85	51′
9	4″	45	12′	90	53′
11	5″	50	18′	95	55′
13	7″	55	25′	100	57′
15	9″	60	31′	105	59′
20	15″	65	37′	110	61′
25	2′	70	42′	115	62′
30	3′	75	46′	120	63′

The average age of release was forty years.
The average annual growth for the first forty years was 0.15 feet.
The average annual growth for the second forty years was 1.08 feet.
The average annual growth for the third forty years was 0.35 feet.

Volume growth before and after release was not determined, due partly to the fact that the height growth figures were not considered to have a strong enough basis. Furthermore, although released trees grow very rapidly near the butt, they usually show little or no increase in the upper portion of the trunks.[5, 6] Hence it would be necessary to procure measurements on form change before any conclusions could be reached in regard to volume change. Even if such figures were obtained they would only have a limited application to trees which had not undergone a similar degree of suppression.

Factors Which Affect Recovery after Release

Density of Stand

Great variations were found in the degree of recovery of hemlock following release, and several factors seemed to have an important effect on the rate of acceleration. Where the removal of the suppressing overstory was complete, as it generally was, the one factor which appeared to have the greatest influence was the density of stocking of the released trees. To bring out this point, the stands studied were divided into two groups: those with more than 150 trees per acre and those with less than 50. Table 5 shows the ratio of growth for forty years after release as against growth for forty years before release for stands in each of these groups.

TABLE 5

EFFECT OF DENSITY ON THE ACCELERATION OF GROWTH AFTER RELEASE

	Stands with more than 150 trees per acre	Stands with less than 50 trees per acre
	Ratio	*Ratio*
	12 –1	5½–1
	8½–1	4½–1
	7½–1	4½–1
	7 –1	4½–1
	6½–1	4½–1
	6½–1	4 –1
	6½–1	4 –1
	5½–1	4 –1
	4 –1	4 –1
	4 –1	4 –1
		3 –1
Average,	6¾–1	4¼–1

Table 5 demonstrates that the well stocked group exhibited a sixty per cent better recovery than the sparsely stocked one. This in itself is suggestive enough, but even more striking is the fact that with two exceptions every stand in the former group was ahead of the best in the latter. Therefore, it seems clear that not only does a good stocking bring improved quantity and quality for the stand as a whole, but it also results in an increased growth in the individual trees.

There are several causes for this. In the first place a dense stand of hemlock excludes most of the less tolerant and more rapidly growing pine and hardwoods which otherwise would seed in and compete with the hemlock. Furthermore, the thick hemlock growth left after logging protects the soil. The close stocking also means that growth after release will be concentrated in the main stem rather than in limbwood. Consequently it seems but natural that well stocked stands should show a better recovery after release than the poorly stocked ones.

Rainfall

It was thought that trees released just before a very dry or a very wet period might show a subnormal or supernormal recovery. However, upon investigation it was apparent that the effect of rainfall in the decade following release was of only minor importance upon the forty year recovery ratio. However, in cases of well-defined drought following the release there was a definite falling off in recovery. The two cases mentioned in the preceding section where densely stocked stands did not show better recovery than the best sparse stands occurred when the liberation was followed by an unusually dry decade. Of course an abnormally wet decade right after liberation resulted in an unusual growth increase for the first ten years, but over the forty year period this advantage was lost. In Table 6 the dense and sparse groups have been divided up into three classes according to the average annual rainfall in the decade following release. A perusal of the table will substantiate the facts mentioned above.

TABLE 6

EFFECT OF RAINFALL ON THE ACCELERATION OF GROWTH FOR FIRST TEN YEARS AFTER RELEASE

Average Annual Rainfall in Decade Following Release		Dense Stocking No. Stands	Dense Stocking Ave. Ratio	Sparse Stocking No. Stands	Sparse Stocking Ave. Ratio
45″+	(Supernormal)	2	6½–1	7	4½–1
42″–45″	(Average)	6	8 –1	3	4 –1
42″–	(Subnormal)	2	4 –1	1	3 –1

Age of Tree Released

For a given diameter it was found that within certain limits the older the tree the greater was the response to the releasing. There is a time when a tree becomes so stunted by long suppression that it will respond but poorly when the overwood is removed. Generally speaking, however, the reverse is true. Table 7 illustrates this point. The figures used were first smoothed graphically.

TABLE 7

EFFECT OF THE AGE AND SIZE OF A SUPPRESSED TREE ON THE DIAMETER INCREMENT EIGHTY YEARS AFTER RELEASE

Diameter When Released	Diameter Increment in Inches at Stump Height Eighty Years after Release				
Age at Time of Release	0–2	2–4	4–6	6–8	8+
11–20	10.82	....	....	....	....
21–30	12.14	....	....	....	....
31–40	13.25	12.74	....	....	....
41–50	14.16	13.00	10.18	....	....
51–60	14.87	13.24	10.90	....	....
61–70	15.38	13.46	11.52		
71–80	**15.40**	13.66	12.04	10.30	10.32
81–90	14.38	**13.84**	12.46		
91–100	13.14	13.70	12.78	11.54	....
101–110	11.68	13.54	**13.00**		
111–120	....	13.36	12.86	12.28	11.22
121–130	....	13.16	12.58		
131–140	....	....	12.22	**12.40**	....
141–150	....	....	....	11.10	**11.92**
151–160	....	....	....	....	....
161–170	....	....	....	....	11.48
171–180	....	....	....	....	....
Culmination Age....	70	85	105	125	150

A Comparison of Suppressed and Open Grown Hemlocks

It frequently occurs that two trees of about the same age, growing close enough together to experience almost identical environmental conditions, differ only in the amount of suppression which they have undergone. One may have seeded into an opening and grown freely, while the other may have germinated under considerable shade and maintained a stunted existence for a number of decades. It would naturally be expected that the tree which was free to grow would always keep ahead of the other in size, even after the latter had been released. The reverse, however, was generally true of the trees examined.

The growth of sixteen adjacent open grown and suppressed trees is contrasted in Figure 7. It will be noticed in every case that the tree which started more slowly eventually surpassed the other in size. Of course such a result will not always occur. Frequently the open grown tree itself overtops the other and continues to keep it under suppression even after the old stand is cut. Furthermore, the suppressed trees could well be stunted for too long a period to ever make up the handicap. It will be noted in Figure 7 that none underwent a period of more than sixty years suppression. Generally speaking even sixty years appears to be too big a margin to overcome, at least within a reasonable period of time. But when a tree is suppressed for from one to four or five decades it generally succeeds in overtaking its open grown neighbor within forty or fifty years of its release.

In Table 2 the average growth of trees starting life under suppression was given for forty years before and sixty years after release. These figures are again presented in Table 8

TABLE 8

GROWTH OF SUPPRESSED AND OPEN GROWN HEMLOCKS BREAST HEIGHT DIAMETER IN INCHES AT END OF DECADE

Age	Suppressed Trees	Open Grown Trees
10	.46	2.62
20	.80	4.56
30	1.08	5.84
40	1.30	6.86
50	3.42	7.60
60	5.36	8.20
70	7.02	8.60
80	8.38	8.92
90	9.46	9.18
100	10.32	9.38

Basis of the above table: 326 suppressed trees, 215 open grown.

to show diameter at the end of each decade, and are contrasted with average diameter growth figures for 215 unsuppressed trees. The result as plotted in Figure 8 is similar to that obtained in Figure 7, the suppressed trees passing the unsuppressed ones at about the age of 85.

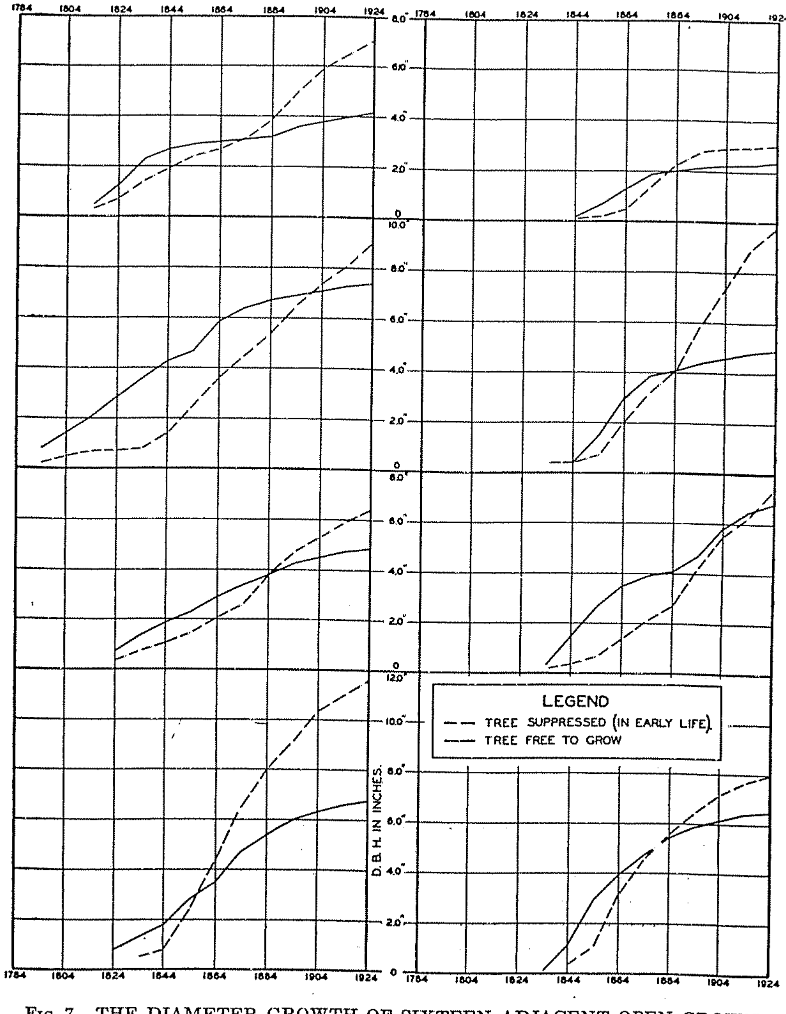

FIG. 7. THE DIAMETER GROWTH OF SIXTEEN ADJACENT OPEN GROWN AND SUPPRESSED TREES

The tree which started more lowly eventually surpassed the other.

It is realized that the data given are not adequate to conclusively prove the point, but they are advanced in the hope of stimulating a more careful investigation.

The causes of the phenomenon discussed above are not at all clear. Competition is one fact which no doubt enters into the answer. When the stand was opened up enough for hemlock to grow unsuppressed there was frequently suffi-

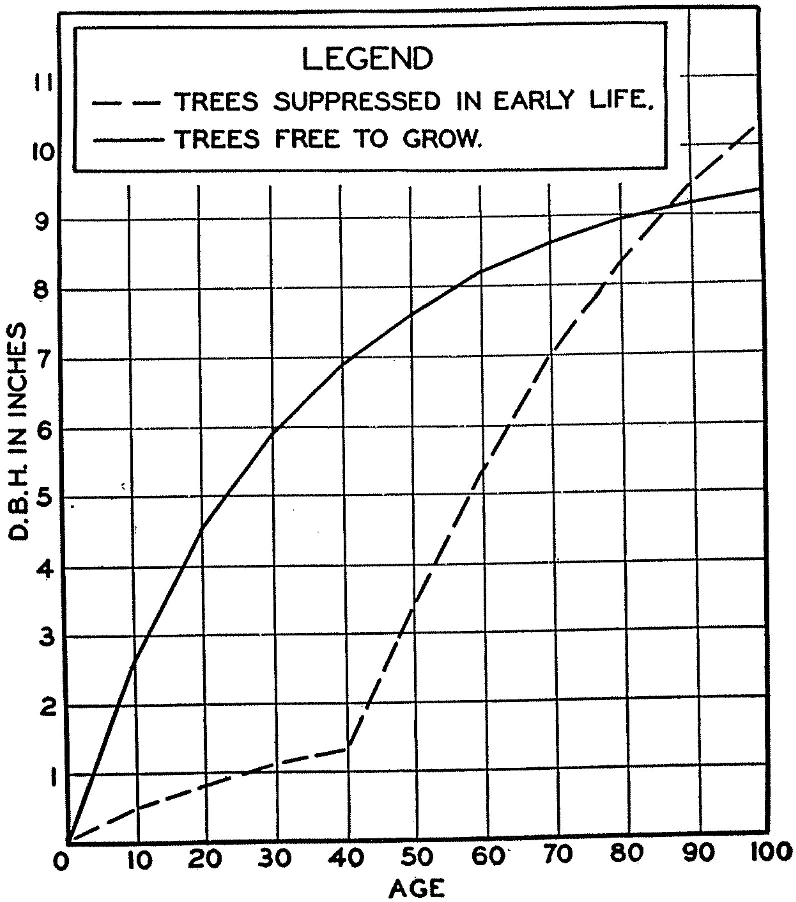

FIG. 8. THE AVERAGE DIAMETER GROWTH OF UNSUPPRESSED TREES CONTRASTED WITH THAT OF TREES WHICH WERE SUPPRESSED FOR 40 YEARS, THEN RELEASED

cient light for pine and hardwoods to start at the same time. Given an equal start, those latter species outgrew hemlock; and if they did not completely suppress it, at least slowed down its growth. Several of the open grown hemlocks were actually found competing with approximately equal aged pine and hardwoods, and this no doubt had considerable effect on the rapid decline in growth.

A second explanation involves the matter of heat and moisture. Hemlock reproduction thrives best in cool, damp sites. This advantage is generally attained when it grows under suppression; but when the seedling starts in an opening its vitality may be seriously impaired both by desiccation and heating.

Gast advances an interesting explanation for the cases in which no pine or hardwood competition has occurred. There is material evidence from the pathology of animal rickets,[7] and etiolation in plants,[8] that irradiation by light, especially of the shorter wave lengths, makes for differentiation of tissue. Maturity and later senility are consequent upon differentiation. It is possible, therefore, that the open grown hemlocks have matured by the influence of the light to which they have been exposed. But the suppressed hemlocks which have not been so exposed retain a youthful quality which enables them not only to respond readily to the release from suppression, but also to maintain a higher average growth rate than their open grown companions. The ultimate result for a tree starting under suppression is a larger size than is reached by trees continuously exposed to light.

RELATION OF HEMLOCK GROWTH TO METEOROLOGICAL FACTORS

Precipitation

A great deal of discussion has taken place during the past dozen years on the relationship between rainfall and tree growth. Prominent ecologists have differed first as to which method of computing rainfall is most pertinent. Precipitation during the year of growth, precipitation during the preceding year or years, and precipitation during the growing season have all been considered, but no one method has definitely been proven to be the best criterion.[9, 10] Douglass[11] has worked out an equation which gives due weight to the influences in all three periods, but he admits that the derivation of a generally practical formula is still a matter for the future. In this study there has been no endeavor to solve the problem. The primary object has been to determine whether in the long run rainfall has had an appreciable effect on the growth of the hemlocks considered. Annual fluctuations were not deemed to be of special moment, but it was considered important to determine whether one can predict increased or diminished growth as a result of a wet or dry period. Therefore the decadal instead of the annual tree growth and rainfall were computed, and the degree of correlation determined.

But disregarding the method of computing precipitation, ecologists have also differed as to its importance in affecting tree growth. For instance, Huntington[12] believed there was a close correlation between the rainfall of preceding seasons and growth in the big tree, while Antevs[5] asserted that this relationship was not very great. MacDougal[13] has probably summed up the matter as well as existing knowledge permits when he remarks: "It is suggested that the thickness of a woody layer is the resultant of the favorable conjugation of a number of factors in which seasonal relative humidity may be an important factor."

But under what conditions is precipitation of primary importance? Apparently, as Douglass[14] has indicated, under those conditions where there is a tendency to deficiency of soil water. On dry areas moisture is the limiting factor of tree development, and so the curves of precipitation and growth coincide more or less closely. In other words, given two sites, one wet and one dry, it naturally would be expected that growth and precipitation would show a much closer correlation in the latter than in the former case.

Such has indeed been true in this study. Seventeen areas were examined on which the trees had been free to grow for at least half a century. These were divided into two groups. The first, which embraced ten of the areas, consisted of light, sandy, rapidly drained sites, becoming decidedly dry at the surface in time of drought. The second group, with seven areas, consisted of sandy to loamy, relatively poorly drained sites which were not seriously affected by ordinary droughts. Here excess precipitation appeared to be more of a hindrance than a help, partly because it meant less sunlight. The first group had a correlation coefficient between rainfall and radial growth of $.70 \pm .04$. This is considered by statisticians to be a good correlation. The moist site group, on the other hand, had a correlation of $-.06 \pm .09$, which is entirely insignificant, since a zero correlation means that there is absolutely no relationship between two variables.

Figure 9 shows the striking relation between rainfall and growth in the dry site group in a different way. The increments by decades for each of the ten areas in this group have been plotted, one under the other, for the period since the time of release from suppression. It is at once evident that in almost every case there are growth peaks in the decades ending in 1864 and 1894, while in 1884 and 1914 there are distinct depressions. The base curve indicates the total decadal rainfall, and here we note that the two sharp peaks and two distinct depressions coincide in point of time with those in the growth curves. This coincidence is so regular that the effect of rainfall seems unquestionable.

An interesting factor which was noted in this study of dry site hemlocks was the difference of correlation between the crown classes. The suppressed trees had a correlation coefficient of .74; the intermediates .57; the co-dominants

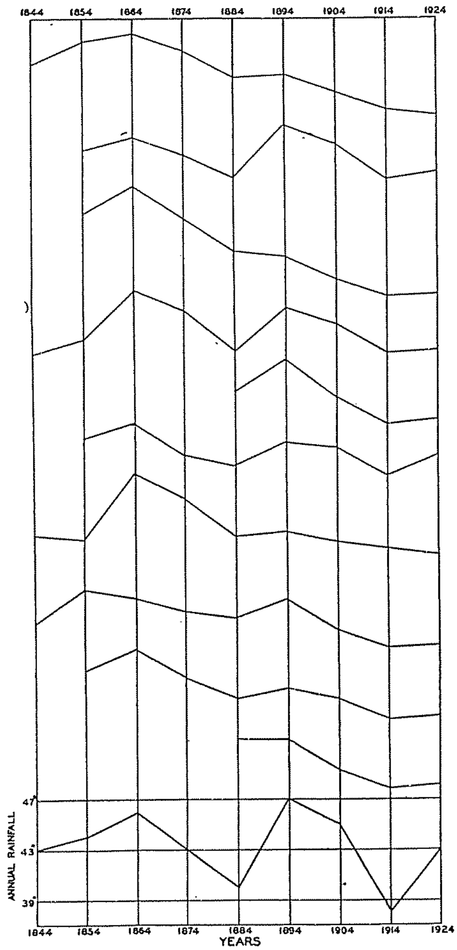

Fig. 9. THE RELATION BETWEEN RAINFALL AND RADIAL GROWTH ON DRY SITES

.49; and the dominants .61. The probable error averaged .04. According to Pearl[15] it is practically a universal custom among biometric workers to regard a difference of three or more times the probable error as almost certainly significant. Thus these differences in correlation appear large enough to demand further consideration.

Theoretically the reason why the most suppressed trees should show the best correlation with rainfall appears to be twofold. In the first place their root systems have the poorest development. They do not penetrate deeply into the soil and consequently any desiccation is readily reflected.

The deep roots of the other crown classes can still obtain water from the lower layers of the soil when drought has so dried the surface that growth in the suppressed trees may be almost inhibited. In the second place the suppressed trees at best maintain a precarious existence. They obtain so little sunlight that a shortage in any of the other necessities of life, as for instance water, is apt to have an extremely deleterious influence. On the other hand, an excess makes the loss of sunlight a trifle less serious. Thus it is probably a combination of poorly developed root systems and scanty light which makes the growth of the suppressed trees coincide most closely with rainfall.

One would naturally expect a steady retrogression in the correlation of the higher crown classes. This is true as regards the intermediates and co-dominants, but the dominants show a correlation second only to that of the suppressed trees. This can be explained in that the effect of suppression has been practically negligible in the lives of the dominants, while among the co-dominants and intermediates it has frequently made the growth quite irregular, for unlike the dominants which have been entirely free to grow and the suppressed trees which have been completely shaded, the degree of suppression among the co-dominants and intermediates has varied throughout their lives.

The close relationship between growth and rainfall is of great importance to the forester. If he does not carefully consider the matter of precipitation, any conclusions which he draws in regard to increment are liable to grave error. A few examples may make this point more clear. If the first cut in a shelterwood operation had been made in 1904, just before the driest decade on record, a forester, examining the reserved trees when they were felled ten years later, would conclude that very little acceleration could be expected as a result of such a system. On the other hand, had a similar silvicultural method been employed immediately preceding a very wet decade like 1885–1894, the deduction would be drawn that a great advantage of the shelterwood method was the phenomenal growth made by the reserved trees. Both ideas of course would be erroneous. A thinning made before a very dry decade would result in little stimulation in growth, and the conclusion might be reached either that the thinning was not heavy enough or that the species under consideration was not responsive. As a matter of fact the normal result of such a silvicultural measure might be an excellent acceleration. Furthermore, mistakes can be readily made in determining the proper time to cut a stand. A person boring into one of the hemlocks on the Adams-Fay Lot in 1884 or 1914 would have assumed that growth was falling off so rapidly that the time for logging was at hand. Yet had any such operation been performed at the former date it would have been a decided mistake, while even at the latter time a ten year wait would have been preferable. Similarly, in collecting data on growth and yield, it is easy to understand how the results might prove almost worthless. Therefore, in order to avoid such errors, it seems important that the forester should consider precipitation in studying growth.

Temperature

Temperature is generally considered to be one of the most important factors affecting growth. Unfortunately no temperature data going back more than twenty years in the vicinity in which this study was conducted are available, and so no correlation can be determined.

Sun Spot Cycles

In 1909 Douglass [16] first called attention to the periodicity in tree growth which corresponds to the periodicity manifested in sun spot maxima and minima. Since that time other men have made further investigations with both positive and negative results.

In this study the annual growth was measured on eight hemlocks growing on a dry, sandy site. The results were plotted as indicated in Figure 10. In order to eliminate the factor of abnormal growth following the releasings of 1844 and 1884, the entire graph was reduced to a common base

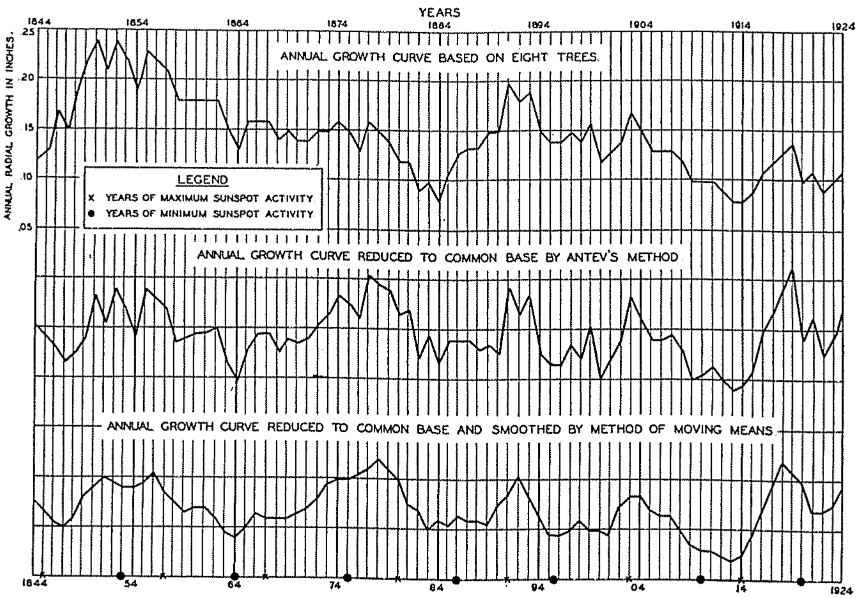

Fig. 10. THE RELATION OF SUN SPOT MAXIMA AND MINIMA TO GROWTH

In the upper graph, measurements of annual radial growth have been plotted directly; in the middle graph they have been reduced to a common base by Antev's method; in the lower graph insignificant fluctuations have been eliminated by using the method of the moving mean.

by the method used by Antevs.[17] Thus the normal downward trend of growth from the time of releasing was eliminated.

Following Douglass [18] this has been smoothed by the method of the moving mean. The mean of the year in question and one year on either side of it was in each case determined and these revised values plotted. The result has been the partial elimination of the minor fluctuations which are of no significance. The sun spot maxima, displaced three years to the left, have been indicated on this graph. This moving of the maxima is exactly what Douglass[19] found it necessary to do with the hemlocks he examined near Windsor, Vermont. The reason for such displacement has not been explained, but it often results in a correlation where otherwise there would be none. It will be noted that five of the seven displaced sun spot minima correspond with troughs in the growth curve. However, only four of the seven maxima appear to coincide with growth maxima. Thus, while a slight relation between sun spot cycles and growth seems evident in these trees, it is not nearly so striking as the rainfall correlation.

SUMMARY OF CHARACTERISTICS OF HEMLOCK GROWTH

It should be recalled that the following summary of characteristics of hemlock growth are based very largely on measurements made in a small region, northern Worcester County, Massachusetts. Hence the results of the study should be considered of regional significance only, at least until further research may prove them to be of wider applicability.

1. Suppressed hemlocks show a remarkable increase in growth when released. An examination of 326 trees showed that the ratio of diameter increment for forty years before and forty years after release was as 1 is to $5\frac{1}{2}$. In other words, a tree which had grown only one inch during forty years of suppression grew five and one-half inches during the forty years following its release.
2. There is little relation between the diameter and age of hemlocks which have been suppressed. Hence it would be impossible to even approximate the age of a given tree knowing only its diameter.
3. The response of hemlock stands to release is influenced by their density, the well stocked stands showing greater acceleration in growth than poorly stocked stands.
4. An abnormally wet or dry decade following the release of hemlock, while greatly affecting the growth during that period, exerts no measurable influence on the growth of the normal years which follow.
5. The length of the period of suppression influences the rate of growth after release. For a given diameter it was found that the older the tree when released, the greater its response to freedom.
6. Other things being equal, hemlocks which started life under suppression, after being released, generally overtook their open grown neighbors. Unsuppressed hemlocks showed a rapid decline in increment, and by eighty years they had almost stagnated.
7. Hemlocks growing on relatively dry sites showed a close relation between decadel increment and decadel precipitation. On the other hand, those found on moist sites showed no relation whatever between growth and precipitation. The correlation coefficient of the former group was $.70 \pm .04$; of the latter, $-.06 \pm .09$.
8. Hemlocks in the suppressed crown class showed the closest correlation of growth with precipitation, having a coefficient of .74. Next in order were the dominants with .61; the intermediates with .57; and the co-dominants with .49.

9. The close relation between tree growth and rainfall on dry sites influences any predictions of future growth which are based purely on a study of past increment. The unsuccessful early results of a thinning may be due entirely to a dry period. For the same reason reserved trees on a reproduction cutting may fail to show accelerated growth. In the use of yield tables the forester should consider that stands may be growing quite differently today from what they did at a similar age during some other phase in the climatic cycle.
10. A weak correlation was noted between culminations in growth and the third year before the year of maximum sun spot activity.

SILVICULTURAL CONCLUSIONS

The Value of Preserving Advance Growth Reproduction

As a result of this study, several conclusions have been reached in regard to the silvicultural treatment of hemlock. The first concerns itself with the handling of advance growth reproduction. In the past it has not been customary to take pains in preserving unmerchantable hemlock at the time of logging. Even among foresters there has been some doubt as to its ability to survive exposure. Frequently the operator has gone out of his way to cut down the suppressed trees which he believed would never amount to anything in order to clear the ground for the next crop. But the facts already presented indicate that a well-stocked stand of released hemlock is capable of making as rapid a growth as any species which could be introduced. Furthermore, the expense of establishing a new stand is eliminated, a small volume of timber already present is thrown in gratis, and a certain amount of protection is afforded the site. Therefore, it would seem that when a good understory of suppressed hemlock exists in a stand about to be cut, good silviculture demands that this hemlock be preserved for the next crop.

On the other hand it frequently occurs that there is only a scattering of suppressed trees in the old stand. It has been shown that sparsely stocked hemlock areas exhibit a lower recovery ratio than the well stocked stands. Furthermore, hemlocks in sparsely stocked stands will spread out and become very limby. Their crowns will take up an area greatly in excess of what is justified by the volume produced, and the quality of the lumber is poor. Therefore, where released trees are very scattered, it generally would not be desirable to save them. However, if the trees are not more than a few feet high, it might be profitable to leave the hemlock and fill the gaps with planted pine. The pine would then outgrow the hemlock and would succeed in getting into the main canopy before it closed. In this event the most beneficial influences of a pine hemlock mixture[20] would be obtained, and the advance growth hemlock would be utilized.

The Need of a Short Rotation for Unsuppressed Hemlock

In Table 8 and Figure 8 the rapid decrease in increment of hemlocks which have never been suppressed is very striking. Obviously it would not be profitable to manage such trees on a long rotation. A definite rotation cannot be prescribed, however, without accurate figures on volume growth, and none are obtainable. Nevertheless, it can safely be said for northern Massachusetts that a tree the diameter increase of which is less than half an inch in a decade is no longer growing rapidly enough to be profitably retained in the stand. According to the table mentioned above, the growth in the seventh decade averages only .4 inches. Therefore, it would appear as if sixty years should generally be considered a maximum rotation in this region for unsuppressed hemlock.

Advantages of Suppressing Hemlock

One of the beneficial results of suppression is reflected in the quality of the tree. The limbs are relatively small, and will be pruned early in life. In the long run the suppressed tree will make better growth than the open grown one. In the third place, suppressed hemlock in a mixture with less tolerant species may serve a very useful purpose as a pruning agent. This has been found to be especially true with white pine.[20] Finally, it is possible by means of overlapping rotations to save much time in growing repeated crops of hemlock timber, since reproduction may be established several decades before the old crop is ripe. The reproduction will become firmly established, put on a certain amount of increment, and be ready to make the best possible growth when the mature overstory is removed.

Advantages of the Group Selection Method

Generally speaking the group selection system appears to be the best silvicultural method of treating pure hemlock stands in this region. On the Adams-Fay Lot it was found that although the group selection area contained the smallest volume of any area on the lot, nevertheless considering the amount of space taken up by the mature timber it really ranked first. Over fifty per cent of the acreage contained unmerchantable material, half a rotation behind the mature trees, and *half a rotation ahead* of any reproduction on the remainder of the lot. If the volume per acre was figured only on the basis of area ripe for cutting, this stand would rank far in the lead with at least 35M bd. ft. per acre, as against 28½M bd. ft. for the next best stand.

Theoretically, the advantages of the group selection system in pure hemlock appear sixfold.

1. The removal of small patches of timber and the avoidance of anything resembling clear cutting protects the site from serious injury due to exposure. This is of importance on shallow or light sandy soils, where the primary requirement of successful silviculture may be the maintenance of a protective cover.

2. Dense reproduction is easy to obtain. The small areas cut in the group selection method, even if they have no advanced growth hemlock, will readily be seeded from the side. As has been previously explained, dense reproduction results in high volume, good quality, and rapid growth, three factors of vital importance in successful stands.

3. The advantages of suppressing hemlock have already been discussed. Suppressed reproduction may be readily procured by the group selection method. The diffusion of small cleared patches throughout the area will introduce

enough side light in the most dense stands to assure the survival of reproduction. Furthermore, even those trees which start after the removal of the overstory receive a certain amount of shading early in life from the surrounding uncut groups.

4. The group selection method is admirably adapted for a forest managed on the sustained yield principle.

5. In the selection system the fire danger is less than in any other silvicultural method, for uneven aged stands are produced. Large unbroken areas of reproduction which would provide a relatively great fire hazard are avoided by this method.

6. The group selection method is distinctly practical from a logging standpoint. The area cut may be made sufficient in size to avoid difficulty in felling timber, and the cost of operating may be kept as low as in any system except clear cutting. Only relatively large timber is cut and this saves expense in felling, hauling, and milling.

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