HARVARD FOREST

BULLETIN NO. 27

RESULTS OF THE FIRST THIRTY YEARS OF EXPERIMENTATION IN SILVICULTURE IN THE HARVARD FOREST, 1908-1938

PART II

NATURAL REPRODUCTION METHODS IN WHITE PINE-HEMLOCK STANDS ON LIGHT, SANDY SOILS

By

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FOREWORD

A progress report on the first thirty years of silvicultural experiment at the Harvard Forest was planned to comprise three parts. Part I, on "The conversion of stands of old field origin by various methods of cutting and subsequent cultural treatments," was published in 1947. Part II was designed to cover experiments in natural regeneration on the light, sandy soils in Compartment IX of the Tom Swamp Block. Part III was to describe the results of plantation experiments. The present report is Part II in this series. For a general description of the Harvard Forest — its content, history and research policy — the reader is referred to the introductory material presented in Part I, which was issued as Bulletin No. 23. Circumstances affecting the preparation of Part II, however, require some further explanation.

Causes for the long delay in the publication of Part I have been even more effective in the case of Part II. The hurricane of 1938, the salvage operations after the hurricane, and finally the disruption of the Forest's activities during the war, all served to thwart the kind of reflective study necessary to an appraisal of long-term experiments. Still more significant were the state of development of the experiments in Compartment IX in 1938, and the devastating effects of the hurricane itself. The experiments were started in 1924, and although only 14 growing seasons had elapsed by 1938, there was at hand some information with which to analyze the causes of success or failure of the silvicultural methods. All of the experiments involved partial cuttings with studies of the effects on reproduction and on the residual stands. Nearly all of the residuals were destroyed by the hurricane. Because much of the natural regeneration prior to 1938 had not been promising, and because most of the seed sources had now been eliminated, there was considerable doubt as to whether the experiments were worthy of continuation. Observations made in the past few years, however, not only indicate that continuance will be highly profitable, but also they throw some light on the earlier experimental results. Although study of the area will continue, this report will summarize experience to late 1949.

The authors of the present bulletin are no longer members of the Harvard Forest staff. Mr. Cline came to the Forest as a student in 1922 and remained as a staff member in various capacities until 1946. He was

Director of the Forest from 1938 to 1946. Thus his term at Petersham covered most of the period involved in the experiments described in this paper. Mr. Lutz came to the Forest as a student in 1938, and served as Assistant to the Director from 1939 until he left for war service in 1941. His term here was coincident with the period of greatest activity in the assembling of materials for this progress report, and he was responsible for much of this work.

The first manuscript for Cases 15–18 was prepared while the authors were still at the Harvard Forest. As noted above, however, the effects of the hurricane were so great that it was thought best to delay publication until some later assessment could be made. Information on the state of the experiments since 1946 has been gathered by the staff and students at the Forest, and has been incorporated in the discussions of the four cases. Most of this material was assembled by Dr. Earl E. Smith, Mr. A. C. Chable, and Mr. Alfred Pleasanton, from observations made in the late summer of 1949. At that time the boundaries of all of the original cutting areas were reestablished, and a study of regeneration based upon 1100 milacre sample plots was carried out.

The land involved in Cases 15–18 was not a part of the original Harvard Forest tracts that were acquired by the University in 1907. In 1924 it was in the possession of the New England Box Company of Greenfield, Massachusetts, held by that company for the timber it contained. The late Richard T. Fisher, first director of the Harvard Forest, realizing the significance of the area for additions to the research program of the Forest, was largely responsible for an arrangement with the Box Company whereby experimental cuttings could be made. The Forest staff was permitted to design and manage the cuttings, beginning in 1924, while the Company took the lumber.

At that time the property was known as the "Adams-Fay Lot," and has continued to be called by that name in the Forest records. It adjoins Compartment VIII of the Tom Swamp Block on the north, and after the Box Company transferred it to the Forest in 1932 it became Compartment IX of that block.

Students of silviculture may properly raise the question of why the four case histories in natural regeneration described here are thus segregated from those described in Part I. The answer is to be found in the behavior of white pine regeneration as related to soils in this region. All but one of the cases described in Part I are situated on upland loams which were there subdivided as "heavy," and "medium," soils. It should be noted that none of these soils is heavy in the sense of being clayey, but rather of having a relatively higher percentage of fine sands and silts. White pine

can be induced to regenerate and become dominant on them only by fairly intensive cultural practices.

As will be noted in the following pages, pine can be more readily regenerated and induced to become dominant on very light gravelly and sandy soils such as are found on glacial outwash plains. Here hardwood competition with the pine is reduced to a minimum. However, the silvicultural methods differ from those used on the upland loams. In terms of local forest geography, therefore, and in terms of silvicultural methods, the glaciofluvial gravels and sands of our region form a rather distinctive group of sites that are worthy of separate treatment.

Grateful acknowledgment is made to the Friends of the Harvard Forest who, by their generous gifts, have supplied the funds for the present publication.

HUGH M. RAUP
Director

AUTHORS' ACKNOWLEDGMENTS

As in Part I, this report is based upon the many field studies and observations made over a period of years by Harvard Forest staff members and students.

The history of the stands on the four case areas here described was worked out in considerable detail by Marshall (1927) from stump analyses made in 1924, at the time of the first cuttings under the direction of the Harvard Forest staff. His observations contributed much toward an understanding of existing stand conditions, particularly of the successive changes in stand form and composition that resulted from previous logging operations and other disturbances.

Tarbox and Reed (1924) showed that quality of white pine was influenced by associated species. Their work was helpful in developing plans for the cuttings that recognized the beneficial effects of hemlock on the form and quality of pine when the two species are grown in a certain relationship with respect to crown position.

Arthur A. Davis, another graduate student at the Harvard Forest, had immediate supervision of the 1924–25 logging operations on the four case areas. His devotion to carrying out the cuttings in conformance with the plans, in felling only marked trees and avoiding undue damage to the residual stand in logging and slash disposal, assured an excellent start of the experiments in reproduction methods and the necessary base from which to measure and observe the results of the treatments. His observations of the influence of weather, stand form, and density on logging and slash disposal constitute a valuable record.

The work of Cline and Steed (1933) on reproduction in the white pine type on light soils included the area described in Case No. 12 [1], which is located in the same tract as Cases Nos. 15 to 18. This study advanced knowledge of the effects of different types of ground cover on the establishment of pine reproduction and aided in appraising the results of the 1924–25 reproduction cuttings.

[1] See Harvard Forest Bull. No. 23, pp. 143–152.

INTRODUCTION

The well-known "old field" white pine type of central New England owed its existence to the accident of farm abandonment. The area occupied by this temporary forest type, which reached its greatest extent and productiveness around the turn of the twentieth century, has been drastically reduced. On heavy and medium soils, its place has been taken, following cutting, by mixed stands in which hardwoods predominate. The extreme difficulty of maintaining any considerable proportion of pine in the ensuing stands on such soils was brought out by the first eleven cases presented in Part I. On the contrary, pine was maintained with ease on light, sandy soils, as illustrated by Case No. 12.

Thus, in view of the proven temporary character of old field pine, interest in a future raw material supply among owners of the pine wood-using industries has shifted to some extent to what has been termed the "permanent" pine type. This is found scattered throughout the region on sandy glacial outwash soils in the valley bottoms. Locally once famous (now beneath the Quabbin Reservoir) were the Dana sand plains, a source of both pitch and white pine for nearly two centuries; and, to the north of Petersham, the Winchendon sand plains, similar as to origin and character of tree cover. The Walker Forest (Cline, 1930), noted for the sustained yield of pine logs during several generations of the Walker family, was located in the Dana sand plains.

No precise estimate of the area represented by pine stands on light, sandy soils (Hinckley and Merrimac series) in the region is at hand, but from available soils maps (Latimer, Martin, and Lanphear, 1927) and local observation it appears to be of the order of five to ten percent of the total forested area. These light soils, characteristic of glaciofluvial terraces or plains, are made up of stratified layers of gravel and sand. The sandy nature of the surface layers and the porosity of the underlying gravelly material account for the comparative dryness of the site as its occupancy by white pine, pitch pine, hemlock, and, generally as a minor element, certain hardwoods. Such a marked difference in site characteristics and species composition as compared with the upland forests of the region obviously suggests silvicultural methods differing from those developed for stands growing under the latter, and much more common, condition.

The application of periodic "thinnings" in the Walker Forest over a

long period of time had demonstrated the effectiveness of conservative partial cuttings, resembling either uniform- or group-selection cuttings, as a means of securing natural reproduction and maintaining the light-soil pine type without substantial change. Observations elsewhere in the region likewise indicated the comparatively permanent character of the type and its susceptibility to being maintained indefinitely under conservative cutting practices. It was also a matter of common observation, as pointed out in Case No. 12, that clear-cutting, or heavy cutting of any sort, encouraged the prompt establishment of a heavy ericaceous ground cover that hampered reproduction and, in some cases, resulted in openings that persisted for as long as several decades. Light soils, it was evident, could not withstand the extreme exposure of clear-cutting and still come back promptly with a full stocking of trees, an accomplishment characteristic of the heavier till soils of the uplands. It was decided, therefore, that for the case areas herein described, all of them on light, sandy soils, variations of the selection and shelterwood methods of reproduction should be used, both of which are methods affording protection to the site during the regeneration period.

As far as can be determined from evidence on the ground, and from studies of the history of land use on the Harvard Forest properties (Raup and Carlson, 1941), the cutting area had always been forested. Some of the trees dated back to 1652, about 80 years before the coming of white settlers to Petersham. Logging operations had been carried on from time to time in different parts of the tract, but the land had never been cleared for farming. Marshall (1927) related most of the age classes in the forest to cutting operations, and his dates will be used in this paper. It should be noted, however, that the surface of the land is plentifully sprinkled with earthen mounds formed by the windthrow of trees. It is possible that some of the releases evident in the older trees may be ascribed to windthrow rather than to cutting. The composition in general was predominantly of white pine, with varying proportions of hemlock and a light representation of hardwoods.

An analysis of the growing stock of the entire area was made before any cuttings were laid out, and the design of the cuttings was based to a considerable degree on differences in composition. Thus, for a small portion of the area which supported almost pure hemlock in a somewhat groupwise distribution, a group selection cutting was decided upon; and for an area where white pine and hemlock were quite evenly represented, the decision was made to use modifications of the uniform shelterwood method. Another portion was set aside for strip cuttings, with strips of varying widths. These strip cuttings were the nearest approach to clear-

cutting and served as a check against the more conservative selection and shelterwood cuttings.

Since neither the selection nor the shelterwood method had been applied to stands of the light-soil pine type under controlled conditions in the Petersham locality, the cuttings were necessarily experimental in character. Their main purpose was to test on a small scale silvicultural methods which appeared best adapted to existing stand and site conditions, and their success was to be measured primarily by the kind and quantity of natural reproduction obtained. In addition to the usual silvicultural records, records of logging costs were also to be kept for the several different case areas, even though it was recognized that the areas were too small to provide a reliable basis for estimating costs on larger operations.

Duffield and Kraemer (1935) made an intensive analysis of the shelterwood cutting areas, Cases Nos. 15 and 16, and the many changes in stand and site conditions which had taken place during the ten-year period following the first shelterwood cuttings in 1924–25. Their findings served as a most valuable guide in planning the second series of cuttings on these areas, carried out in 1935, as well as a more refined basis for determining the effects of the earlier cuttings. Their report was drawn upon heavily in writing the case histories for the two shelterwood areas.

Charles S. Simmons, Division of Soil Survey, U. S. Department of Agriculture, identified and mapped the soils in the several cutting areas in 1939, thus providing basic information on a most important element in the local environment.

CASE NO. 15

Two-Cut Shelterwood Method of Reproduction in the White Pine-Hemlock Type

Block: Tom Swamp
Compartment: IX
Stand: P-7, 4.0 acres

History to September, 1949

Introduction

The shelterwood system of reproduction ordinarily is applied to even-aged stands in the form of a series of partial cuttings terminating with a final removal cutting, the aim being first to establish reproduction under the partial shelter of the overwood, then in due time to free it, completely, to form a new even-aged stand. In the uniform shelterwood system, of which this case is an illustration, the cuttings are applied uniformly to the entire stand, rather than by strips or groups.

Ideally, the new stand is secured by a series of partial cuttings extending over a period of several years designed to prepare the forest floor as a seedbed, stimulate abundant seed production, encourage the start of seedlings, and so firmly to establish the new generation, by adequate light and soil nutrients, that it can safely withstand complete removal of the overstory. However, under existing economic conditions in New England, it appeared desirable to try out a shortcut, that is, telescoping the conventional series of cuttings into only two, the first to be a combined preparatory and seeding cut to establish adequate reproduction of pine and hemlock, and the second to be a final removal cut to free the new generation. For convenience, it was called a two-cut shelterwood method. The two cuttings were thought of as coming some five to ten years apart.

Tarbox and Reed (1924), in their study of the form and quality of white pine, observed the characteristically straighter bole and smaller limb size of pine growing in mixture with hemlock. In the earlier years of the stand, the heavy-crowned, shade-tolerant hemlock protects the pine to some degree from attack by the white pine weevil (*Pissodes strobi*) and assists weeviled individuals to straighten after the loss of their leaders. Later, as the stand develops, the hemlock hastens natural pruning of the pine, particularly in places where the hemlock, because of slower height growth, falls behind and acts as a trainer for the pine. Tarbox and Reed observed that the effectiveness of the hemlock as a protector and trainer of

pine is increased where the hemlock is somewhat the older; where both species start even, there is a tendency for the pine quickly to outgrow the hemlock and thus be less subject both to the hemlock's beneficial suppressive action at the start and to its pruning action later on.

Also taken into consideration were the differing degrees of tolerance of the two species. Hemlock is a markedly tolerant species, which can grow beneath white pine; pine is seldom found growing in its own shade, that is, under a closed canopy, but becomes established beneath hardwoods. It was thought that a partial cutting just heavy enough to encourage hemlock reproduction would result in no pine. Thus, if reproduction of both species was to be established and fully freed in only two cuttings, the first cutting should be heavy enough to favor the pine, regardless of the effect on reproduction of the hemlock.

Location and Physical Properties of the Site

The area is located in the central portion of the compartment (Fig. 1) at an elevation of about 850 feet. The soil materials consist of glaciofluvial sands and gravels derived from granites, gneisses and schists. Simmons (1939) mapped these soils as the Hinckley soil series, which includes well-drained, rapidly permeable brown podzolic soils found on kames and eskers. In this area the soils show an incipient true podzol profile characterized by a thick layer of litter, duff, and humus on top of a gray, bleached layer (A_2 horizon). Directly beneath the latter is a dark-brown sandy loam a few inches thick, grading into a brown gravelly sandy loam, which in turn grades into the parent outwash material. The substrata exhibit a rough assortment of sand and gravel in layers. Drainage is chiefly internal, and is rapid and thorough to the point of being excessive in dry periods. The ground surface is made uneven by small hummocks and hollows.

Land Use History

The land has never been cleared for agricultural use. Marshall's study (1927) of the area revealed that there had been logging operations in the past, the last one in 1846–48, but that the general composition of the stand had not been greatly altered thereby. On these light, sandy soils the hardwood component, predominant on upland sites, has been secondary to white pine and hemlock. Despite logging operations for pine in earlier years, this species, together with hemlock, still maintained dominance. Conifers had followed conifers — a fact that stood out in sharp contrast to the succession common to stands of white pine followed by hardwoods on upland old fields (see Cases 1 to 11).

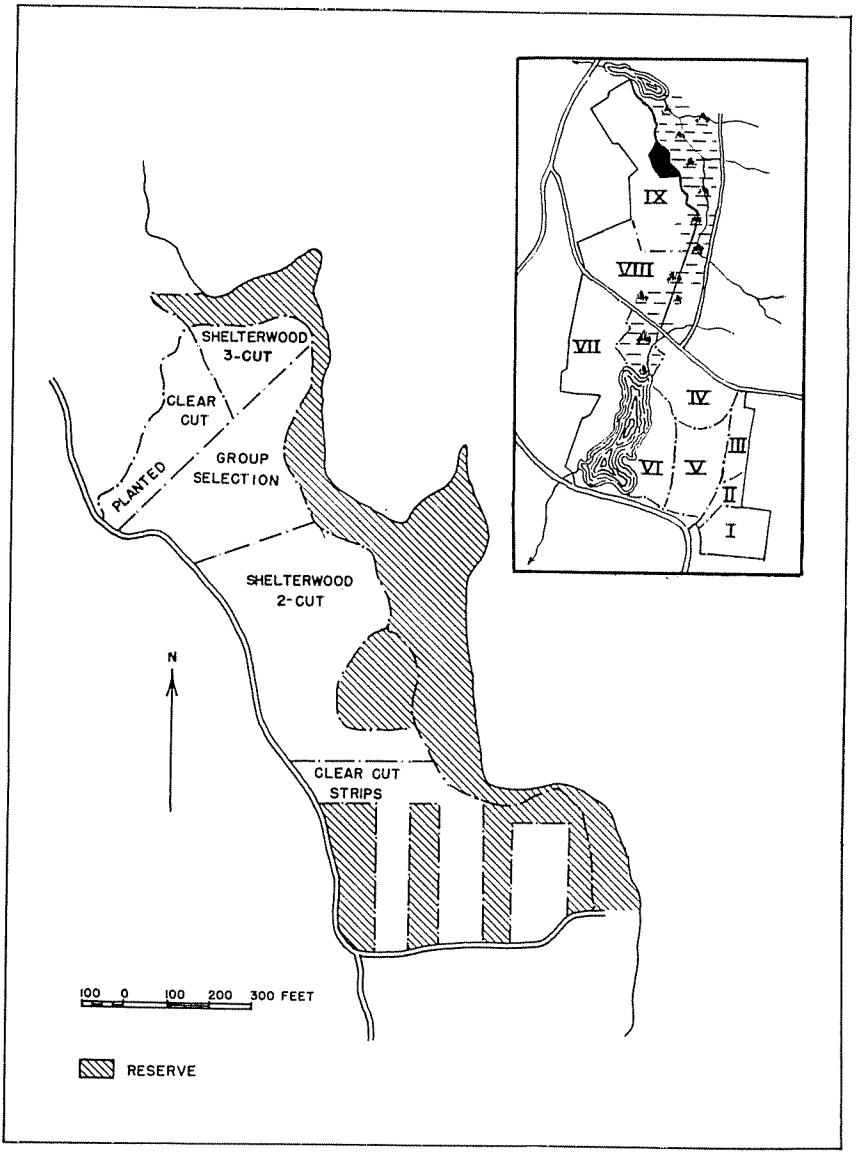

FIG. 1. MAP SHOWING LOCATION OF CASE AREAS

Small inset is map of Tom Swamp Tract, Harvard Forest, with study area shown in black.

Marshall also observed that hemlock generally had played a secondary role to the pine, existing in a suppressed state beneath the pine canopy until such times as cutting relieved the pressure. Then the hemlock had quickly responded to the new freedom and had grown at a greatly increased rate. Thus the ratio of pine to hemlock in the stand's composition doubtless varied from generation to generation, depending upon the timing and intensity of cutting.

The composition and relative abundance of the hardwood element also must have been influenced to some degree by logging operations, but at no time was it strong enough to attain a leading position. Chestnut, beech, red maple, red oak, and black, yellow and paper birch probably were the chief hardwood representatives for many generations.

The last logging on the area, in 1846–48, was a heavy one, resulting in the prompt establishment of a dense stocking of white pine. Some small understory hemlocks escaped logging; these together with new hemlock reproduction made up the hemlock element. Some of the older individuals succeeded in securing a place in the main canopy, but seedlings the same age as the pine soon fell behind. By 1924, some 75 years after the last logging, the stand was a fairly uniform, even-aged mixture of white pine and hemlock with scattered hardwoods and red spruce. There was a dense understory of hemlock, much of it about the same age as the overstory. Average tree age was 75 years.

First Shelterwood Cutting — January, 1925

The table on the following page shows the composition of the stand according to height classes, just prior to cutting:

White pine constituted 71 percent of the number of trees in the three uppermost height classes, with hemlock strongly dominating in the remaining classes. The composition, based on number of trees, was 30 percent white pine, 57 percent hemlock, and 13 percent hardwoods and red spruce. By volume, 78 percent was pine, 18 percent hemlock, and 4 percent hardwoods.

The advance growth was sparse except in two small openings in the stand, one in the north-central and one in the west-central part of the area, both supporting thickets of hemlock a few feet tall. There had been a good hemlock seed crop the fall before logging, and it was expected that this seed would be available for the immediate establishment of reproduction.

	Number of Stems per Acre Total-height Class (in feet)								
Species	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*Total*
White pine		*	*	9	33	66	52	*	160
Hemlock	25	50	82	67	45	24	10	*	303
Red maple		4	2	4	15	5			30
Black birch		1	3	4	8	2			18
Chestnut		*		*	3	4			7
Beech		*	*	1	*	1			2
Red oak					1	2	*		3
Black cherry				*	*		*		*
Paper birch				*	*				*
Poplar				*	*				*
Red spruce				*	*	*			*
Total	25	55	87	85	105	104	62		523

Total stems per acre — 529

* An average of less than one tree per acre; all together these equal six trees per acre.

FIG. 2. OCTOBER, 1924. STAND ON THE TWO-CUT SHELTERWOOD AREA MARKED FOR CUTTING

The marked trees included the coarsest dominants, all overtopped hemlocks, and enough trees of other kinds to leave about half a full crown canopy after cutting. Advance growth and ground cover were almost entirely lacking because of the extremely high density of the stand.

In this first operation, all hardwoods, regardless of species, and all hemlocks occurring in the understory were taken out and the main canopy opened drastically. Especially marked for removal were coarse dominant trees, for, although they might be good seed bearers, they would profit less from additional growth than better-formed trees and would cause more damage to the reproduction when finally cut.

In mind at the time of marking was the need to open up the canopy sufficiently to establish pine reproduction, with the expectation that the more tolerant hemlock would come in anyway. Because of the light soil, very little competition from hardwood reproduction was anticipated. The seedbed condition was thought to be bad, because of the thick, dry organic layer. However, it was hoped that even winter logging would sufficiently break up the organic layer and mix it with the mineral soil to effect some improvement. A heavy opening up of the canopy also might lead to an increased rate of decomposition in the organic matter.

Also considered was the lack of any recent cuttings in the stand and the resultant high density of stocking, making the stand susceptible to windthrow following a partial cutting. There was little that could be done about this beyond favoring the better-formed individuals for the remaining stand.

About three-quarters of the stems and one half of the volume were removed in the first cutting, leaving about half of the previous full crown canopy. A total of 54,500 board feet was removed from the 4.0 acres, or 13,625 board feet per acre, of which about one half was pine and the remainder mostly hemlock. A total of 409 trees per acre out of an original number of 529 was cut. The residual stand consisted of the following:

	Number of Stems per Acre Total-height Class (in feet)					
Species	*30*	*40*	*50*	*60*	*70*	*Total*
White pine		2	17	39	15	73
Hemlock	11	12	18	5	1	47
Red spruce		*	*	*		*
Total	11	14	35	44	16	120

* An average of less than one tree per acre.

Logs were hauled to a portable mill less than a quarter of a mile distant by means of horse-drawn scoots, or single-runner sleds. The operator reported that the area was hard both to cut and to log, the principal difficulty being

that all the small understory trees had to be cut. Cutting the small hemlocks constituted much extra work for the choppers for which they received little pay because they were employed on a piece-work basis. It also resulted in a great amount of slash, which further hindered progress. The choppers felled the trees as best they could and tried to keep the slash off the logs; but, as the trees had to be felled in whatever direction they would best go, it was impossible to keep the skid roads open without an extra swamper.

There was some snow on the ground during the operation, and the weather was extremely cold. Because of the high density of the stand, a great many trees were "hung up," and those which were heavy enough to break loose snapped off the green limbs of neighboring trees as though the latter were made of glass. It was obvious that such partial cuttings should be made in milder weather in order to avoid damage through breakage.

Burning the large amount of slash required a great deal of labor, owing to the unfavorable weather conditions and a desire on the part of the operator to do a clean job. The green slash was burned in small scattered piles as part of the logging operation.

FIG. 3. MARCH, 1925. THE RESIDUAL STAND OF WHITE PINE AND HEMLOCK

With the cutting completed, the stand is now characterized by greatly increased room for crown expansion, reduced root competition, added light reaching the forest floor, and a growing stock made up of the best-formed trees available.

Soil Scarification — Spring, 1925

The first cutting was intended to serve both as a preparatory and a seeding cut, but there were doubts as to the breaking down of the heavy organic layer. Because snow prevented any effective scarification of the soil during logging, it was decided to scarify the top soil layers by special means. In the spring, a spike-toothed harrow was dragged over the cutting area by a team, but the thick litter balled up under the spikes, causing the harrow to slide ineffectually over the ground. This treatment was abandoned as being generally unsatisfactory and expensive. Later a few small experimental plots were scarified by mixing the litter and underlying mineral soil with a hand fork. Plots were established before and after the seed fall of 1924, in 1927 and in 1934.

Weeding — May, 1929

At the end of the fourth growing season following cutting, rank-growing sprouts from stumps of overstory hardwoods had reached a height of ten feet or more. These were cut with machetes to favor newly-established white pine and hemlock seedlings. Elsewhere thick patches of berry briars containing scattered pin cherry and poplar were partially cut in an attempt to enlarge the area favorable for coniferous reproduction. At this time pine and hemlock seedlings were gaining a foothold, except in places where a thick layer of duff and litter still remained.

A total of 3.5 man-hours per acre was required for the weeding.

Inspection of the Cutting Area — October, 1931

The densest stocking of both tree reproduction and herbaceous ground cover plants was found on the spots where slash had been burned. In most of the depressions there was a fairly dense growth of tree seedlings and ground cover plants, even where slash had not been burned, while on most knolls there was little reproduction or ground cover. The amount of moisture in the surface layers of the soil undoubtedly influenced the differences. Slash burning consumed the organic layer leaving behind a bed of moisture-absorbent charcoal on top of the mineral soil, while the organic layer in the bottoms of the depressions acquired moisture through drainage from the surrounding higher ground.

Occasional dense thickets of tree seedlings and herbaceous plants were found in small circles around large hardwood stumps. This phenomenon has been observed frequently in other areas where scattered hardwoods occur in stands predominantly coniferous.

The quantity of pine reproduction was generally thought insufficient

for a fully stocked new stand. Hemlock seedlings were more abundant, but it was believed that they could not make up for the deficiency in pine, the major species.

Weeding (North Portion, 1.5 Acres) — May, 1933

Contrary to expectations in 1925, certain hardwoods, chiefly black birch and pin cherry, had in places seeded in abundantly following logging. There was a difference of opinion as to whether the coniferous reproduction, especially hemlock, would finally work its way through the overtopping hardwoods. To help answer this question, only the northern portion of the area was weeded, and the southern portion left untreated, as a control. In spots well seeded to pine or hemlock all overtopping hardwood weeds were cut. Elsewhere, desirable hardwoods, such as seedling paper and yellow birch, were given preference.

This weeding required 5 man-hours per acre.

Progress Study of Stand Conditions — Winter, 1934–35

(By Duffield and Kraemer, 1935)

As previously noted, a complete cruise of the stand was made prior to and directly after the first cut; a similar cruise was made during the winter of 1934–35 to measure the changes in volume and growth rate during the ten-year period following cutting. The following table summarizes the changes that had taken place:

	Pine	*Hemlock*	*Total*
		(Board feet per acre)	
Original stand — 1924	18,456	7,364	25,820
Residual stand — 1925	9,112	3,066	12,178
Volume of stand in 1934	13,117	4,435	17,552
Volume increase since 1925	4,005	1,369	5,374
		(Percent)	
Increase in percent since 1925	43.9	44.7	44.2

The volume of the residual stand as of 1925 increased 44.2 percent in ten years, or at an average rate of 537 board feet per acre annually between 1925 and 1934. Although about half the total volume was removed in the cutting of 1925, the growth for the next ten years replaced nearly half the amount removed, including deductions for mortality, which amounted to the loss of 5 trees ranging from 9 to 16 inches d.b.h.

A count of the seed fall of 1934 was also made at this time. Specially constructed traps were placed at 25-foot intervals within an area of about one-quarter acre. It was estimated that some 337,000 pine and 11,700,000 hemlock seeds fell per acre. These amounts, equivalent to 21.6 pounds of pine and 60.6 pounds of hemlock, were enormously in excess of the needs for full stocking as estimated by Toumey and Korstian (1942), namely, 5 to 9 pounds of pine and 3 to 6 pounds of hemlock seed per acre.

Reproduction counts showed the following stocking:

	Coniferous Reproduction Number of Stems per Acre Height				
	Less than 6 in.	*6–18 in.*	*18–36 in.*	*36 in. and over*	*Total*
Hemlock	8,935	972	429	568	10,904
White pine	979	2,377	178	42	3,576

	Hardwood Reproduction Number of Stems per Acre Height		
	Less than 36 in.	*36 in. and over*	*Total*
Black birch	1,485	1,983	3,468
Red maple	1,032	137	1,169
Pin cherry	42	279	321
Gray birch	105	112	217
Paper birch	45	66	111

Coniferous reproduction seemed only partially successful. There were many hemlocks, but most of the seedlings (80 percent) were less than 6 inches high and lacking in vigor. Pine reproduction was much less abundant, and most of it was of such size as to be highly susceptible to damage by the pales weevil (*Hylobius pales*) after logging. Seedlings of both species were patchy in occurrence. Small areas with high stocking were interspersed with areas of low stocking; other places were entirely bare.

The occurrence of coniferous reproduction appeared to be related to ground cover types. Those cover types that included *Hypnum* and *Polytrichum* moss as the principal components had the most coniferous reproduction; those having an abundance of blackberry and dewberry, the least. Blueberry, referred to in Case No. 12 as being most inhibitive of all ground cover types to the establishment of coniferous reproduction, was

not present in any great abundance, presumably because of too dense an overstory.

The vigor of the pine seedlings growing under the partial shade of the overstory was compared with that of seedlings growing fully exposed in an adjoining clear-cut area. The average heights and dry weights of seedlings of the same age from the two areas were as follows:

	Height (Inches)	*Dry Weight (Grams)*	*Number of Branches per Whorl*
Two-cut shelterwood area	12.4	6.97	3–6
Clear-cut strips	18.8	22.46	5–8

Such a marked difference in size was further evidence of the need for a more open canopy in the shelterwood area.

To determine the effects of the different degrees of cutting on the upper layers of the soil, profile measurements were taken in the two areas. According to Duffield and Kraemer (1935), the average thickness of the

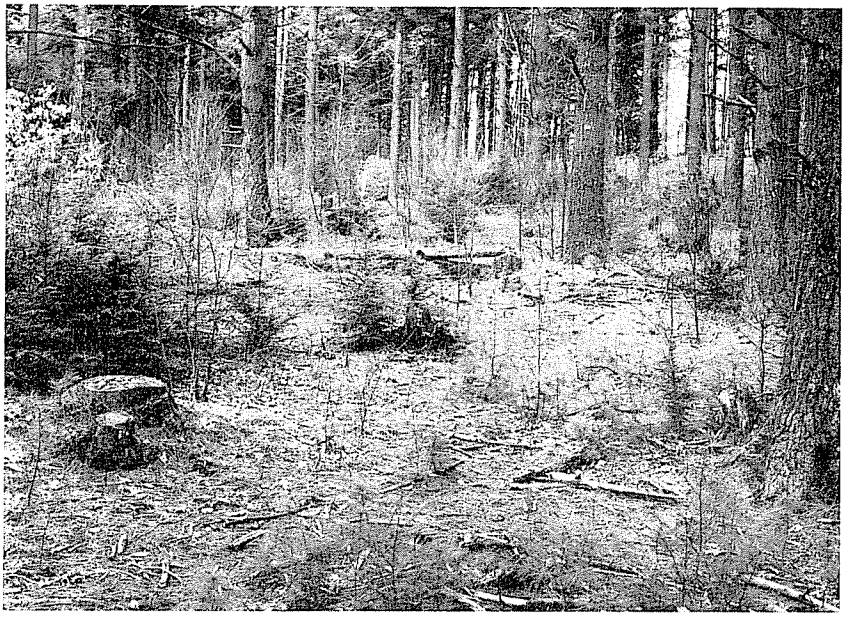

FIG. 4. APRIL, 1935. TEN YEARS AFTER THE FIRST SHELTERWOOD CUTTING

The sparse, slow-growing pine reproduction was unsatisfactory. In order to obtain adequate reproduction of pine a further opening up of the stand evidently was necessary.

organic layers in the shelterwood area was 1.7 inches, compared with 1.2 inches in the cleared strips. Another difference was in the thickness of the bleached layer; under the shelterwood, it was 0.3 inches, compared with an almost imperceptible trace in the clear-cut strips. Soil profile measurements for 1924–25 were not available. Duffield and Kraemer concluded that decomposition of the organic layers was more rapid in the open than in the shelterwood area.

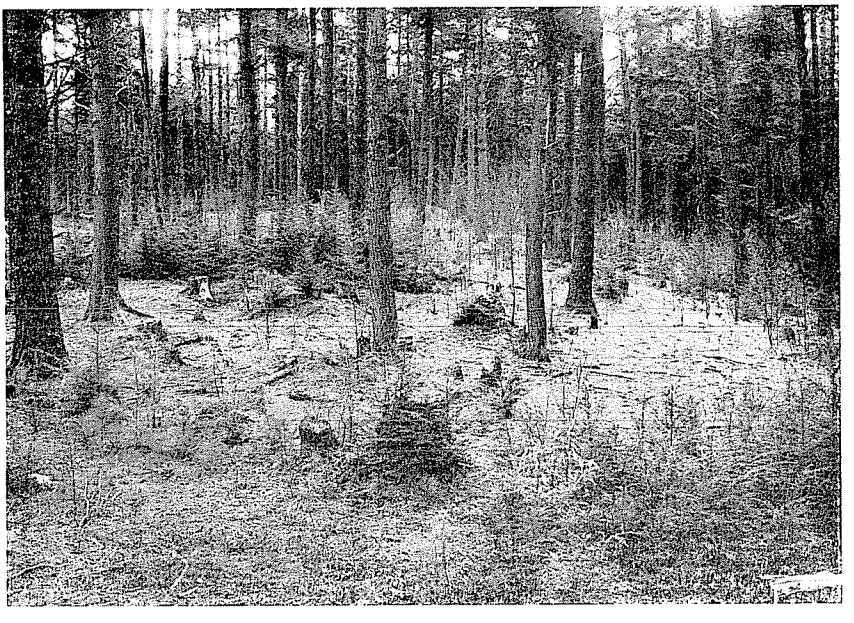

FIG. 5. APRIL, 1935. TEN YEARS AFTER THE FIRST SHELTERWOOD CUTTING: ANOTHER PORTION OF THE AREA

Hemlock reproduction was generally more plentiful and thriftier than the pine. The dense group on the knoll came in on a charcoal bed where a pile of slash was burned in 1925.

Second Shelterwood Cutting — December, 1935

The findings of Duffield and Kraemer (1935) showed that the two-cut plan would have to be abandoned and another cutting made without delay in order to obtain satisfactory white pine reproduction. Existing pine seedlings obviously were suffering from insufficient light and strong root competition with the residual trees. Hemlock reproduction was generally abundant enough to permit removal of the overstory hemlocks, thus considerably increasing the amount of light reaching the forest floor and reducing root competition for the limited supply of moisture and nutrients.

The stand was marked for cutting, and the felling and logging carried out in the same way as in the first cutting. Following is a tally of the trees removed from the entire area (4.0 acres):

	Number of Stems on Four Acres D.B.H. (in inches)														
	6	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*Total*
White pine		1	1	1	4	3	1	2		1		1			15
Hemlock	2		6	13	16	15	12	7	6	4	1	2	2	1	87
															102

The removal of 102 trees left a residual stand of 378 trees, or about 95 trees per acre, made up of 73 percent pine, 26 percent hemlock, and 1 percent red spruce. The total volume per acre removed was 524 board feet of pine and 2,056 board feet of hemlock.

FIG. 6. JANUARY, 1937. GENERAL VIEW OF THE STAND TWO YEARS AFTER THE SECOND SHELTERWOOD CUTTING

A second opening of the overstory has resulted in improved vigor of the older reproduction, and the start of more pine reproduction from the seed year of 1934. Better stem form and crown development of the residual stand are also evident.

Stand Conditions — September, 1941

The stand left after the cutting of 1935 was completely blown down by the hurricane of September 1938. The stumpage was sold to a private operator. Because of the tangled condition of the trees, oftentimes piled in criss-cross fashion to a depth of twenty feet, no attempt was made to control the cutting or the extraction; the logging was done at the discretion of the operator. The logs were hauled on scoots by tractors. Although the logging was done in the winter, there was very little snow on the ground; consequently much of the remaining organic layer was broken up and mixed with the mineral soil, particularly along the many skid trails. After logging was completed, the slash was ricked and partly burned.

The hurricane and attendant logging operation caused heavy damage to the reproduction; much of it was broken by falling trees or knocked down in the course of logging. Fortunately there was a good crop of pine seed on the trees when the hurricane struck. With the improved seedbed conditions brought about by the second shelterwood cutting and the further scarification of the soil caused by cleaning up after the hurricane, a fairly abundant new reproduction started in 1939.

Seedling counts made in the fall of 1941 gave the following results:

		Number of Stems per Acre
Coniferous Reproduction		
	White pine	5,003 *
	Hemlock	2,801
	Total	7,804
Hardwood Reproduction		
	Black birch	1,467
	Pin cherry	467
	Gray birch	200
	Red maple	133
	Paper birch	67
	Red oak	67
	Total	2,401

* Number of stems per acre by seed year as follows: 1927 — 133; 1930 — 667; 1934 — 1,335; 1938 — 2,868.

The coniferous reproduction had been reduced to almost half that present in 1935 (7,804 stems per acre as compared with 14,480). More than half of the white pine reproduction was from the seed crop of 1938, and

over 80 percent from the combined crops of 1934 and 1938. Most of the seeedlings were less than ten inches tall, the older reproduction having suffered the greater amount of damage. Hemlock losses were greater than those of pine. From a total of nearly 11,000 hemlock seedlings per acre reported in 1935, less than 3,000 per acre remained, and some of these had become established from the seed crop of 1939, after the hurricane. Unlike the pine, the greatest losses in hemlock took place in the smaller size classes, presumably due to less successful resistance to exposure resulting from damage to the overstory. The exceptionally dry summer (1939) following the hurricane may have contributed to the high mortality. Most of the older hemlock groups, even those occurring as advance growth at the time of the first cutting in 1924, had survived and appeared to have suffered little from the effects of the hurricane and subsequent logging operations.

The young hardwoods likewise suffered from exposure and drought. Their numbers had been cut in half since 1935. This loss was due chiefly to heavy mortality in black birch. The observation has often been made in the Harvard Forest that the cutting back of black birch advance growth at the time of clear-cutting the overstory is attended by heavy losses the following season.

Except for a few seedlings of pin cherry and paper birch that seeded in after the hurricane, most of the hardwood was of sprout origin and of low vigor. Even the usually vigorous sprouters, such as red oak and red maple, are noticeably less vigorous on light soils.

Despite the untimely destruction of the old stand by the hurricane, there was fair promise of a well-stocked new stand. The danger from those agencies most destructive to pine reproduction, namely logging and the pales weevil, was past; also, accessions to stocking could be expected from time to time from a few remaining seed trees, both pine and hemlock, standing on adjacent areas.

Stand Conditions—July, 1949

Nearly eleven years after the hurricane, a survey of the area showed that 56 percent of the ground [2] was desirably stocked with pine and hemlock reproduction together with a scattering of better hardwoods. Twenty-eight percent of the ground area was undesirably stocked, that is, with short-lived species or rank-growing stump sprouts; and the remaining 16 percent was bare. White pine was the dominant species on 52 percent of

[2] Based on 400 milacre (6.6 feet square) plots for each of which the stocking was rated "desirable," "undesirable," or "no stocking" and a record made of the dominant species present.

FIG. 7. SEPTEMBER, 1949. THE NEW STAND

Twenty-five years after the first shelterwood cutting and eleven years after the hurricane, the new stand of white pine and hemlock with scattered hardwoods has taken over the area. It is not dense enough to produce the best-quality timber, but will eventually form a well-stocked stand.

the desirably stocked milacre samples, and hemlock on 41 percent, the conifers thus maintaining their traditional superiority in numbers. Red maple was the most common species among the longer-lived hardwoods, as in the old stand; chestnut was missing, the blight (*Endothia parasitica*) having reduced it to occasional clumps of coarse sprouts from the bases of dying stems. On the plots where stocking was rated "undesirable," gray birch and pin cherry, both short-lived species, predominated.

Aside from overtopped hemlocks (amounting to nearly 1,000 stems per acre), there were some 525 free-to-grow pines and hemlocks per acre, 90 stems of better hardwoods, and 210 stems of inferior hardwoods — scarcely enough material to permit developing an excellent stand, but enough fully to occupy all growing space within a few years and eventually make a well-stocked saw-timber stand of fair quality.

A very large percentage of the free-to-grow white pines were less than 15 years old, indicating heavy losses in the older reproduction caused by the hurricane and attendant logging. Nearly 75 percent of them had been attacked by the white pine weevil and showed the characteristic crooks, forks, and bushiness resulting therefrom, a further reflection of insufficient density of stocking.

Discussion

There is little doubt that failure to obtain adequate reproduction after the first shelterwood cutting was due to a poor seedbed. Over a period of 75 years, stands of white pine and hemlock build up a thick, tough organic layer on top of the mineral soil that cannot be decomposed within a few years even with a heavy opening up of the canopy. Although those in charge of the cuttings recognized in advance that the heavy organic layer might cause trouble, they underestimated the length of time and degree of exposure required to reduce it. They also misjudged the effectiveness of logging, with horses and scoots on frozen ground, as a means of soil scarification. Scarification with a harrow was subsequently tried but this, too, proved ineffectual and costly. However, it was strikingly demonstrated on small hand-treated plots that thorough scarification results in a highly satisfactory catch of reproduction.

These are the more immediate and current observations. From a silvicultural standpoint, failure to apply timely thinnings and improvement cuttings during the half century prior to 1924 — treatments that periodically would have opened up the canopy and promoted decomposition of the organic material on the ground — contributed to the unsatisfactory results of the first shelterwood cutting. Through such intermediate cuttings over the earlier life of the stand, the heavy accumulation

of litter and duff might have been forestalled and seedbed conditions made much more favorable when the time came for reproduction cuttings. Further, thinnings would have resulted in thriftier larger-crowned trees capable of producing heavier crops of seed, not to mention the main object of thinning — the increased yield of wood per unit area for a given crop rotation. Such benefits were evidenced in part by the good results obtained during the 10-year period between the first and second shelterwood cuttings, when the residual trees showed a marked increase in rate of growth.

It may be argued that a heavier first cut, in 1925, would have brought in more reproduction and thus eliminated the need for a second partial cut in 1935. In this way the original aim of both securing adequate reproduction and removing the old stand in only two cuttings might have been fulfilled. However, a heavier first cut would have required removing more than half the original volume and three quarters of the original number of stems, leaving an open stand of trees that, by virtue of having grown under conditions of high density of stocking for many years, would have been highly susceptible to windthrow. Although there was little loss from this cause after the first shelterwood cutting under the more conservative plan, this may have been a stroke of luck. Therefore, it does not necessarily follow that in another reproduction period of similar length heavy winds, short of hurricane force, would not have done great damage to the thin residual stand. With conditions as they existed in 1924, it now appears that a plan calling for three cuttings instead of two would have worked out much better. In fact, resort finally was made to a three-cut plan, after the first cutting failed to serve its purpose; but better results would have followed had the interval between the first two cuts been on the order of five years rather than eleven. The lapse of more than a decade allowed considerable closing in of the canopy with resultant weakening of the reproduction and a retarded rate of progress in seedbed improvement.

Weedings to free pine and hemlock reproduction from hardwoods of seedling origin seemed to be generally unnecessary on these sites, though failure to control rank-growing hardwood stump sprouts did make sizable breaks in the coniferous stocking.

From an ecological point of view, the reemergence, following a hurricane and three cuttings, all within a period of fifteen years, of a young stand having essentially the same composition as the previous stand shows an inelasticity in composition on the light, sandy soils that is quite in contrast with the distinctive successional stages common to old field types on heavier soils. However, this is not to say that the composition and

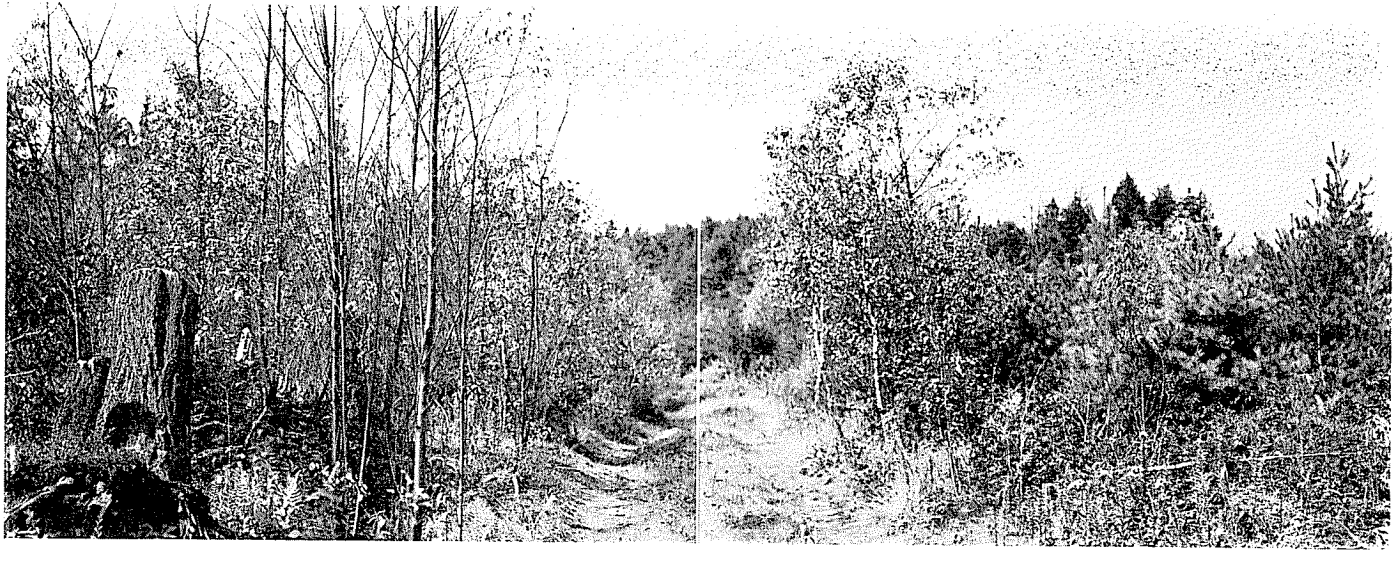

FIG. 8. SEPTEMBER, 1949. CONTRAST BETWEEN REPRODUCTION ON THE SHELTERWOOD AREA (right) AND AN UNTREATED AREA (left)

A dense hemlock stand with scattered white pine on the left side of the road had received no treatment prior to the hurricane of 1938. A very thick, matted organic layer had developed, so thick that almost no coniferous reproduction became established during the ten years following the hurricane logging. On the right side of the road, where two partial cuttings preceded the hurricane logging, coniferous reproduction was sufficient to form a well-stocked stand.

adequacy of stocking generally remain unchanged, regardless of the kind or severity of cutting. That coniferous reproduction can fail is illustrated by the accompanying photograph showing the shelterwood area on the right-hand side of the road and, on the left, an area where no cutting was made until the former dense stand of pine and hemlock was blown down by the hurricane. On the latter area, only a few scattered young pines and hemlocks came in during the decade following the hurricane logging, altogether too few to form a stand in the foreseeable future.

CASE NO. 16

Three-Cut Shelterwood Method of Reproduction in the White Pine-Hemlock Type

Block: Tom Swamp
Compartment: IX
Stand: P-Hm-4, 0.9 acres

History to September, 1949

Introduction

The original plan for reproducing this stand was influenced by the findings of Tarbox and Reed (1924), namely, that in mixed stands of white pine and hemlock the quality of the pine is best where the hemlock usually is older by some five to ten years.

Unlike the preceding two-cut shelterwood plan, the aim here was to establish hemlock reproduction in advance of the pine, by opening up the canopy in the first cut enough to permit the start of hemlock, then bringing in the pine through a second, and heavier, cut. The reproduction thus secured was to be freed by the third, or removal, cutting.

No cutting or treatment of any kind had been carried on in the existing stand; consequently, there was a thick mat of needle litter and duff on the ground when the shelterwood cuttings were begun. A more unfavorable seedbed could hardly be found anywhere in the region. It was expected that the organic layer would be broken up to some extent in the course of the logging, which was to be done with horses and scoots.

Location and Physical Properties of the Site

This area is close to the two-cut shelterwood area on the north (see Fig. 1), and conditions of site are essentially the same as those described in Case No. 15.

Land Use History

In common with the two-cut shelterwood area, the land never had been cleared for farming. The original stand consisted of a mixture of white pine, hemlock, red spruce, and various hardwoods, the proportions of the several species varying from generation to generation depending largely upon the severity of cutting.

The last logging operation, according to Marshall (1927), took place between 1833 and 1837, at which time the old stand was ". . . cut relatively lightly and left with a dense growth of small hemlock . . ." The result, by 1924, was a fairly uniform, mixed stand in which hemlock predominated, both in numbers and volume. The white pine was about 85 years old, and the age of the hemlock ranged from a few years to a few decades older than the pine.

The First Combined Preparatory and Seeding Cut — October-December, 1924

Before marking the stand for the first cut, a complete tally of trees was made. The following table shows the composition of the stand by species and height classes:

	Number of Trees per Acre Total-height Class (in feet)									*Percent*
	10	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*Total*	
Hemlock	28	18	33	47	87	128	60		401	77
White pine			1	3	11	20	36	3	74	14
Chestnut			3	7	9				19	9
Red maple		1	1	5	6	3			16	
Black birch				3	5				8	
Red spruce						2			2	
Total	28	19	38	65	118	153	96	3	520	100

The stand, in contrast to that on the two-cut shelterwood area, was predominantly hemlock rather than pine (65 percent hemlock and 27 percent white pine, by volume). Apparently, the difference was due largely to the differing severity of cutting in the logging operations that took place in the period 1833–1837. The much lighter cut on the area now designated as the three-cut area presumably favored the greater survival of the small understory hemlocks, which would give them a decided lead in height over pine reproduction that started in openings created by the logging.

Under the heavy hemlock canopy the ground was nearly bare of both ground cover and advance growth. A large crop of hemlock seed had matured and was on the ground before logging commenced.

The stand was marked for cutting. All hardwoods, nearly all of the smaller understory hemlocks, and enough of the mainstory hemlock and white pine were removed to reduce the crown canopy to approximately two-thirds of full closure.

FIG. 9. OCTOBER, 1924. VIEW OF THE THREE-CUT AREA JUST BEFORE THE FIRST SHELTERWOOD CUT

The bare forest floor is well illustrated here. The organic layer, topped by a dry, slippery litter of pine and hemlock needles, was thick and matted.

The following table shows the diameter-class distribution of white pine and hemlock before and after cutting:

D.B.H. Classes (inches)	*Number of Trees per Acre*					
	Original Stand			*Residual Stand*		
	Pine	*Hemlock*	*Total*	*Pine*	*Hemlock*	*Total*
2 to 6 (inclusive)	10	149	159	0	9	9
8 to 12	40	192	232	26	112	138
14 to 18	24	59	83	20	54	74
20 and over	0	1	1	0	1	1
Total	74	401	475	46	176	212

About 55 percent of the trees were removed. The heaviest cut was in the smaller diameter classes — 94 percent in the 2 to 6-inch class and 41 percent in the 8 to 12-inch class, compared with only 11 percent in the 14 to 18-inch class and none in the largest class. Of the trees remaining, 79 percent were hemlock and 21 percent pine.

The volume of the original stand was 35,076 board feet per acre, of which 10,355 board feet were pine (30 percent) and 24,721 board feet hemlock (70 percent). The volume cut amounted to 7,320 board feet per acre, 1,872 board feet of which were pine and 5,448 board feet hemlock. Thus, the total volume of the stand was reduced by about 21 percent.

Felling and bucking were not especially difficult despite the lightness of the cut. A crew of two men cut an average of 235 board feet of logs per hour. The logging was done on bare ground. The slash was burned green in small piles made in openings. The logs were left on the ground until early December, when they were hauled on scoots about one eighth of a mile to the portable mill.

FIG. 10. NOVEMBER, 1924. VIEW DURING THE FIRST SHELTERWOOD CUT

About half the original number of trees were removed and about 20 percent of the original volume. The aim was to open up the canopy sufficiently to secure hemlock reproduction but not pine. The slash was burned green in small piles.

Inspection of the Cutting Area — October, 1931

Six growing seasons after cutting, almost no hemlock reproduction had become established except in the scattered spots where slash had been burned and on a small sample plot where the ground had been thoroughly scarified by mixing the organic layer with the mineral soil by means of hand tools. Pine reproduction was not expected, but a few seedlings appeared on the burned spots. Failure to obtain reproduction of hemlock apparently was caused by the unfavorable seedbed condition. Logging, even on bare ground, did not effectively break up the organic mat, some two to three inches thick on the average, and expose the mineral soil. On the hand-scarified plot, a very dense group of hemlock seedlings had become established. Likewise, on the charcoal beds where slash had been burned, hemlock and hardwood seedlings along with various herbaceous plants formed small green patches in the otherwise lifeless gray mat of needle litter.

Progress Record of Stand Conditions — Winter 1934–35

Duffield and Kraemer (1935) made a special study of the increment on the residual stand and the reproduction resulting from the first shelterwood cutting. In order to determine the growth rate of the residual stand during the decade from 1925 to 1934, a complete cruise was made in 1934, and the new compared with the old, as follows:

	Pine	*Hemlock*	*Total*
		(*Board feet per acre*)	
Original stand — 1924	10,355	24,721	35,076
Residual stand — 1925	8,483	19,273	27,756
Volume of stand in 1934	11,407	21,554	32,961
Volume increase since 1925	2,924	2,281	5,205
		(*Percent*)	
Increase in percent since 1925	35.4	11.8	18.8

The increase in volume on the residual stand of 1925 was 18.8 percent. Expressed in annual increment per acre, this is equivalent to 520 board feet, as compared with 537 board feet per acre in the two-cut shelterwood area. About one fifth of the total volume was removed in the first cut; and in the decade 1925 through 1934 almost two thirds of this volume was regained by growth. There were no cases of windthrow.

The situation with regard to reproduction remained substantially unchanged after ten years. The thick mat of organic matter still covered the

ground, except where slash had been burned and in the small spot where soil scarification had been done by hand.

A count of the seedlings on the small burned spots showed the following average numbers per 1/500 acre:

Hemlock	453
White pine	2
Black birch	10
Gray birch	5
Willow	3
Poplar	1

The dense stocking of hemlock reproduction on these burned spots and on the hand-scarified plot was continuing evidence that a poor seedbed condition on the rest of the area, rather than lack of seed or too dense an overstory, accounted for the scarcity of reproduction. However, the canopy had closed in considerably since the first cutting in 1924, and nothing short of another cutting could be expected to correct the generally unfavorable conditions for the establishment and growth of reproduction.

FIG. 11. APRIL, 1935. TEN YEARS AFTER THE FIRST SHELTERWOOD CUT

The small scarified plot in the foreground supports a dense group of hemlock seedlings, in contrast to the surrounding area. At the left is a burned spot covered with reproduction, and beyond it is a group of advance-growth hemlock.

Second Combined Preparatory and Seeding Cut — December, 1935

The second cut was made with two aims in mind, both of which were expected to bring about an improvement in regeneration: (1) by concentrating on the hemlock, the denser crowned and predominent species, to open up the canopy enough to assure the establishment of hemlock reproduction, if not pine as well; and (2) to scarify the top soil through the mechanical action of logging.

The tally of trees marked for cutting was as follows:

	Number of Trees per Acre D.B.H. (in inches)											
	8	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*Total*
Hemlock	1	10	10	9	6	9	3	2	1	1	1	53

The volume of the cut amounted to about 5,248 board feet, or nearly 20 percent of the volume of the stand before cutting.

The operation was carried out in late December, and the logs trucked to a mill set on another part of the Forest. The small amount of logging slash was lopped and scattered. The volume removed in the second cut was only 80 percent of that in the first cut, and the cost of felling and bucking, in man-hours, was somewhat less. The lowered cutting cost was due primarily to the much larger average tree size in the second cut.

Stand Conditions — September, 1941

Aside from the burned and scarified spots, practically no reproduction dating from the first shelterwood cut (1924) was present. After the second cut (1935), however, and up to the time of the hurricane of 1938, scattered hemlock and pine became established over the entire area. A fair stocking probably would have been obtained following one or two more seed years if the hurricane had not interfered.

The overstory was completely windthrown by the hurricane. In addition to the damage to the older trees, much of the reproduction that had become established after the second cutting eventually was also destroyed, either by drying out following removal of the overstory or by injuries from the hurricane clean-up. Most of the remaining reproduction consisted of small, dense groups of firmly established hemlock.

The reproduction of both conifers and hardwoods on the area was very

much less than that on the two-cut shelterwood area (Case No. 15). Reproduction counts showed the following stocking:

	Number of Stems per Acre		
	Coniferous Reproduction		
	1934 Seed	*1938 Seed*	*Total*
White pine	400	1,000	1,400
			1,265
Total			2,665
	Hardwood Reproduction		
	Seedlings	*Sprouts*	*Total*
Pin cherry	2,464		2,464
Black birch		132	132
Red maple		132	132
Aspen	67		67
Total			2,795

The coniferous reproduction numbered only about one third that on the two-cut area (about 2,700 stems per acre as compared with 7,800). All the pine reproduction was from the two most recent seed years, 1938 and 1934. Its distribution was patchy, the older seedlings occurring in the larger openings made by cutting and the younger where logging had broken up the organic layer or where the mineral soil was exposed around upturned stumps.

Hemlock reproduction was tallied only according to number and size because of the difficulty of determining its age. Of the total number, 64 percent ranged in height from 6 to 18 inches; 26 percent, from 18 inches to 3 feet; and 10 percent, over 3 feet. Like the pine, the hemlock had spotty distribution, occurring in dense groups where slash had been burned, on exposed edges of the old stand or, in the case of the smallest size class, on top of old piles of well-rotted slash. The hardwood element was made up almost entirely of inferior stems; most of it was pin cherry, with a scattering of black birch, red maple, and aspen. The sprouts of both black birch and red maple appeared weak.

The amount of pine and hemlock seedlings available was insufficient for the development of a fully stocked stand, mainly because of a patchy distribution. More than half of the ground space was still open. Whether these openings would eventually be taken over by undesirable ground plants or by pine and hemlock remained to be seen.

Inspection of the Area — July, 1949

Analysis of the young stand at this date showed 53 percent of the area [3] desirably stocked, 22 percent undesirably stocked, and 25 percent open. Hemlock and white pine strongly predominated on the desirably stocked plots, and gray birch and pin cherry on the undesirably stocked. A scattering of red maple, red and black oak, black cherry, and red spruce completed the composition. In addition to free-to-grow hemlocks — tallied as the dominant element in 43 percent of the desirably stocked milacre plots — there were some 840 overtopped hemlocks per acre. White pine was in second place, being dominant in 39 percent of the desirably stocked plots. The age of the white pine ranged from 8 to 13 years, half of it originating after the hurricane.

Discussion

As in Case No. 15, an unfavorable seedbed condition at the beginning of the experimental cuttings was chiefly responsible for failure to secure adequate reproduction within a reasonable length of time. The abundance of hemlock seedlings in a small hand-scarified plot, and fairly plentiful reproduction on spots where the organic layer had been destroyed by burning slash and where trenching had reduced root competition gave proof that there was no shortage of seed or any critical lack of light. A heavier cut in 1924, especially one approaching the seed tree method in intensity, almost certainly would have resulted in more plentiful reproduction, but it would have been a mixed reproduction of hemlock and white pine not in accord with the aim of the cuttings.

The original plan to establish hemlock reproduction several years in advance of white pine probably could have been achieved through the development of a more favorable seedbed prior to 1924. This might have been done through a series of thinnings during the previous 50 years, which might have prevented the accumulation of a thick organic layer.

The possibility of establishing a mixed reproduction of white pine and hemlock in which hemlock is the older by several years is yet to be demonstrated. However, the fact that such a relationship has been found locally in wild stands gives assurance that with adequate knowledge satisfactory results could be obtained on an experimental basis.

The strong tendency of the reproduction to reflect the composition of the previous stands — white pine and hemlock with scattered hardwoods — is displayed both by this case and by Case No. 15. Even after

[3] Based on 100 milacre (6.6 feet square) plots the stocking of each of which was rated as "desirable," "undesirable," or "no stocking."

complete exposure, in this instance caused by a hurricane, the result is the same. These facts indicate the wide range in reproduction methods applicable to this cover type as found on the light, sandy soils of the region. It is evident that various forms of the shelterwood method will prove well suited to these conditions, and that there is wide latitude for varying the timing and intensity of preparatory and seeding cuttings to secure the most desirable reproduction of white pine and hemlock.

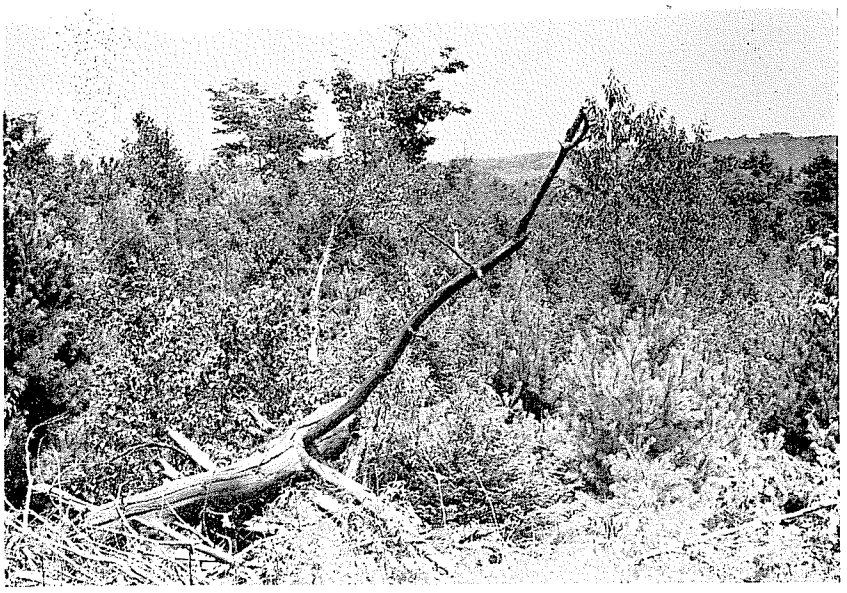

FIG. 12. JULY, 1949. ELEVEN YEARS AFTER THE HURRICANE

The residual stand was destroyed by the hurricane of 1938, thus abruptly terminating the experiment in shelterwood reproduction. The present young stand is poorly stocked in comparison with the stocking to be expected from the shelterwood method of reproduction, but its composition is very similar to that of previous generations.

CASE NO. 17

The Group Selection Method of Reproduction in the Hemlock Type

Block: Tom Swamp
Compartment: IX
Stand: Hem-2, 2.4 acres
Map: 1937–38

History to September, 1949

Introduction

Natural stands of white pine and hemlock on light, sandy soils frequently occur in a more or less uneven-aged, groupwise form. The area, arrangement, and age of the groups in an unmanaged stand appear to be largely a matter of accident, depending upon the history of cutting. If, at the time of the previous logging, the lumber market was good and the cutting heavy, the ensuing stand might be made up of large groups varying in age by not more than 30 years. On the other hand, a lighter cut, removing only groups of larger trees, might result in a stand composed of smaller groups having a wider range in age.

This case deals with the group selection method of reproduction applied to an uneven-aged stand of hemlock which had been so logged in the past as to give rise to fairly well defined age classes. Although pure hemlock is not a common forest type in the region, the presence of a stand with a groupwise distribution offered an excellent opportunity to try a cutting method aimed at maintaining the groupwise arrangement. Unlike the shelterwood method, the selection method is applied to uneven-aged stands and, ideally, to stands in which all age classes, from seedlings and saplings to mature trees, are present in equal numbers. In the group — as contrasted with the single-tree — selection method, a number of trees of the same age constitute a cutting unit, an arrangement that facilitates harvesting and reduces the amount of damage to young trees when the mature trees are felled.

Location and Physical Properties of the Site

This stand is contiguous to the stands dealt with in the two previous cases, and the conditions of site are similar.

Land Use History

According to Marshall (1927), this area, like the two preceding ones, has always been in forest. Prior to any cutting, the stand doubtless consisted principally of white pine and hemlock with a sprinkling of hardwoods, as did the stands on the adjoining areas.

FIG. 13. NOVEMBER, 1924. THE HEMLOCK STAND JUST BEFORE CUTTING.

A group of older hemlocks appears at the left, and a middle-aged group at the right. The former had its origin in suppressed hemlocks released in the cuttings of 1843 to 1845, the latter in hemlocks freed in the logging operation of 1884. There was a thick, matted organic layer on top of the mineral soil and almost no ground vegetation of any kind under the hemlock canopy.

Some very light cutting may have been undertaken around 1822, as indicated by accelerated growth on scattered trees examined by Marshall in 1924. Partial cuttings were made around 1843 and again in 1884.

According to Marshall (1927):

> 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.

Group Selection Cutting — Winter of 1924–25

At this time the stand was made up of four fairly distinct age classes: 20–30, 35–45, 50–60, and 85 years. In addition, there were scattered trees considerably older, up to 130 years. An inventory showed an average stocking per acre of 620 trees 10 feet and over in height. Of this number, 81 percent were hemlocks, 4 percent white pines, and 15 percent mixed hardwoods. Black and yellow birch and red maple were the most abundant hardwoods; beech, chestnut, red oak, and paper birch also were present. Before cutting, the stand had the following composition and stocking:

	Number of Stems per Acre Total-height Class (in feet)			
Species	*10–30*	*40–60*	*70*	*Total*
Hemlock	280	195	30	505
White pine		22	6	28
Black and yellow birch	11	34		45
Red maple	14	16		30
Beech	2	3		5
Chestnut		3		3
Red oak	2			2
Paper birch		2		2
Total	309	275	36	620

The canopy was broken only by a few small natural openings in which some hemlock had already started; in the largest of the openings, about three square rods in size, there was a dense stocking of young seedlings. Under the heavy hemlock canopy a matted organic layer was present, in many places measuring 2 to 3 inches in thickness. Beneath the hemlock canopy there was little or no tree reproduction or ground cover of any kind.

In mind when marking the stand for cutting was the desirability of harvesting the mature trees, providing favorable conditions for natural reproduction, and improving the general arrangement, size and shape of the remaining groups and openings with a view toward improved distribution of age classes. Cutting was confined mostly to the oldest group,

the 85-year class, and some of the scattered older trees. All hardwoods and most of the white pines also were cut. In a few cases thinnings were made in younger hemlock groups where stocking was very dense. The areas from which mature trees were removed ranged from small circular openings some 20 feet across, to one 100 feet long and 50 feet across. The trees were felled away from the openings in order to avoid heavy accumulations of slash that would interfere with the establishment of reproduction.

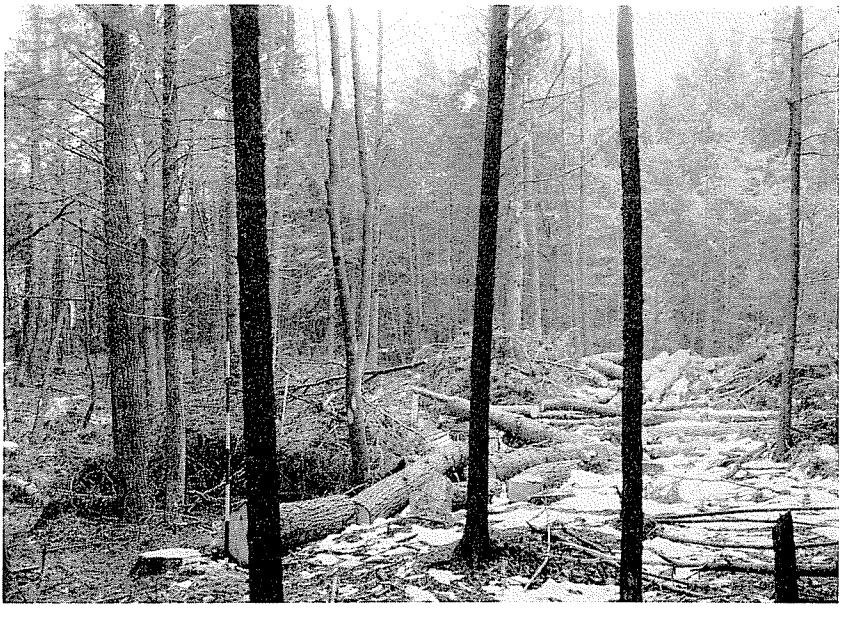

FIG. 14. NOVEMBER, 1924. CUTTING A GROUP OF THE OLDEST HEMLOCKS

An opening has been made by removing a group of hemlocks in the 85-year class. It was expected that hemlock reproduction would later become established.

By so doing, a few trees in the surrounding groups were damaged, and these also were removed. Tops were lopped and the slash scattered, the only exception being along the woods road, where it was piled and burned. The group openings were large enough to facilitate the felling, and small enough, it was hoped, to inhibit the establishment of light-demanding hardwood species. The logs were hauled on wooden scoots to a nearby portable mill.

The matted condition of the organic layer, the frozen and partially snow-covered ground, and the comparatively small volume of logs

extracted all worked against breaking up the litter and duff and exposing the mineral soil.

Volumes per acre removed amounted to 2,440 board feet of white pine, 6,310 board feet of hemlock, and about 5 cords of hardwood fuelwood. Volumes per acre remaining in trees 6 inches and over amounted to about 14,200 board feet of hemlock and 350 board feet of pine.

FIG. 15. OCTOBER, 1928. A GROUP OPENING FOUR YEARS AFTER CUTTING

In the opening at the right, black birch and other hardwoods came in abundantly; but hemlock seedlings were comparatively few in number and overtopped by the hardwood seedlings. In contrast to the stocking of the opening, there is little or no reproduction under the uncut hemlock group at the left. Same view as Fig. 14.

Stand Conditions — September, 1931

Some hemlock and much larger quantities of hardwood, including black, paper, and gray birch, pin cherry, poplar, red maple, red oak, and beech, had seeded in the openings made by the cutting of 1924–25. Black birch was most abundant; the others occurred sparingly. Hemlock seedlings were present in small numbers in all the openings, but were invariably overtopped by hardwoods. The hemlocks were only from one to two feet high, while the hardwoods ranged up to seven feet. There was much uncertainty as to whether the hemlocks would eventually outgrow

the hardwoods. Density of the reproduction, both hemlock and hardwood, varied more or less directly with the size of the opening in the canopy. Dense patches of slow-growing hemlock seedlings had become established on well-rotted stumps and logs. In contrast, under the uncut portions of the stand there was virtually no reproduction.

With the lapse of seven growing seasons, it was evident that expectations with respect to reproduction had not been fully realized. The group cuttings had brought in hemlock, but, unexpectedly, they had also encouraged the coming in of much faster growing hardwoods, including some long-lived species.

Stand Conditions — September, 1938

The hurricane of 1938 completely destroyed the stand. Prior to this event, satisfactory hemlock reproduction had been obtained only in the largest group-cut openings. The abundance of hardwood reproduction on such a sandy site was wholly unexpected, and it was thought that weedings would have to be made to free the hemlock reproduction beneath it. Most abundant, by far, was black birch. Other species occurring less frequently included gray and paper birch, pin cherry, poplar, beech, red maple, and red oak.

Aside from hemlock and hardwood saplings in the group-cut openings, the general appearance of the stand was similar to that in 1925 immediately after logging. The groupwise form was still clearly defined. There were some 265 hemlocks per acre, ranging from 2 to 17 inches d.b.h. and 30 to 80 feet tall.

Stand Conditions — September, 1941

Two seasons had passed since the completion of the hurricane salvage operations. The openings made in the group cuttings of 1924–25 stood out in sharp contrast to the rest of the area. In spite of losses in reproduction caused by the hurricane salvage operations, most of the 1924–25 openings supported enough coniferous reproduction to form the basis of a well-stocked stand. The largest openings had the best stocking. One of the largest had a stocking of 17,000 hemlocks and 1,000 white pines per acre. Practically no pine reproduction had become established prior to the hurricane, presumably because the group-cut openings were too small. All pine seedlings, except a few in the largest group-cut opening, originated from the seed crop of 1938.

Most of the hemlock occurred in dense clumps, usually associated with well-rotted slash, and most of the pine had started on beds of *Polytrichum* moss. No reproduction except that which had come in after

the hurricane, such as pin cherry, gray and paper birch, and a few red maples, had started on the uncut (in 1924–25) portions of the area, where a heavy organic layer still existed.

Contrary to earlier forecasts, the hardwood reproduction had not seriously handicapped the development of the conifers. Many of the hardwoods, especially black birch, had died following the hurricane. Hardwoods that sprouted or seeded in following the hurricane salvage operations were not vigorous, and appeared unlikely to offer serious competition to the hemlock and pine; rather, they might prove useful in providing partial shade for the young conifers and in improving soil fertility.

Inspection of the Area—July, 1949

An analysis of the young stand which occupied the area eleven years after the hurricane showed that 51 percent of the ground area [4] was stocked with trees of desirable species, 35 percent with those of undesirable species, and that 14 percent was open. Hemlock was the dominant species on 48 percent of the desirably stocked plots, white pine on 37 percent, and better hardwoods on the remaining 15 percent. Among the hardwoods, black and paper birch were most common; an occasional yellow birch and red maple completed the composition of the better hardwood element. Among the inferior hardwoods, occupying the undesirably stocked plots, gray birch was in the lead, followed by pin cherry and aspen. There were, additionally, some 1,300 overtopped hemlocks per acre.

As shown in Figure 16, the total stocking in many places was too light to permit developing the best-quality timber stands. White pine, in particular, had coarse branches and weeviled leaders characteristic of this species when open-grown.

Measurements showed the organic layer to be fully an inch thick on the average even though more than a decade had elapsed since the ground was exposed through destruction of the residual stand by the hurricane.

Discussion

This experiment in reproducing a hemlock stand by a group-cutting method turned out more favorably than those previously described, in which modifications of the uniform shelterwood method were used in an attempt to reproduce mixed white pine and hemlock. On these sites hemlock is more readily reproduced than white pine under any system of natural regeneration that retains a substantial crown canopy during the reproduction period.

[4] Based on 200 milacre (6.6 feet square) plots the stocking of each of which was rated as "desirable," "undesirable," or "no stocking."

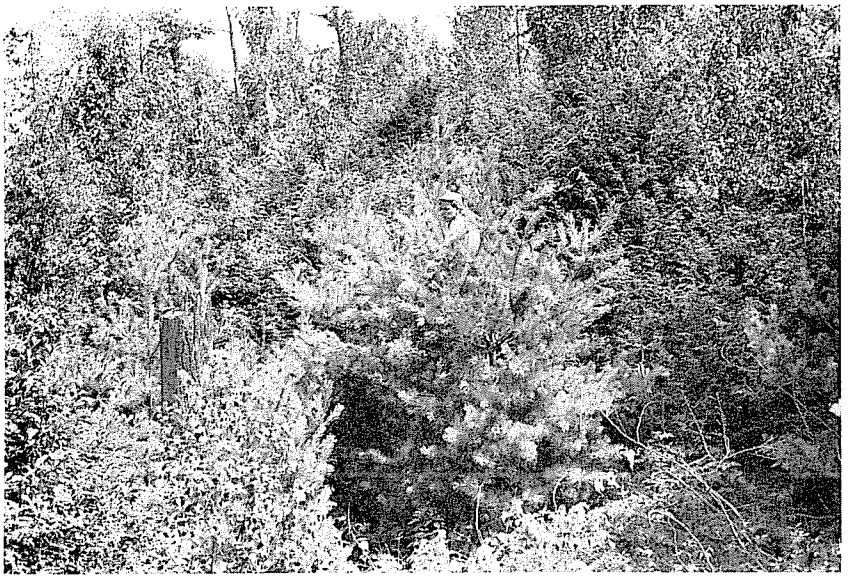

FIG. 16. JULY, 1949. ELEVEN YEARS AFTER THE HURRICANE

The stocking of trees of desirable species was generally low except where group openings made in the cutting of 1924 resulted in dense reproduction. Some white pines exhibit the extreme limbiness of open-grown trees.

That the group cutting was generally more successful than the first shelterwood cuttings in the two previous cases is apparently accounted for by the larger openings made in the stand by the removal of groups of trees, as compared with the removal of scattered single trees. The abundance of hemlock reproduction in the largest group openings, constitutes evidence that sizable openings are preferable — at least 40 feet in shortest dimension.

The early fear that hemlock reproduction would be seriously suppressed by faster-growing seedlings of black birch and other hardwoods apparently was unjustified. All observations lead to the conclusion that hemlock has been, and will continue to be, the leading species on this particular site, with hardwoods and white pine forming minor elements in the stand.

CASE NO. 18

The Clear-Cutting in Alternate Strips Method of Reproduction in the White Pine-Hemlock Type

Block: Tom Swamp
Compartment: IX
Stand: P-9, 3.9 acres

History to September, 1949

Introduction

Clear-cutting in alternate strips was chosen as a reproduction method differing basically from both the shelterwood and group selection methods, yet offering promise of equally good results under existing conditions. The establishment of an adequate stocking of coniferous seedlings in the clear-cut strips would, it was thought, depend on a favorable seedbed condition, abundant seed from the trees on the intervening uncut strips, and a reduced intensity of competition from herbaceous and shrubby vegetation and inferior hardwoods.

Because the soil was light and sandy and the old stand predominantly white pine and hemlock, little competition from hardwood reproduction was expected. Where clear-cutting by strips had been tried in old field pine stands on heavier upland soils in the Harvard Forest, the result almost invariably had been a thicket of seedlings and sprouts (from stools of the advance growth cut at the time of logging) and complete suppression of any pine reproduction.

As shown in Figure 1, there were three strips oriented in a north-south direction, their widths ranging from 80 to 140 feet, and a fourth strip, running east and west, 100 feet wide. It was hoped that differences in the amount and distribution of white pine and hemlock reproduction could be observed and related to the width and direction of the cleared strips. An abundance of both pine and hemlock trees of seed-bearing age in the intervening uncut strips and surrounding reserve area assured an adequate supply of seed.

Location and Physical Properties of the Site

This area immediately adjoins the two-cut shelterwood area on the south and is characterized by the same type of relief. The soil is similar, being made up of stratified layers of coarse-textured glacial outwash, with

a surface layer of organic material two to three inches thick underlain by a thin gray bleached layer.

Land Use History

According to Marshall (1927), this portion of the tract was never cleared for agricultural use. The original stand consisted principally of white pine and hemlock with a sprinkling of red spruce and such hardwoods as chestnut, beech, red maple, yellow birch, and red oak. Some light cuts were made between 1849 and 1853; these destroyed most of the understory trees, largely slow-growing hemlocks. White pine became the dominant element in the new stand. The young pine was extremely dense in places; and as it developed, the trees became tall and spindling with small branches. Underneath the main canopy of pine was a subordinate stand of hemlock its age being about the same as that of the pine. By 1924 this stand had reached an age of 60 to 70 years and was generally two-storied, with pine over hemlock. In portions of the stand the hemlock had effectively pruned the pine, making clean, straight stems. For the most part, the stocking of pine was dense, resulting in small crowns, low vigor, and an unusually large amount of red rot (*Fomes pini*).

Just prior to logging, in the winter of 1924–25, the following observations were made in the strips that were laid out for clear-cutting.

East-West 100-foot Strip

In this strip the composition was equally divided between pine and hemlock, with about 300 trees per acre of each species. In volume, however, white pine constituted 85 percent and hemlock only 15 percent. There were a few scattered hardwoods, notably some poplars in the southwest corner. Advance growth consisted of a small group of hemlock a few feet tall on the high ground in the northeast corner of the strip and another clump in the bottom of a hollow. Ground cover was practically absent except for a little ground hemlock.

North-South 80-foot Strip

Here the pine was nearly twice the height of the hemlock, although the age of both species averaged between 60 and 70 years. The stocking averaged about 500 trees per acre. The composition by stems was 70 percent pine, 22 percent hemlock, and 3 percent hardwood; by volume, 90 percent was pine and 10 percent hemlock. The stand was dense enough to exclude all advance growth and ground cover except scattered, stunted hemlocks

FIG. 17. 1925. THE TWO-STORIED CHARACTER OF THE STAND

In places, a high density of stocking and an understory of hemlock had produced tall, slim white pines with comparatively clean boles. Under such conditions diameter growth is slow, and white pine is more subject to attack by red rot.

and some ground hemlock. At the bottom of a depression in the center of the strip, laurel, spinulose shield fern, and ground hemlock occurred scatteringly.

North-South 110-foot Strip

With the exception of its extreme northern end, this strip had the densest stocking of all four strips. The trees were tall and slender with very little taper. The stocking averaged 675 trees per acre. The composition by stems was 48 percent pine, 48 percent hemlock, and 4 percent hardwood; by volume, approximately 90 percent was pine and 10 percent hemlock. In the northern end the form of the pine was more like that of the old field type, more widely spaced and coarser in quality.

North-South 140-foot Strip

This strip contained the poorest quality trees and the lowest stocking, with only 392 trees per acre. In the north end the pines were scattered, scrubby, and of small size; in the south end there was considerable hardwood. Scattered hemlock and pine advance growth was present, particularly in the natural openings.

Clear-Cutting in Alternate Strips — January-February, 1925

All trees in the strips laid out for clear-cutting were felled. At the time of logging the weather was particularly bad, with deep snow and subzero temperatures; the logs were frozen and covered with snow, thus slowing down the operation. The density and quality of the timber as well as differences in topography influenced the efficiency of felling and log extraction. The 140-foot strip yielded the poorest logs. The 80-foot strip was the best, both as to quality of timber and ease of logging.

The volume of timber removed from the four clear-cut strips, based on a mill tally of the lumber produced, was as follows:

	Area in acres	*Board feet per acre cut*
East-west 100-foot strip	0.9	29,882
North-south 80-foot strip	0.8	33,297
North-south 110-foot strip	0.9	32,187
North-south 140-foot strip	1.3	19,317
	3.9	

Cutting and extracting were facilitated by felling the trees in windrows (See Fig. 18), a practice common locally in clear-cutting old field white pine stands. Burning the windrows of slash was delayed until the summer of 1925, owing to the urgency of other work.

FIG. 18. JANUARY, 1925. THE NORTH-SOUTH 80-FOOT STRIP

The trees were felled so that logs and slash formed separate windrows, a practice commonly followed in clear-cutting even-aged white pine stands to facilitate the extraction of the logs. The slash was burned several months after logging.

Because 1924 was a good seed year, for both white pine and hemlock, it was thought that reproduction would come in abundantly during the 1925 growing season.

The horses and scoots used in extracting the logs did not break up the organic layer and expose the mineral soil to any appreciable extent.

Inspection — September, 1931

Contrary to expectations, in the interim between 1925 and 1931 very little coniferous reproduction had seeded in on the clear-cut strips in spite of the occurrence of three pine seed years, 1924, 1927, and 1930, and at least as many for hemlock. The seed present at the time of logging from the crop of 1924 failed to produce successful reproduction, probably because

of the thick organic layer. Because logging had been done with snow on the ground, the organic layer was only slightly disturbed; in 1931 it was still over an inch thick. Coniferous reproduction was present where slash had been burned and where beds of *Polytrichum* moss had become established. Hardwoods, mainly pin cherry, paper and gray birch, red maple, and oak, seeded in thickest along the southern and western borders of the cleared strips under the partial shade of trees in the residual strips. Elsewhere they occurred only scatteringly.

A detailed description of each strip follows.

East-West 100-foot Strip

In the extreme western end of the strip, which was protected on three sides by the surrounding forest, there was a good stocking of hemlock and some pine. The areas where slash had been burned were well stocked with gray and paper birch, hemlock and pine. Pine reproduction was especially thick on *Polytrichum* moss beds.

Between the western end and the depression, or pothole, there were scattered stump sprouts of red maple and black cherry, seedling poplar and pin cherry, and some red oak. Plenty of bracken, blackberry, grass, sweet fern, and aralia supplemented the hardwood regeneration. There was insufficient good material for a new crop.

In and around the pothole some pine reproduction had become established, particularly in the moister places; and on the south side, poplar root suckers, scattered gray and paper birch, poplar, and pin cherry seedlings formed a partial shade over a heavy ground cover that included blackberry, grasses, ferns, and wild sarsaparilla.

The eastern end of the strip, which is on higher, more exposed ground, supported only a few seedlings of white pine, pin cherry, and gray birch; but the usual thicket of blackberry, grasses, wild sarsaparilla and sweet-fern (on burned spots) was present. On a *Polytrichum* moss bed near the old fire weather station several white pine seedlings were noted, but almost none elsewhere in this portion of the strip.

North-South 80-foot Strip

North of the depression, near the center of the strip, in places where slash had been burned, a dense growth of sweet-fern, sumac, gray birch, willow, and blackberry had come in. With the exception of sweet-fern there was no striking difference in the amount or kind of vegetation on the burned spots as compared with the adjoining unburned area. In the case

of the shelterwood cuttings, willows and birches outnumbered other species on the burned spots, but in this case sweet-fern predominated.

Elsewhere hardwoods, chiefly pin cherry, had become established scatteringly or in small groups. A few sprout clumps of red maple had developed from stumps of trees in the previous stand. Altogether the hardwoods occupied not more than 30 percent of the ground area.

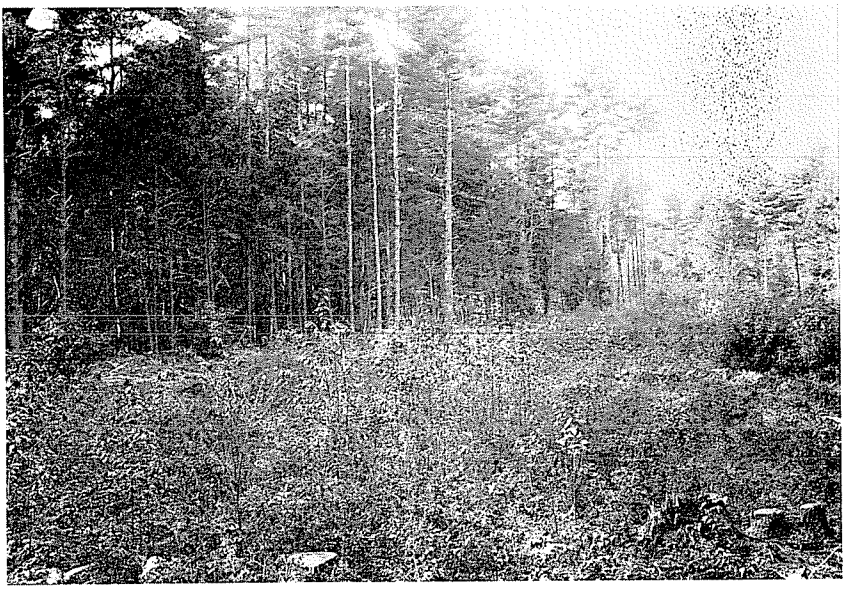

FIG. 19. NOVEMBER, 1928. SOUTHERN PORTION OF THE NORTH-SOUTH 80-FOOT STRIP

Four years after cutting, seedlings of pin cherry, poplar, gray birch, red maple, and oak had come in scatteringly over much of the cutting area. Some white pine reproduction was found on moss beds and in places where slash had been burned.

Pine reproduction was uneven but generally thrifty, the greatest amount of it being where there was least ground cover. There was no hemlock reproduction except in the extreme southern end of the strip, bordered on three sides by high forest.

The ground cover was generally distributed over the area and composed chiefly of blueberry, raspberry, spiny aralia, sarsaparilla, with lesser amounts of goldenrod, grasses, *Polytrichum* moss, sweet-fern, wintergreen, and *Maianthemum*.

The organic layer was still one to two inches thick.

North-South 110-foot Strip

In the southern half of the strip about 60 percent of the area was covered with pin cherry, scattered gray birch, paper birch, sprout clumps of red maple, black cherry and poplar. The ground cover was dense, composed chiefly of aralia, blueberry, raspberry, and sweet-fern. Where slash had been burned, grass, goldthread, and twinflower were also found. Pine reproduction was scanty and no hemlock reproduction was present.

The northern half of the strip contained much less hardwood regeneration and much more grass. Pine reproduction was very scanty, and hemlock was absent.

The new stand on this strip was not at all satisfactory. Pine reproduction was insufficient to form the basis of a new crop and the hardwoods were largely of weed species. No treatment was recommended until after one or more pine seed years, in the hope that a sufficient quantity of new seedlings would come in to form an adequately stocked stand.

North-South 140-foot Strip

About 20 percent of the ground area was covered with gray birch, pin cherry, and poplar seedlings, together with a few sprout clumps of red maple and black cherry. Under the hardwoods and over the remainder of the area there was a uniformly dense ground cover made up chiefly of blackberry, with some spiny aralia, grass, *Polytrichum* moss, sweet-fern, and *Maianthemum*.

Pine reproduction was scanty, even in the most open places, and hemlock was practically absent.

The amount of desirable reproduction on this strip was likewise inadequate. With the exception of the extreme southern end, where there was enough paper birch to form a stand, the area was very poorly stocked with either white pine or better hardwoods. The organic layer was still one to two inches thick. It remained to be seen whether future pine seed crops would result in adequate restocking.

Weeding, 3.9 acres — June, 1937

Twelve years after the strip cuttings, a fairly satisfactory reproduction of both pine and hemlock was present in places where there was a cover of hardwood saplings. Beds of *Polytrichum* and *Hypnum* moss, occurring throughout the clear-cut strips, also supported some pine and hemlock reproduction. Over the larger part of the cutting area, however, a thick organic layer or a heavy ground cover of blueberry and blackberry apparently had inhibited the establishment of coniferous seedlings.

The weeding was for the purpose of freeing reproduction of pine and hemlock from the suppressive action of hardwoods, chiefly pin cherry, gray birch, and red maple. All hardwoods in an overtopping position were cut back close to the ground with machetes. The operation was very light, being completed in 7 man-hours.

Stand Conditions — September, 1941

Damage to the reproduction in the clear-cut strips by the hurricane of 1938 was slight. Some losses were caused by falling trees from the intervening reserved strips, and also by the salvage operation following the blow-down. But the greatest loss to the established reproduction was from a fire during the hurricane salvage operation that swept over the northern portions of the three north-south strips.

The stocking per acre in 1941 in the four strips clear-cut in 1925 was as follows:

	Stocking (Number of Stems per Acre)			
Species	*East-West 100-foot Strip* *	*North-South 80-foot Strip* **	*North-South 110-foot Strip* †	*North-South 140-foot Strip* ‡
White pine	7,130	400	1,300	3,090
Hemlock	2,260	none	600	630
Red oak	none	none	100	90
Gray birch	460	100	200	1,180
Poplar	800	100	none	270
Pin cherry	330	3,800	2,500	270
Red maple	200	100	800	270
Black cherry	130	none	none	none
Paper birch	200	100	100	90
Yellow birch	none	none	100	none
	11,510	4,600	5,700	5,890

* Based on 20 random milacre plots.
** Based on 10 random milacre plots.
† Based on 10 random milacre plots.
‡ Based on 11 random milacre plots.

There was nearly twice as much reproduction per acre in the east-west 100-foot strip as in any other. The 80-foot strip had the lowest density of all four. The difference in stocking between the east-west strip and the north-south strips seems to be associated with orientation rather than

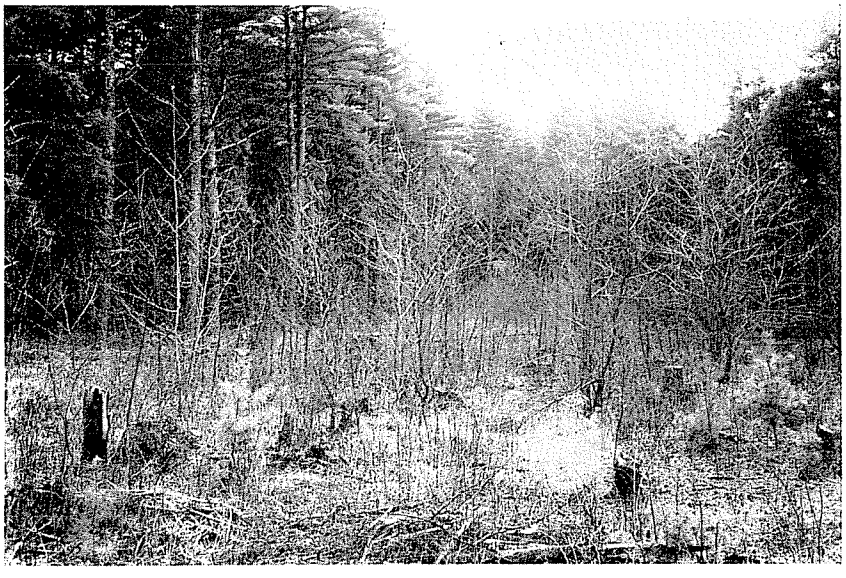

FIG. 20. APRIL, 1935. NORTHERN END OF THE 80-FOOT STRIP

At the end of ten years, only a little white pine reproduction had come in, and this was mostly under the hardwoods.

FIG. 21. APRIL, 1935. WHITE PINE REPRODUCTION IN THE EAST-WEST STRIP

White pine reproduction was most plentiful on the slope along the southern edge of the western end of the strip, especially under the protection of poplar root suckers. At the time of this photograph, some of the poplar had been cut to free the pine.

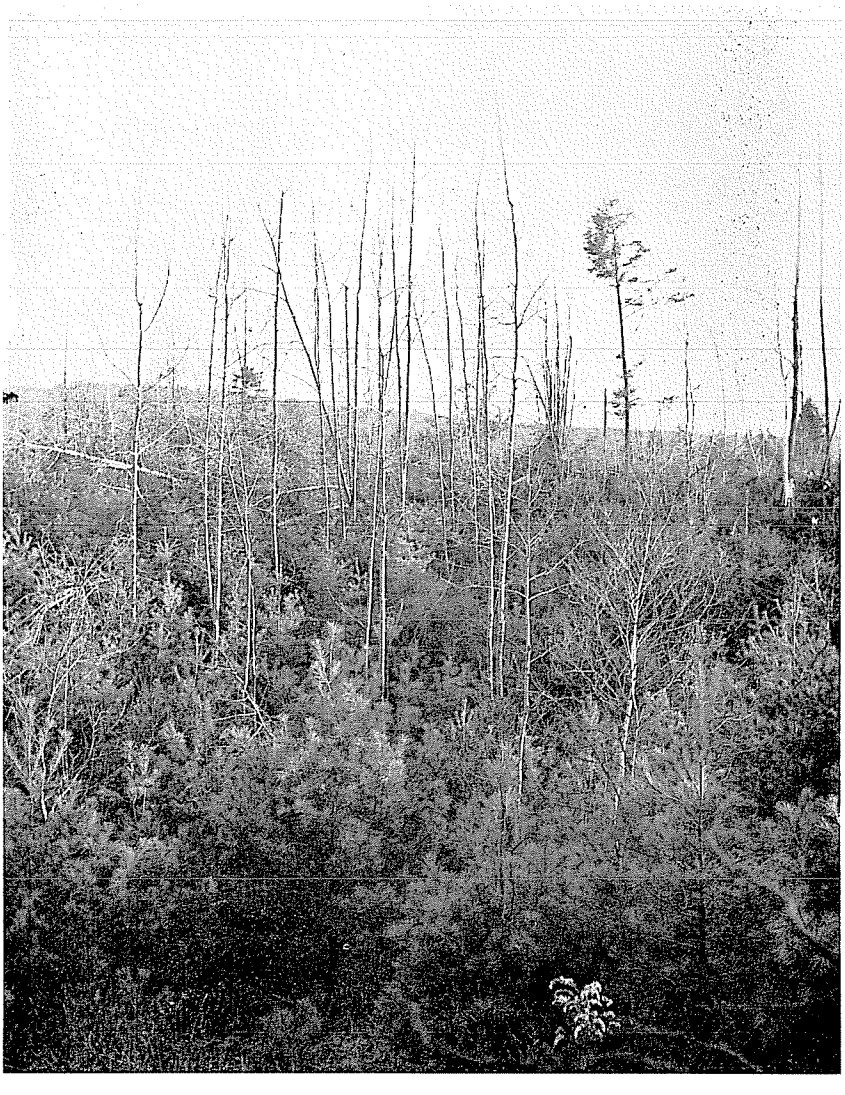

FIG. 22. NOVEMBER, 1941. WESTERN PORTION OF THE EAST-WEST 100-FOOT STRIP

Seventeen years after the strip cutting and three years after the hurricane blow-down, a well stocked group of white pine occupied the southern side of the western end of the strip. Partial suppression of the pine by the overtopping poplar has improved the form of the pine.

differing widths of strip. Variations in the quantity of reproduction among the north-south strips themselves is due largely to the forest fire; more area was burned over in the 80-foot strip than in either of the other two.

In all four strips the tree reproduction was most plentiful in areas that were most shaded — the southern and western edges. The heaviest concentrations of pine and hemlock reproduction were invariably associated with hardwoods, which in nearly all cases had preceded the conifers. The east-west strip, with its long southern edge, had the advantage over the north-south strips. The largest single concentration of coniferous reproduction was on the southern bank of the pothole in the east-west strip where there was an overstory of poplar root suckers. Here the pines and hemlock were making the best growth. Poplar seems to make an excellent nurse tree for conifers on this kind of site.

None of the strips had a sufficiently good distribution of coniferous reproduction to make a fully stocked stand. Many large areas supported nothing but mats of sweet-fern or blueberry. Other areas, open at the time of the hurricane, had since seeded in with pin cherry, gray birch, and other light-demanding hardwoods. Some of the hardwoods established soon after the cutting of 1925, particularly poplar, had reached a height of 30 to 40 feet; others, like gray and paper birch, red maple and oak, were only 15 to 20 feet tall. Poplar and pin cherry were already dying out, thus freeing the conifers growing beneath them.

The hemlock reproduction was of small size, most of it having seeded in since 1930. The white pine reproduction varied from seedlings only a few inches high to saplings 10 to 12 feet high. The quantity of white pine reproduction per acre in the four strips according to seed-year origin was as follows:

	Number of Stems per Acre				
	Seed Year				
	1938	*1934*	*1930*	*1927*	*Total*
East-west 100-foot strip	6,133	266	666	66	7,131
North-south 80-foot strip	. .	400		. .	400
North-south 110-foot strip	700	100	500		1,300
North-south 140-foot strip	2,727	272	90		3,089

Most of the pine was from the seed crop of 1938, the year of the blowdown; none antedated 1927.

Inspection of the Cutting Area — July, 1949

A tally of stocking on 100 milacre plots in each of the four clear-cut strip areas showed the following:[5]

	Desirable Stocking	*Undesirable Stocking*	*No Stocking*	*Total Plots*
East-west 100-foot strip	62	14	24	100
North-south 80-foot strip	36	46	18	100
North-south 110-foot strip	52	33	15	100
North-south 140-foot strip	50	40	10	100

The incidence of the better species occurring in a free-to-grow position on the plots with desirable stocking was as follows:

	White Pine	*Hemlock*	*Red Spruce*	*Paper Birch*	*Black Cherry*	*Red Oak*	*Red Maple*	*Total Plots*
East west 100-foot strip	57	2	1		1		1	62
North-south 80-foot strip	33	1				1	1	36
North-south 110-foot strip	51	1						52
North-south 140-foot strip	43	4		3				50

Although the intervention of the hurricane, with attendant salvage operation and forest fire, prevented comparison of the stocking in the four strips as influenced by strip width and direction, there were interesting observations to be made with respect to species composition. White pine was much the most abundant among trees of the better species tallied as "free-to-grow," thus again showing its ability to thrive in mixed stands on these sites. Several hundred overtopped hemlocks per acre were tallied, thus assuring the development of another predominantly coniferous stand of two-storied form.

In all cases, gray birch was the leading species occurring on the undesirably stocked plots, followed by pin cherry, red maple and poplar.

Examination of the soil showed the presence of an organic layer ranging in thickness from 1 to 2 inches; and beneath it, a gray or bleached, layer ranging from a trace to an inch or more in thickness.

As shown in the accompanying photograph (Fig. 23), the stocking was light and, as a consequence, most of the trees in free-to-grow positions

[5] On each plot the stocking was rated in one of the three classes.

FIG. 23. JULY, 1949. THE EAST-WEST 100-FOOT STRIP TWENTY-FIVE YEARS AFTER CUTTING

This view, looking east from near the middle of the strip, shows the poorer stocking (left) on the northern edge of the strip as compared with that on the southern (right).

were bushy. Most of the white pines had been attacked by the white pine weevil, an additional cause of bushiness.

Discussion

In the plan for the strip cuttings, the width of the three north-south strips ranged from approximately the height of the tallest white pines to double that height. Strip width was varied so that the effect of distance from seed source upon density of the pine and hemlock reproduction could be studied. The width established for the two intervening strips (70 feet) to be left uncut as a source of side protection and seed was considered sufficient to prevent undue blow-down and provide plenty of seed trees.

An east-west strip of intermediate width (100 feet) was added, in the form of a connecting corridor extending across the northern ends of the north-south strips, in the expectation that some further knowledge of the influence of strip orientation on the occurrence of coniferous reproduction would be gained.

Because of the lightness of the soil and the relatively few hardwoods in the old stand, it was thought that the clear-cut strips would seed in satisfactorily with white pine and hemlock, at least along the edges of the surrounding uncut stands and in the more protected spots.

From the beginning, the thick organic layer was looked upon as a hindrance to the establishment of reproduction. The season following cutting, an attempt was made in the 80-foot strip to scarify the soil with a spike-toothed harrow; but, as demonstrated on the two-cut shelterwood area, there was too much organic material for such a tool to work, and the attempt was abandoned. Nevertheless, it was believed that full exposure of the ground to sun and rain would result in rapid decomposition of the litter and duff, and that the start of pine and hemlock seedlings would not be delayed more than a few years.

What actually took place after the strips were clear-cut was an unexpectedly large influx of inferior hardwoods, notably pin cherry, and the development of a ground cover that was dense enough in places to inhibit conferous reproduction. The reproduction area, with its irregular distribution of hardwoods — including scattered rank-growing stump sprouts — and patchy ground cover, took on an untidy and disordered appearance quite in contrast to the shelterwood and selection areas, as well as to the surrounding residual stands, which continued to lack both reproduction and ground cover of any kind.

Pine and hemlock reproduction did come in slowly and scatteringly, apparently being hampered in some places by the persistent thick layer of litter and duff and in others by beds of blueberry, sweet-fern, and other

ground plants. That it did not come in more abundantly and promptly following the good seed crop of 1924 was undoubtedly due to the unfavorable seedbed. The scarcity of pine and hemlock reproduction following the subsequent seed years was likewise due to a poor seedbed and the competition of ground cover that became established within a few years after the cutting. Only in a few places where piles of slash had been burned and on the protected south slope at the western end of the east-west strip in a thicket of poplar root suckers did white pine come in thickly.

As in the previous cases, it is clearly evident that successful regeneration depends upon so handling the stand before the time of final harvesting as to prevent the accumulation of a thick, matted organic layer — a layer which if comprised of pine and hemlock needles and twigs is extremely resistant to decomposition. This might be accomplished through periodic thinnings of sufficient degree and frequency; otherwise, resort must be had to mechanical scarification by specially designed equipment.

CONCLUSIONS

Prior to 1924, there had been no cuttings in the case areas for 75 years or more. The accumulation of a mat of organic material some two to three inches thick on top of the mineral soil indicated the resistance of coniferous debris to decay under the continuous heavy shade of the pine-hemlock canopy.

That the quantity of coniferous reproduction was less than required for optimum stocking of the cutting areas was due largely to the poor condition of the seedbed caused by the thick organic layer. Tests made by hand-scarifying the soil in small plots showed that a great abundance of desirable reproduction would have resulted in all four cases had it not been for this thick layer of needle litter and duff. Furthermore, coniferous reproduction was plentiful on the small areas where the organic layer was destroyed by burning slash.

Proof of seed abundance was gained through seed traps which permitted actual count of seed fall.

The rate of decomposition of the organic layer under any of the partial cutting systems applied apparently was too slow to permit adequate reproduction within a reasonable length of time. Mechanical scarification of the soil — mixing the organic material with the mineral soil — is effective but too costly to apply under existing economic conditions.

From a silvicultural standpoint the presence of a thick organic layer is indicative of a stand allowed to remain too dense too long. The heavy, dark canopy shades the ground and shortens the growing season; the natural processes that decompose organic matter are retarded; and "black knots" are apt to develop in white pine. A high density of stocking of the overstory, accompanied by a dense understory of hemlock, causes acute competition for soil moisture and nutrients; the result is slow growth and stagnation.

The probable remedy for the condition described above is timely silvicultural treatment. Periodic thinnings might have prevented both the stagnation of the stand and the accumulation of a heavy organic layer. Under this kind of management, by the time the stand has reached the beginning of the reproduction period the seedbed should be nearly ready for the reception of seed.

Since clear-cut areas in the white pine-hemlock type on light soils

have been observed in numerous instances to come in to blueberry and other ericaceous plants with only scattered tree reproduction, some form of conservative partial cutting system should hasten tree establishment.

From the case histories here recorded, it would appear that any method of partial cutting, such as the shelterwood or selection, or even clear-cutting in narrow strips, would be suitable under conditions similar to those found on the Adams-Fay lot. As in the four cases comprising this study, the type of cutting may be advantageously modified to conform with variations in stand form and composition. Thus, in places where there is a more or less groupwise distribution by age classes, a group-selection type of cutting is indicated; and where the stand is essentially even-aged, some form of the shelterwood method.

In planning the cutting, attention should be centered on the size of opening. Openings should be large enough to promote seedbed improvement and the creation of conditions favorable for the establishment of desired reproduction, but not so large as to encourage the formation of a mat of ericaceous plants that would inhibit reproduction. Further experimentation will be required to determine just how large the openings should be, or to what degree the canopy of the parent stand should be opened up. For the present, perhaps the tentative finding of Case No. 12, that openings should not be more than 50 to 75 feet across, is as good as any to follow in the case of group cuttings.

The weedings applied to control undesirable hardwood elements during the regeneration period were of doubtful value except in the case of rank-growing stump sprouts, chiefly red maple. It appears that white pine and hemlock reproduction can be counted upon to hold its own with seedling hardwoods of like age on such sites, thus reducing crop establishment costs as compared with those in mixed stands on the heavier upland soils.

The near absence of blow-down in the residual stands, prior to the hurricane, may indicate greater windfirmness of white pine on light than on heavy soil; but it appears likely that the sheltered location, in the valley bottom, was also an important contributing factor.

The good response of the residual stands in the shelterwood areas to reduced competition, through the removal of a very substantial portion of the original stocking, was in accordance with expectations. Trees of the ages here encountered in stands of high density that have never been thinned may be expected to show a marked increase in growth rate following partial cutting. As shown by Marshall (1927), suppressed hemlock is particularly responsive to release.

The cutting areas were too small and weather conditions too variable during the course of logging operations to permit valid comparisons of

logging costs for the four cases. In general, logging and slash burning costs were highest in the shelterwood cases, the heavy understory of hemlock in the two-cut area (Case No. 15) being especially difficult to handle. Slash disposal in this area in the 1924–25 operation involved piling and burning large masses of hemlock tops and branches and required 38 man-hours per acre. Slash disposal in the strip cuttings, where slash could be burned in windrows, was much less costly; but even here, as throughout the entire cutting area, the presence of large numbers of small-sized understory hemlocks added substantially to all operating costs. In well-managed stands the accumulation of a dense, stagnated understory would be avoided.

The results of the experimental cuttings as well as general observations elsewhere point to the comparative ease and low cost of growing white pine on light, sandy soils in central New England. The much greater difficulty of growing this species on the heavier soils is directly related to the severe competition of hardwoods on these sites and the necessity of applying drastic treatments, particularly weedings, to prevent the hardwoods from choking out the pine. This was illustrated by the first eleven cases in Part I.

The pine-using industries of central New England, such as the New England Box Company, which made possible the Adams-Fay lot cuttings, can be assured that softwood timber will continue to grow on the light soils with a minimum expense for silvicultural treatment. Successful management, it is clear, hinges largely on an understanding of the relation of stand density to soil conditions. Through timely thinnings of moderate degree and conservative reproduction cuttings that avoid large openings and full exposure of the ground, the white pine-hemlock type probably can be managed indefinitely in a highly productive form. Proper cuttings will not only assure repeated crops and full yields of these species but will also make possible materially shorter sawtimber rotations through an increased rate of growth of the crop trees.

APPENDIX

LIST OF SPECIES MENTIONED IN TEXT

Trees

Scientific name [6]	*Common name*
Acer rubrum L.	red maple
Betula lenta L.	black birch
Betula lutea Michx. f.	yellow birch
Betula papyrifera Marsh.	paper birch
Betula populifolia Marsh.	gray birch
Castanea dentata (Marsh.) Borkh.	chestnut
Fagus grandifolia Ehrh.	beech
Picea rubens Sarg.	red spruce
Pinus rigida Mill.	pitch pine
Pinus Strobus L.	white pine
Populus grandidentata Michx.	poplar
Populus tremuloides Michx.	aspen
Prunus pensylvanica L. f.	pin cherry
Prunus serotina Ehrh.	black cherry
Quercus rubra L.	red oak
Quercus velutina Lam.	black oak
Salix spp.	willow
Tsuga canadensis (L.) Carr.	hemlock

Shrubs and Herbs

Scientific name [6]	*Common name*
Aralia hispida Vent.	spiny aralia
Aralia nudicaulis L.	wild sarsaparilla
Comptonia peregrina (L.) Coult.	sweet-fern
Coptis groenlandica (Oedar) Fern.	goldthread
Dryopteris spinulosa (O. F. Muell.) Watt	spinulose shield fern
Gaultheria procumbens L.	wintergreen
Kalmia latifolia L.	laurel
Linnaea borealis L. var. americana (Forbes) Rehd.	twinflower
Pteridium aquilinum (L.) Kuhn	bracken
Rhus spp.	sumac
Rubus spp.	blackberry, dewberry, raspberry
Solidago spp.	goldenrod
Taxus canadensis Marsh.	ground hemlock
Vaccinium spp.	blueberry

[6] Nomenclature follows *Gray's Manual of Botany*, by M. L. Fernald. American Book Company, New York, 8th Ed., 1950.

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