ABSTRACT

STAND COMPOSITION IN THE HARVARD FOREST AS INFLUENCED BY SITE AND FOREST MANAGEMENT

Stephen Hopkins Spurr

Forty years of recorded stand history in the Harvard Forest, Petersham, Massachusetts, provide an opportunity to evaluate the influence of site and forest management on stand composition. During this period, the white pine types on the 1852 acres in the study area have become progressively less abundant and the open lands have largely been planted to conifers. Hardwoods have increased in abundance while hemlock has emerged as a major forest species. Although the forests have become complicated as a result of the complex pattern of past land use, it is possible to isolate the influences on stand composition of site as subdivided into soils and local climate, and of forest treatment as subdivided into silvicultural management and the effects of the 1938 hurricane.

The present forest is composed largely of red maple, red oak, hemlock, and white pine. The two hardwoods occur prominently in three-quarters of the stands, the maple being most abundant on the wetter sites and the oak on the drier sites. White pine is characteristic of pioneer associations on old fields, of all successional stages on very well drained soils, and occurs as a minor constituent of all successional stages on well drained soils. Hemlock does equally well on all sites, characterizes late successional associations, and is becoming increasingly prominent.

Present-day associations are closely related to soil drainage, while local climate apparently affects the distribution of only those species near the borders of their natural range. The success of softwood plantings is largely related to the amount of hardwood competition. Relatively less weeding is needed to eliminate pioneer hardwoods than is required to control transition hardwoods. Heavy cutting operations on glacial till soils have generally led to transition hardwood associations, although shelterwood cutting on well drained soils coupled with later weeding shows promise of bringing through at least some white pine. Partial cutting in hardwood stands encourages the development of a vigorous hemlock component. Logged-over hurricane blowdown areas develop the same associations as similar cut-over lands. Blowdown areas not salvaged apparently develop into late successional stages. Both cutting and hurricane blowdown, however, bring about the same forest associations that are found in the normal successional series.

The present forest associations, then, are apparently complicated, but turn out to be fairly simple in their broader aspects, being closely related to soil drainage and to successional stage. A well defined series of associations relate the white pine sand-plains to the spruce bogs. On well drained sites, short-lived species such as gray birch, pin cherry, and aspen characterize pioneer associations, with white pine as the main old field species. The transitional association is basically a red oak-red maple type with other hardwoods making up a minor proportion of the stand. This in turn develops into late successional stages in which hemlock and an occasional white pine join with red oak and red maple to make up the basic association.

STAND COMPOSITION IN THE HARVARD FOREST AS INFLUENCED BY SITE AND FOREST MANAGEMENT

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Stephen Hopkins Spurr

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PREFACE

This treatise summarizes much of the work which the author has done over a period of nine years at the Harvard Forest, Petersham, Massachusetts as Instructor, Acting Director, and Assistant Professor of Forestry. It was prepared under the general direction of Professor Harold J. Lutz of Yale University, to whom grateful acknowledgement is given for help and support in many ways.

Results of value from an experimental forest are obtained over a period of years only through the cooperative efforts of the many individuals who have worked there. Although the author has collected much of the data upon which this work is based, he has also drawn freely from the Harvard Forest records which represent the combined efforts of many previous and contemporary co-workers. Particular acknowledgement is due to A. C. Cline, former Director of the Forest, from whom the author learned much about silviculture and the Harvard Forest, and also to C. T. Brown, Jr. and Richard C. Rose who assisted the author for a time in experimental work and in managing the tract.

The source of the material utilized is indicated wherever possible. The analysis of the data and the writing of the treatise is, of course, exclusively the work of the author. The illustrations are also the work of the author except for Figures 5, 6, 18, and 20 which are by C. T. Brown, Jr. and the author.

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Chapter 1

INTRODUCTION

The problem

The present study represents an effort to explain so far as possible in the light of present knowledge the composition and occurrence of forest types in the Harvard Forest.

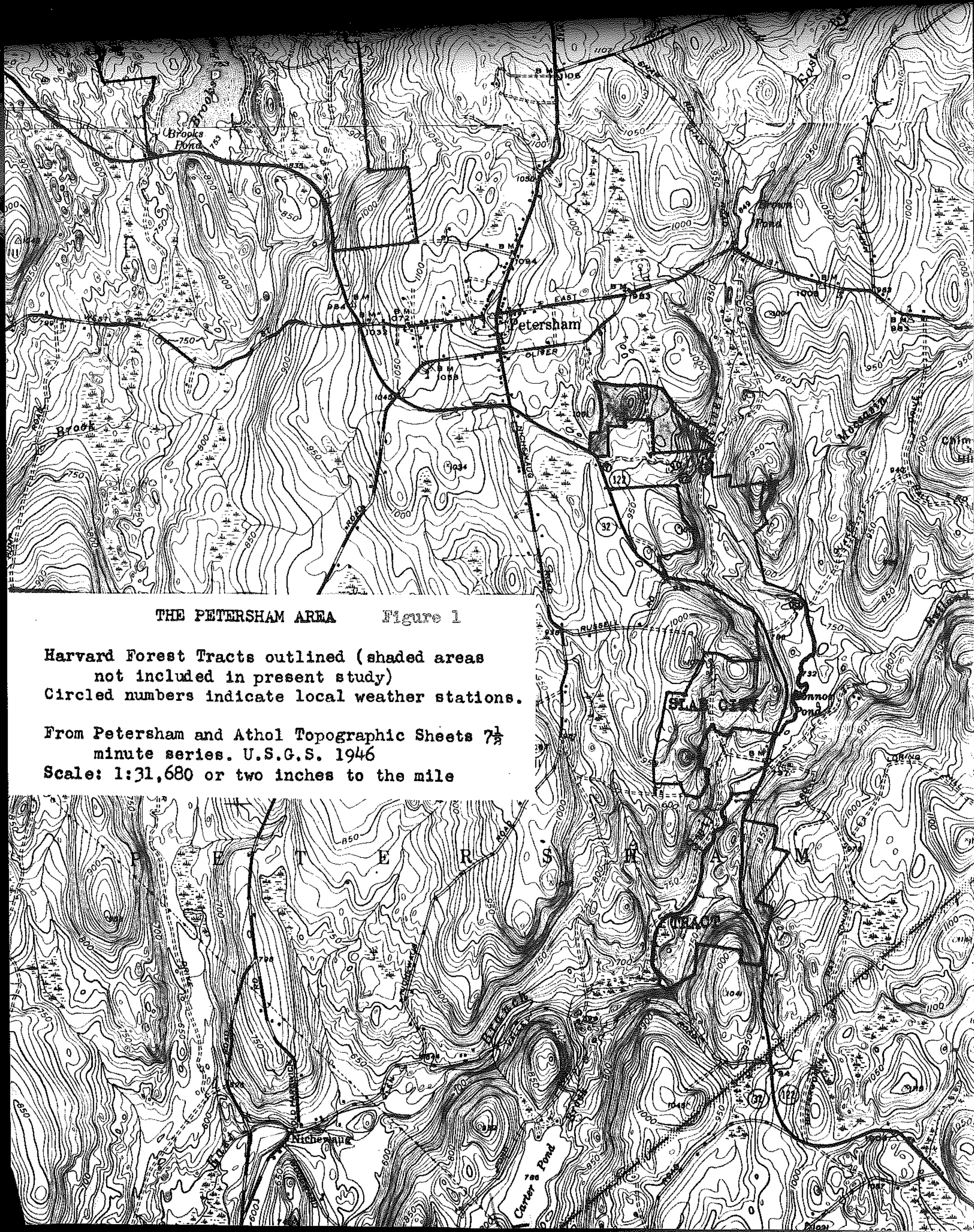
The Harvard Forest in Petersham, Massachusetts has been maintained as an experimental area since 1907. The long-term research program which has been centered here for more than forty years is based upon the belief that the history and development of forest communities can best be understood by selecting a small area — some 2,400 acres in this case — and recording at intervals the composition, volume, and other characteristics of each community, as well as detailing all cutting operations and other disturbances.

Major emphasis in the Harvard Forest research program has long been placed on silvicultural experimentation designed to find out how forest establishment, composition, and growth may be controlled by man's influence, chiefly in the form of cutting operations. More and more, however, the foresters responsible for this program have come to realize that natural forces, even more than man's interference, have shaped the forest communities to their present form, and that a knowledge of these forces is essential before sound silvicultural systems can be evolved.

Much material relating to these forces has been gathered since 1907 by many investigators. The purpose of the present paper is to show how the detailed records of the Forest, gathered over many years, can be reduced to a common base and interpreted so as to supply needed information concerning the ecological factors, both static and dynamic, which have combined to produce our present series of forest communities.

All illustrations are restricted to the first forty year period of University management, that from 1907 to 1947; and in general to those parts of the Forest which have been owned by the University since the start. More specifically, we shall deal with Compartments I through VIII of the Prospect Hill Block, I through VIII of the Tom Swamp Block, and II through X of the Slab City Block. Omitted are Prospect Hill IX, the Higgins addition to Prospect Hill IV, Tom Swamp IX (the Adams-Fay lot), Slab City I (formerly Slab City XI), various outlots, and all tracts which have been sold by the University. Those parts of the three main blocks omitted cover 264 acres, or 12.5 percent of the land area of these blocks. A total of 1852 acres of land are covered, of which 763 or 41 percent are in the Prospect Hill Block, 642 or 35 percent are in the Tom Swamp Block, and 447 or 24 percent are in the Slab City Block. Figure 1 shows the location of the portions of the Forest included and excluded in this study.

PROSPECT HILL
TRACT
ADMINISTRATION BLDG
HARVARD FOREST
P E T E R S H A M
P H I L L I
Lake Ellis
Reservoir No. 1
Phillipston Reservoir
Ward Hill
Reservoir No. 2
Bates Powers Reservoir
Davenport Pond
Prospect Hill
Riceville Pond
Tom Swamp
Swift River
Bigelow
Nelson
MOHAWK
TRAIL
BRIGGS
LINCOLN
BLAKES
CORNER



THE PETERSHAM AREA Figure 1

Harvard Forest Tracts outlined (shaded areas not included in present study)
Circled numbers indicate local weather stations.

From Petersham and Athol Topographic Sheets $7\frac{1}{2}$ minute series. U.S.G.S. 1946
Scale: 1:31,680 or two inches to the mile

The study is further confined to the composition aspects of the forest. Silviculture may be defined as the theory and practice of controlling forest establishment, composition, and growth (Spurr, 1945). In the present paper, composition is emphasized; and growth are dealt with only to the extent that they affect composition. In this respect, the present study represents quite a different approach to that of Lutz and Cline (1947) in Part 1 of "Results of the first thirty years of experimentation in silviculture in the Harvard Forest, 1908-1938," and the two studies should be considered as complementary rather than as dealing with the same problem.

The problem is exceedingly complex. The existing forest stands are small and highly variable. They owe their present-day existence to the interaction of a great many factors, among the most obvious of which are the migration of tree species into the area; pre-colonial distribution of species as governed by site, fire, wind damage and other agencies; land-use history from the time of settlement and soil formations; the depth of the water table; the aspect and elevation of the site; variation in local climate between one point and another and between one type of forest stand and another; the influence of insects and diseases such as the gypsy moth, the white pine weevil, and the chestnut blight; and the impact of fires and climatic agencies, especially the great hurricane of 1938. Many other factors could be named.

Obviously, any attempt to reason directly from these factors to explain the forest composition is fraught with danger. So many possible variables exist that to consider all would be impossible and to concentrate upon a chosen few would introduce a highly subjective element which would greatly increase the possibility of error. A deductive approach may therefore be ruled out on the grounds that the problem is too complex to be encompassed by any simple theory, and that the findings from such an approach would be too largely based on personal bias and too little on facts.

For these reasons, an attempt has been made to deal with the problem on an inductive basis in so far as is possible. Although the complex nature of the problem renders the complete elimination of subjective judgement impossible, it is believed that by beginning with the actual forest and working back into the contributory factors, the dangers of subjectivity can be minimized.

The approach adopted, then, has been to start with a detailed discussion of known changes in forest composition (Chapter 2). Up to 1907, the basic data are necessarily weak. Since that time, a series of forest stand maps together with the Harvard Forest stand and cutting records provide a detailed account of composition changes.

The forest stand maps prepared in 1946 and 1947 with modern aerial photographic techniques provide much better information on stand composition than do the earlier maps, and an analysis of these maps, together with a study of sample plot data, give a clear view of present-day forest associations (Chapter 3).

These studies of changes in forest composition over a period of years and of present-day composition reveal that site and forest management factors have apparently played the largest part in determining composition over the past forty years. These factors are considered in detail. Site is broken down into its terrestrial aspects (Chapter 4) and its aerial aspects (Chapter 5). Under the broad heading of forest management, particular attention is given to silviculture (Chapter 6), and the problem of post-hurricane regeneration (Chapter 7).

It is recognized at the outset that the summary and conclusions of this study (Chapter 8) cannot be complete and must be subject to modification as new data are accumulated. At the same time, it is hoped that this detailed survey of a small area will serve to point out the interrelationships that exist between ecology and forest management, and to show the extent to which man, working with natural forces, can modify forest stand composition.

Basic Materials

Three sources provide much of the data drawn upon: the Harvard Forest map series, the Harvard Forest stand and experimental records, and original field work.

Basic are the series of stand and type maps extending back over a forty year period. The maps vary in quality and accuracy but give an excellent overall picture of composition changes. Preliminary topographic maps to a scale of 1 inch to 400 feet and a contour interval of 10 feet were constructed by the early classes. That part of Tom Swamp east of Harvard Pond was mapped by the class of 1908; Tom Swamp VII and VIII were mapped about 1917; the Prospect Hill Tract was mapped by the class of 1910, and the Slab City Tract by the Classes of 1909 and 1912. The first type maps were constructed shortly afterwards. Beginning in 1919, the entire forest was mapped at intervals. The 1919 maps were prepared by J. Nelson Spaeth for use by R. T. Fisher in his Harvard Forest Bulletin 1 (1921). Subsequent maps were prepared in 1923 by A. C. Cline and Clifford H. Foster; in 1925, 1926-27, 1929, 1931-32, and 1937 by Neil W. Hosley, A. C. Cline and graduate students; and in 1946-47 by Stephen H. Spurr, Richard C. Rose, and Earl P. Stephens.

The earlier maps were constructed by compass and pacing traverses, those of 1925 and 1937 being constructed at a scale of 200 feet per inch. The 1937 map is particularly valuable because it records the types on the Harvard Forest just before the 1938 hurricane and because the location of compartment lines was carefully determined for the first time by transit traverses tying in permanent boundary stakes.

The most recent map was prepared from aerial photographs supplemented by careful ground checking after the techniques described by Spurr (1948). For the first time, an effort was made to list the actual species present according to their relative importance in individual stands, and to assign height and density values to each stand. Thanks largely to the availability of recent infrared photographs of good scale (1:4,800 and 1:12,000) and to the improved techniques of mapping and classification, these maps have proved much more accurate and useful than previous map series. Copies are included in the appendix.

Differences in scale and disagreements between the various base maps make comparisons between the original maps difficult. Beginning in 1944, the author has redrawn a large selection of the maps to a common base. Base maps of each compartment were prepared by correcting the 1937 transit traverses through the use of aerial photographic information. These maps were offset-printed to a scale of 1:4,800 or 400 feet per inch. Composite maps of the Prospect Hill Block including type maps as of 1907, 1919, 1929, and 1937, transferred to a common base, were exhibited at the annual meeting of the American Association for the Advancement of Science in Boston in 1946 in conjunction with the presentation by the author of a paper on "The historical development of forest communities in the Harvard Forest," the precursor of the present work. Photographic copies of these maps are included in later chapters.

The second major source of basic materials has been the Harvard Forest stand and experimental records. These records are voluminous and date back to the acquisition of the area in 1907. Although highly variable in quality and in degree of detail, they do provide a clear understanding of the cultural history of each stand over a forty-year period. An idea of the amount of information obtained for certain stands of particular interest can be had by perusing Harvard Forest Bulletin 23 by Lutz and Cline (1947). In the present study, no effort was made to pick out individual areas of interest. Rather, a concise case history was prepared for every stand in the Forest which was greater than one acre in area and had received treatment affecting composition since 1907. Many of these one-page case histories have been offset-printed (Spurr, 1944). Those most pertinent to the present study are included in the appendix. In this way, 71 case histories dealing with natural stands and 125 case histories dealing with softwood plantings were obtained. These cover essentially the entire silvicultural and management history of the Forest.

Additional material pertinent to the study came from the experimental records; dealing with such topics as hardwood plantings, regeneration studies, permanent sample plots, and soil survey. The periodic inventories of the tract also yielded information of interest.

The third source of basic material has been original field work. The author has spent several years in the Forest in various research and management activities. He thus has participated actively in the maintenance and development of the record system and has obtained first-hand knowledge of practically every stand in the Forest. Among the special studies drawn upon in the present work are field investigations of local soils, the measurement of permanent sample plots, a two-year study of local climatic variations throughout the Forest, surveys of post-hurricane regeneration, thinning experiments, and studies of the silvicultural control of various forest tree pests.

Chapter 2

COMPOSITION CHANGES

It has long been recognized that forests are not static, but that their composition and structure is continually changing both as a result of natural development and of disturbances such as fire, windthrow, clearing, and climatic changes. This fact was apparently recognized by early Roman writers, and by several eighteenth-century foresters (Laurent, 1849).

Beginning with Hundeshagen in 1830, the observed changes in forest composition were dealt with in specific articles by a series of writers. Hundeshagen pointed out instances of spruce replacing beech and other hardwoods in Switzerland and Germany, and of spruce and other species taking the place of birch, aspen, and Scotch pine. Gand (1840) added other specific cases. He quoted Michaux as having recognized that in North America conifers spontaneously replaced overmature broad-leaved trees, and Bosc as having remarked in Baudrillart's Dictionary that when the American forests are cut for the first time, the new stand is totally different, oaks replacing pine and walnuts replacing maples. He concluded "that the species are not at all stable, that is to say that in the largest number of forests, they are not able to reproduce themselves indefinitely and there nearly always arrives a time more or less distant, after one or several rotations, when the trees which occupy the soil of a forest are replaced by trees of a different species." Cochon (1846) credits the recognition of alternation of species to the eighteenth century scholar, Telles d'Acosta. Although this concept had by this time become well established in France, Cochon states that the German foresters at the Congress of Baden in 1841 rejected it.

The first detailed North American report of composition changes was prepared by Dawson in 1847 and dealt primarily with the Maritime provinces. He recognized the effects of windthrow and fire in the forests found by the original European settlers, and distinguished between successional trends in small clearings, following cutting, following a single fire, following repeated fires, and as a result of agricultural use of the land.

Douglas (1875, 1888) introduced the terms _forest succession_, and _pioneer species_ into American literature, and presaged modern reasoning in explaining how it happened that a short-lived, light-seeded pioneer species would come in on burned-over pine land.

Although there can be no question but that the composition of our forests is constantly changing, difficulties are frequently encountered in trying to fit known successional changes to the systematized and ideological successional concepts of Cowles and Clements. In the present study, therefore, the attempt is made to confine the discussion of composition changes as far as possible to those changes actually recorded. To avoid implying a specific correlation of recorded successional stages with the formalized classes of Clements, the terms pioneer, transitional, and late-successional will be used, it being understood that these terms represent relative rather than absolute values.

The discussion of composition changes falls naturally into four parts: (1) long-term changes associated with climatic fluctuation, (2) changes up to the time of European settlement, (3) changes from the time of settlement of Petersham in 1733 to the establishment of the Harvard Forest in 1907, and (4) changes in the first forty years of the Harvard Forest from 1907 to 1947. The treatment of the first three phases is largely, but not entirely, in the nature of a review, while that of the fourth phase is largely based upon the Harvard Forest stand maps.

LONG TERM TRENDS RELATED TO CLIMATIC FLUCTUATION

No discussion of trends in forest composition in New England would be complete if it did not consider the possible effects of past climatic variation on the present-day associations. A forest occupies a place in time as well as in space. Although the present study emphasizes the spacial aspects by attempting to relate forest composition to present climate and soils, temporal relations such as land-use and silvicultural history are also included, and the longer term trends cannot be ignored in a region so recently glaciated and exhibiting so many signs of variations in plant distribution within recent geologic time.

Few ecological subjects are so inherently difficult as the reconstruction of past climates and past vegetational complexes. Factual data are scanty and often highly indirect. Any one line of approach by itself may lead to inaccurate findings, and evidence from botanical, geological, and archeological sources must be carefully balanced before valid conclusions can be drawn. Nevertheless, the patient work of a great many investigators has gradually given us a fairly clear picture of the post-glacial climatic and vegetational changes in Europe, and an increasingly understandable account of these changes in eastern North America (Deevey, 1949).

<u>Appearance of present-day forest and climate</u>

From the mass of evidence, mostly fragmentary, certain facts emerge that are of interest in considering present-day forest composition. First and most important is the fact that the climate and forests of New England have not changed greatly over the past five to seven thousand years, -- although they have changed somewhat and are changing today.

This fact is demonstrated by numerous pollen analyses of lake and bog deposits. Most pertinent is the unpublished work of Benninghof on the Tom Swamp bog in the Harvard Forest (personal communication, January 25, 1949). He found that the bottom lake sediments (Dy and fine sedge) were deposited during the period of spruce-fir forests following deglaciation, and that the bog gradually filled in and developed a cover of shrubs and trees of which spruce and an occasional pine have persisted throughout the entire post-glacial period. Of the hardwoods, red maple was probably present from time to time in small quantities as it is today.

Other pollen studies in New England have been made by Deevey (1939, 1943, 1948), Benninghof (1948), and Potzger and Friesner (1948). Deevey, for example, found oak, hickory, pine, beech, birch and hemlock pollen in substantial proportions throughout as many as twenty feet of sediment in southern New England. Similar evidence is obtained from many other pollen studies farther afield in the eastern United States and Canada (Auer, 1930, 1933; Bowman, 1931; McCulloch, 1939; Sears, 1938).

Although there are many sources of error in pollen analysis techniques, and the drawing of conclusions from pollen analyses alone is fraught with danger (Cain, 1944; Smith, 1940), yet the conclusion is inescapable that many of our most abundant forest trees have been well established in New England for a long time.

Just how long a time, however, cannot readily be specified. Little definitive information is as yet available on absolute dating in North America, much less in New England. Recourse must be had to a rather tenuous correlation of North American pollen profiles with absolute chronologies that have been established for Europe. Apparently the most accurate dating is that established in Switzerland by Welten (Deevey, 1946) based upon an exhaustive study of the correlation between pollen counts and annual laminations in the sediments of a small bog. Since Welten's chronology agrees closely with that established in Sweden by Fromm (1938), and with the general European history inferred from archeological and other sources (Russell, 1941), it may be accepted as reasonably satisfactory.

Welten found that a warm climate first appeared about 5000 BC or seven thousand years ago, but that the present beech, spruce and fir forest in northern Switzerland first appeared about 3200 BC. The intervening period of nearly two thousand years was characterized by the predominance of oak. This is the so-called "Climatic optimum" period, or "Atlantic time" that is the most pronounced feature of post-glacial climates (Flint, 1947).

The pronounced warm and dry "Atlantic time" from five to seven thousand years ago may well not have occurred in America as it did in Europe where, as Deevey (1946) has pointed out, the climate was intimately related to the history of the Baltic Sea. Northeastern United States pollen diagrams indicate no early period so much warmer than the present-day that oak forests once grew where spruce, fir, and beech grow today. Rather, the present forest species seem to have become established five to seven thousand years ago, although fluctuations in abundance of the various species indicate climatic and vegetational changes since that time.

The American warm-dry post glacial period

Of the various fluctuations, one is of outstanding importance, both from its duration and the widespread evidence of its occurrence throughout eastern North America. A great deal of evidence -- zoological, archeological, botanical and geological -- such as has been grought together by Raup (1937) and Flint (1947), indicate a warm and dry period in comparatively recent times.

The evidence of this warm-dry period is clear in practically all North American pollen sequences. In southern New England, it is typified by the dominance of oak and hickory with beech and hemlock at a minimum (Deevey, 1943). Similar composition is evidenced in New York (McCulloch, 1939) and in the Central States (Sears, 1938). In southeastern Canada, it is marked by the appearance of species such as maple and hemlock which now have a more southerly range (Auer, 1930, 1933; Bowman, 1931). In Labrador and Newfoundland, it is indicated by the optimum development of the coniferous forest (Wenner, 1947). From the generally xerophytic character of the vegetation, and the occurrence of species north of their present range, it is generally agreed that the climate of this period was both warmer and drier than at the present day.

Perhaps the most pertinent attempt to date this xerothermic period (Deevey's C2) is that of Wenner (1947), a Swedish botanist who studied the pollen sequences of Labrador and Newfoundland in considerable detail. Relying heavily upon the occurrence of five early heath layers in the peat deposits, he suggests a correlation of Labrador profiles with those of Sweden and northern Europe; and relying upon vegetation trends in the pollen sequence, he suggests a correlation of the same Labrador profiles with those to the south in southeastern Canada and northeastern United States. Since similar heath levels had previously been dated in Sweden by Granlund, the evidence is fairly good that this warm and dry period began about 2300 BC and lasted until about 600 BC. Fromm (1938) dates the end of this period at about 1000 BC, a date not inconsistent with that assigned by Wenner in view of the gradual transition over many centuries between one period and another. Welten recognizes no such pronounced warm and dry period for his area in Switzerland, although he does record a mixed beech-fir-spruce period from 1800 to 750 BC which is perhaps related to it. Averaging the three chronologies, the dates of 2000 BC and 800 BC may be presumed to approximately encompass the period.

The period of increasing cold

As has been suggested, the disappearance of the warm-dry climate of three to four thousand years ago was gradual. Beginning about 800 BC, however, trees characteristic of cooler and moister conditions markedly increased in abundance.

The evidence of this trend is pronounced and widespread. A few examples from pollen profiles will suffice to illustrate it. In southern New England, the relative amounts of oak, hickory, and beech pollen decreased, whereas pine, hemlock, spruce, birch and chestnut increased (Deevey, 1939, 1943, 1948). Similar trends are evident in

Quebec (Auer, 1930, 1933; Bowman, 1931). In central New York, pine, hemlock, basswood and yellow poplar increased, while oak, beech, and birch decreased (McCulloch, 1939). In Labrador, the trends were toward wetter conditions and a loss of vigor in the coniferous forest (Wenner, 1947).

This trend toward cooler and moister conditions has persisted, but also has been so slow that less than a thousand years ago the climate was markedly warmer than it is today. From about 1000 AD to 1400 AD, a Norse colony flourished in Greenland, leaving ample historical evidence of a climate warmer than that of today. For example, many of the coffins have since been excavated from ground once unfrozen but now frozen throughout the year, and were found pierced and matted with the roots of many plants (Hovgaard, 1925). That similar relatively warm conditions occurred in New England in the same general period is indicated by recent efforts to date archeologic finds in New England (Johnson et al, 1942; Johnson and Raup, 1947) and by other sources (Raup, 1937). Fluctuations within the general trend have been indicated from various sources, but these do not appear to have been of sufficient magnitude to affect forest composition.

Apparently the height of the period of increasing cold occurred in the last half of the eighteenth and the beginning of the nineteenth century when polar ice and glacier development throughout the world was at a maximum (Ahlmann, 1946). Since meteorological observations have been taken in New Haven, Connecticut since 1780, it is possible to pin-point the maximum cold with fair certainty. The coldest ten-year period since 1780 was that between 1812 and 1821, the coldest five-year period was between 1814 and 1819.

The recent warm trend

The same weather data from New Haven indicate a pronounced trend toward warmer weather ever since the early part of the nineteenth century. That this trend is significant despite periodic fluctuations is indicated by the graph of the ten-year moving average (Figure 2). The mean annual temperature has risen from 47.61 degrees Fahrenheit for the ten-year period ending in 1821 to 51.55 for the ten-year period ending in 1931, a rise of approximately four degrees. Even a smooth curve drawn through the data indicates a rise of about two and one-half degrees.

Kincer (1933) has demonstrated that this rise in temperature is significant, that it is duplicated in records from weather stations throughout the world, and that it is equally apparent at rural as well as at urban stations, obviating the possibility of city development causing the trend.

The effect of rising temperatures is especially apparent in arctic regions. Ahlmann (1946, 1949) has brought together impressive evidence demonstrating this trend. For example, the average thickness of sea-ice in the Polar Sea was found by a Russian expedition in 1937-40 to have been reduced forty percent along a course where measurements had been taken by Nansen in 1893-95. Between 1924 and 1942, drift ice in the Arctic

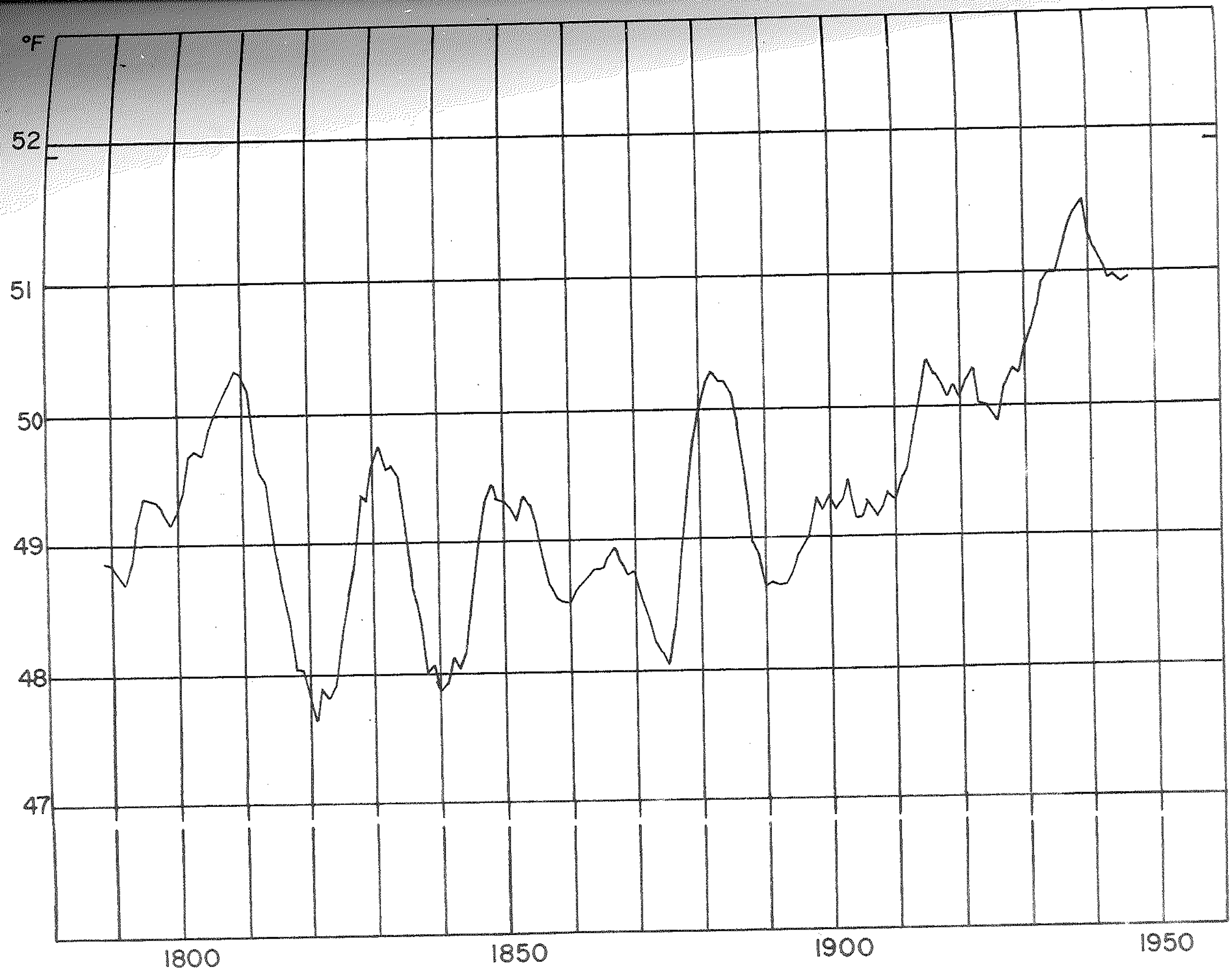


Figure 2. MEAN ANNUAL TEMPERATURE AT NEW HAVEN, CONNECTICUT (Ten-year moving average)

Sea has been reduced by more than a million square kilometers. Glaciers in the Arctic, -- and indeed throughout the world (Flint, 1947), -- have been shrinking rapidly since the early nineteenth century.

In view of the long term of geologic history, and the great length of past climatic periods, there has been a natural tendency to discount the importance of recent climatic trends. The evidence that has been accumulated within the past few years, however, is so impressive that there can be but little doubt that the present trend toward a warmer period represents a major climatic fluctuation, even from a geologic viewpoint, and has already progressed to the extent of substantially modifying our climate.

The present trend has already persisted for one hundred and thirty years, a period not incomparable with that of other trends recorded from the past. For instance, the warm-dry period discussed earlier lasted only from about 2000 BC to about 800BC, a span of 1200 years, while the change from the previous period probably required only a fraction of this time.

In order to assess the importance of the recorded rise in temperature in terms of forest composition, an effort was made to correlate present mean annual temperatures with latitude and altitude. Records for the year 1944 were chosen, as temperatures for this year were not unusual, and as this was the first year of the local climate study in the Harvard

Forest. Only those weather stations from the crest of the Appalachians eastward to the Atlantic coast were used in order to minimize the effect of variables other than those being studied.

As a measure of change, mean annual temperature was used, partly because it was the measure adopted by Kincer in his study of temperature changes, partly because it is the most comprehensive of the conventional temperature measures, and partly because its use tended to minimize the effect of local variation, cold winter temperatures in low spots tending to average out with hot summer temperatures in the same places.

When the mean annual temperature for some thirty stations from Brunswick, Georgia to Fort Kent, Maine were plotted against latitude and altitude, a good correlation was obtained (Figure 3). The mean annual temperature was found to increase systematically as altitude was decreased and latitude increased. Furthermore, the relationship is close to being rectilinear, exhibiting only a slight curvilinearity for mean annual temperature over latitude. The mean annual temperatures of the individual stations fit the generalized curves well, few of the actual values differing from the theoretical values by as much as one degree.

Referring to the curve of mean annual temperature over latitude and altitude (Figure 3), it can be seen that a difference in elevation of 1000 feet represents a change in mean annual temperature of about 2.8 degrees Fahrenheit, and that a difference of one degree in

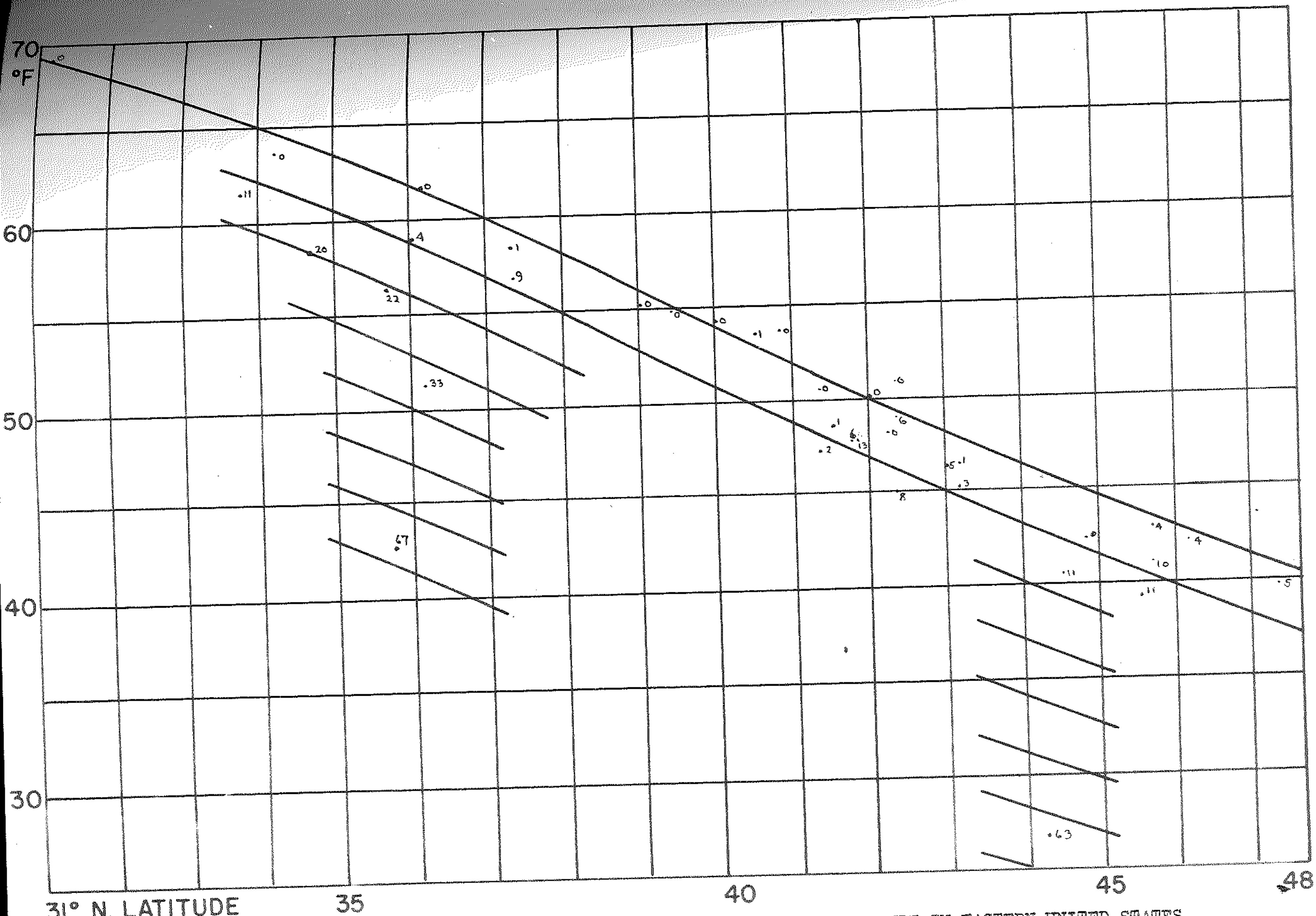


Figure 3. RELATION OF MEAN ANNUAL TEMPERATURE TO LATITUDE AND ALTITUDE IN EASTERN UNITED STATES
(Numbers indicate elevation of stations in hundred feet)

latitude represents a change in mean annual temperature of about two degrees. The rise in temperature since 1817, then, being nearly three degrees, represents a movement of the climate about 1000 feet up in elevation and about 100 miles north at the same elevation.

Past temperatures

The curves of mean annual temperature may also be used to estimate climates in the past, if we only assume that the present-day relationships between vegetation and mean annual temperature have persisted from the past. By plotting the latitude and altitude of various points along the limit of the continuous range of a given species, its range may be defined approximately in terms of mean annual temperature. For example, white pine does not grow to any extent where the mean annual temperature rises above 50 degrees Fahrenheit, and red spruce does not grow in regions having a mean annual temperature above about 45 degrees F.

When criteria such as those indicated above are applied to the pollen spectra of Deevey for southern New England, it is immediately apparent that the mean annual temperature in the New Haven area for the past seven thousand years has been consistently higher than about 45 degrees, the northern limit of abundant oak and hickory; and consistently lower than about 52 degrees, the average southern limit of hemlock and birch. Although the method is crude and the values approximate, the extent of the variation is fairly apparent. Not only does it seem that fluctuations in mean annual temperature in the past several thousand years have not exceeded seven degrees, but also it would appear that actual changes in forest composition within this period can be fully explained by assuming temperature changes of as little as two degrees, provided that the change has lasted for a number of centuries.

Past forest composition

From the information provided by pollen studies and from the reconstruction of past climatic history, it is possible to estimate, at least roughly, the length of time that the important forest trees have been in central and southern New England. This period appears to have been at least seven thousand years for practically all those trees which now occur throughout New England, and whose southern or northern range limits are at least 200 miles south or north of central New England. Of the ten species listed as occurring in more than ten percent of the stands in the Harvard Forest (Chapter 3), all fall within this category. Of the sixteen species occurring in more than 2½ percent of the stands, only one is near its range limit.

It is apparently safe, then, to deal with the major trends in forest composition in the Harvard Forest today purely on a present-day basis. The major species have been long established and should be able to compete and adjust themselves under almost any future climate. True, if the present trend toward warmer conditions continues, the trees having the more southerly ranges may be expected to increase in abundance. On the other hand, if the present trend is reversed, and the much longer trend toward increasing cold is reestablished, the opposite will occur. In any event, the present major species will be the major species for several centuries in the future.

Only five trees, out of a total of twenty which are recorded on the Harvard Forest stand maps, have their northern or southern limits sufficiently near central New England to have been seriously affected by climatic variations since 5000 BC. Hickory (a genus not broken down into species in the Harvard Forest records) and black gum are near their northern limits in central New England. Black spruce, red spruce and tamarack are near their southern limits. None of these species is important in the present-day forest, and four of the five are largely confined to peat bogs.

In view of the established climatic history, it would appear that the warm and dry period of 800 to 2000 BC was sufficiently marked to eliminate spruce and tamarack in southern New England and possibly in the vicinity of the Harvard Forest, although the work of Benninghof indicates that spruce probably persisted in Tom Swamp throughout this period. Quite possibly, black gum and the hickories were introduced during the same time. These latter species have persisted, while spruce and tamarack have definitely been reintroduced into southern New England and possibly into the Harvard Forest region at a much later date by the long trend toward increasing cold.

In a sense, then, black gum and hickory may be considered as relicts, while spruce and tamarack, -- whose appearance in bogs south of their continuous natural range has usually been cited as the classic example of a relict community, -- are not always relicts <u>in situ</u>, but rather may be very recent introductions which have invaded their present swamp habitats from the north, granted that the extent of their southward migration may not have been great when measured in miles because of the higher elevations nearby to the north and west. A related view is expressed by Deevey (1949).

The present poor appearance and vigor of spruce and tamarack in central New England, therefore, does not prove the relict status of these species, but is merely a reflection of the recent trend toward warmer climate, which if continued may well force these species farther north, and bring about a northward extension of the range of such species as black gum and hickory.

THE VIRGIN FOREST OF CENTRAL NEW ENGLAND

Accepting the probability that the present forest species have for the most part been present and important in New England for many centuries and even for thousands of years, we still require knowledge of the virgin forests at the time of settlement by Europeans. Such information must be compiled from fragmentary historical records and from a study of remnants of old-growth timber in the region.

Historical references

The writings of early observers such as Thomas Morton (1632), William Wood (1634), Peter Whitney (1793) and Timothy Dwight (1795-1821) have been adequately summarized and discussed by such contemporary writers as Hawes (1921), Bromley (1935), Raup and Carlson (1941) and Cline and Spurr (1942). In general, they present a panorama of oak, chestnut, and hickory upland forests in Connecticut, Rhode Island and eastern Massachusetts including the town of Petersham. Going north into southwestern New Hampshire, hemlock and northern hardwoods were increasingly abundant. Localized forest types such as pitch pine on sand plains, chestnut oak on xeric ridges, and spruce in bogs and at the higher elevations, had approximately the same distribution as they do today. Both fire and windthrow were apparently important disturbing influences in the pre-colonial forests. The Indians habitually burned the woods at least along the coast, while lightning also may have been the cause for an undetermined number of fires. The mounds and hollows left in the ground by fallen trees were noted by Dawson in 1847, as well as by observers today. Destructive hurricanes were recorded in 1635 and 1815, with lesser storms being noted for intervening years.

Two additional historical records of considerable interest are William Douglass' "Summary, historical and political, of the first planting, progressive improvements and present state of the British settlements in North America" (1755), and Jeremy Belknap's "History of New Hampshire" (1792). The former gives considerable information on utilization and such topics as the size of white pine, concepts of that day as to the quality and value of the wood of various species and sizes, and the scarcity of firewood around Boston, but little about actual forest composition. The latter is more specific and because it has been apparently overlooked by previous writers on the original forest of New England, it is quoted in some detail. Belknap noted in his third volume that:

"In the spring, the trees which have been felled the preceding year, are burned in the new plantations. If the season be dry, the flames spread in the woods, and a large extent of the forest is sometimes on fire at once. Fences and buildings are often destroyed by these raging conflagrations. The only effectual way to prevent the spreading of such a fire, is to kindle another at a distance, and to drive the flame along through the bushes, or dry grass, to meet the greater fire, that all the fuel may be consumed. ... In swamps, a fire has been known to penetrate several feet under the ground, and consume the roots of trees. (page 26)

"The wood on these mountains is of various kinds; but they all have more or less of the evergreens, as pine, spruce, hemlock, and fir, intermixed with shrubs and vines. It is universally observed that trees of every kind diminish in their size toward the summit; many of them, though short, appear to be very aged. .... About two or three feet under the surface of the mountain is a firm earth, called the pan, which is impenetrable by water. (page 33)

"Another thing, worthy of observation, is the aged and majestic appearance of the trees, of which the most noble is the mast pine. This tree often grows to the height of one hundred and fifty, and sometimes two hundred feet. It is straight as an arrow, and has no branches but very near the top. It is from twenty to forty inches in diameter at the base, and appears like a stately pillar, adorned with a verdant capital, in form of a cone. Interspersed among these are the common forest trees, of various kinds, whose height is generally about sixty or eighty feet. In swamps, and near rivers, there is a thick growth of underwood, which renders travelling difficult. On high lands, it is not so troublesome; and on dry plains, it is quite inconsiderable. (page 73)

"As the earth is opened to the sun, many wet places are dried, and brooks become contracted; and as the land is more and more cleared, smaller streams disappear. The best kind of land for roads is where the pitch pine grows; this is generally level, or if not perfectly so, yet always dry. The soil is sandy or gravelly; the trees are sparse; and the undergrowth consists of brakes, fern and whortle bushes, which are easily subdued; but this kind of land is not profitable. (page 76).

"Red oak grows sometimes on high and dry land, but delights in moist soil, and is generally found on the declivities of hills and borders of swamps. (page 96)

".. all woods, which grow on high land, are more firm and solid, and better for timber or fuel, than those which grow in swamps. The same difference may generally be observed between those in the open grounds, and those in the thick shade of the forest. The pine is an exceptional to this remark; but whether the immense age or superior stature of the forest pine be the causes which render it more firm than that which is found in the pastures, cannot at present be ascertained.

"Beside the immense quantity of living wood with which the forest abounds, nature hath provided an ample store of that fossil, ligneous substance called peat. It appears to be formed of the deciduous parts of trees and shrubs, preserved in a peculiar manner, in the earth. It is usually found in swamps between or under hills, where it has been accumulating for many ages. The decayed vegetation of one period having served as a soil in which another growth has taken root and come to maturity. In the town of Dover are two swamps, which, within the last twenty-five years, have been cleared of the stumps and roots of the latest growth, which were pine and hemlock. In digging them up, another tier of stumps were found under them, the roots of which were found; and in some instances a third stump appeared under the second. In such swamps is found the peat; in which the shape of twigs, bark and leaves is very apparent; but on pressure it is consolidated into a soft fatty substance. (page 118)

"In the new and uncultivated parts, the soil is distinguished by the various kinds of woods which grow upon it, thus: white oak land is hard and stony, the undergrowth consisting of brakes and fern; this kind of soil will not bear grass till it has been ploughed and hoed; but it is good for Indian corn, and must be subdued by planting, before it can be converted into mowing or pasture. The same may be said of chestnut land.

"Pitch pine land is dry and sandy; it will bear corn and rye with plowing; but is soon worn out, and need to lie fallow two or three years to recruit.

"White pine land is also light and dry, but has a deeper soil, and is of course better; both these kinds of land bear brake and fern; and wherever these grow in large quantities, it is an indication that ploughing is nexessary to prepare the land for grass.

"Spruce and hemlock, in the eastern part of the state, denote a thin, cold soil, which, after much labor in the clearing, will indeed bear grass without ploughing, but the crops are small, and there is a natural tough sward commonly called a rug, which must either rot or be burned before any cultivation can be made. But in the western parts, the spruce and hemlock, with a mixture of birch, denote a moist soil, which is excellent for grass.

"When the white pine and oyl-nut are found in the same land, it is commonly a deep moist loam, and is accounted very rich and profitable.

"Beech and maple land is generally esteemed the most easy and advantageous for cultivation, as it is a warm, rich, loamy soil, which easily takes grass, corn and grain without ploughing; and not only bears good crops the first year, but turns immediately to mowing and pasture; the soil which is deepest, and the darkest color, is esteemed the best.

"Black and yellow birch, white ash, elm, and alder are indications of good soil, deep, rich and moist, which will admit grass and grain without ploughing.

"Red oak and white birch are signs of strong land, and generally the strength of land is judged of by the largeness of the trees which it produces.

"There are evident signs of a change in the growth on the same soil, in a course of time; for which no causes can be assigned. In some places the old standing trees, and the fallen decayed trees, appear to be the same, whilst the most thriving trees are of a different kind. For instance, the old growth in some places is red oak, or white ash; whilst the other trees are beech and maple, without any young oak or ash among them. It is probable that the growth is thus changed in many places; the only conclusion which can be drawn from this circumstance, is, that the same soil is capable of bearing divers kinds of trees; but still there is a difference sufficient to denominate the soil from the growth.

"The principal growth between the height of land and St. Francis River (i.e. northern Vermont), is beech, maple, birch, hemlock and fir; very few white pines, and no oak of any sort; many cedar, spruce, and hemlock swamps intervene. (page 402)

From the above excerpts, it is apparent that Belknap was a keen and accurate observer of forest conditions of his time. His conclusions as to the distribution of tree species agree closely with those of present-day forest ecologists; he recognized the existence of forest succession; he is one of the earliest writers to appreciate the nature of peat and the importance of fossil wood found in it. All in all, Belknap provides the best contemporaneous description of the virgin forest that we have, and one on which we can place considerable reliance.

From these original sources, we may conclude that the pre-colonial forests of New England were made up of the same species that characterize the region today. Furthermore, specific kinds of sites were occupied by forest types generally similar to those occupying them today. The importance of any given species, or the composition of any given type within the original forest cannot be more than roughly approximated from early descriptions, and any attempt to reconstruct such evidence must of necessity be highly subjective in nature.

Old growth remnants

Prehaps the best sources of information concerning the floristic composition of the pre-colonial forest are the remnants of this forest that have persisted into recent times and which have been studied by botanists and foresters. Remnants in southern New England have been discussed by Nichols (1913) and Hawes (1923). R. T. Fisher, first Director of the Harvard Forest, was influenced by the old growth remnants in southwestern New Hampshire and elsewhere when he described in 1933 the original forest in central New England as:

> "a forest in which broad-leaved trees and hemlock formed a dense stand from eighty to one hundred feet high, above which, either by small groups or single trees and varying greatly in abundance, white pines reached a height of 150 feet or more."

Old growth remnants in the Pisgah Mountain section in the town of Winchester in extreme southwestern New Hampshire were studied in detail by various members of the Harvard Forest staff (Cline and Spurr, 1942). The so-called hemlock-northern hardwoods climax forest, -- consisting in this case largely of hemlock, beech, sugar maple, and black birch, -- was found only in protected sites where fire and windthrow had apparently not occurred for about four hundred years. On the more exposed sites, white pine apparently also occurred as a climax species. Most of the remnants, however, showed evidence of past disturbances which were apparently responsible for the presence of substantial quantities of white pine, paper birch, red oak, red maple, and chestnut in the stands. One paragraph written by the present author and taken from the conclusions to this study may well be repeated:

> "The primeval forest, then, did not consist of stagnant stands of immense trees stretching with little change in composition over vast areas. Large trees were common, it is true, and limited areas did support climax stands, but the majority of the stands undoubtedly were in a state of flux resulting from the dynamic action of wind, fire and other forces of nature. The various successional stages thus brought about, coupled with the effects of elevation, aspect, and other factors of site, made the virgin forest highly variable in composition, density, and form.

In the Harvard Forest itself, areas that have never been cleared for agricultural use and that have always remained forested have been located as accurately as possible by Raup and Carlson (1941). These include an irregular tract, largely swamp land, in the center of the Prospect Hill tract; the southern part of the Adams-Fay lot (Tom Swamp IX, excluded in the present study); the northwest cornor of Tom Swamp IV (the so-called Boulder Site); the northwest corner of Tom Swamp I; the northern part of Slab City III; the northern edge of Slab City VII; and a central lot in Slab City X; as well as a few other areas of smaller size and lesser authenticity. None of these areas contain virgin forests today. Cutting has taken place in all the stands, and many have apparently been cut several times. Because of the record left by hardwood sprouts, however, an interpretation of the original forest can be made from present-day evidence and this has been done by Raup and Carlson (1941).

In two places, trees of considerable age still occupy the land, despite two hundred years of cutting and the 1938 hurricane. These stands have been analyzed in the course of the present study.

In Slab City IX, along the east side of Route 122, is an old growth hemlock stand (Figures 4 and 5). According to Raup and Carlson (1941), the land was first assigned in 1740. Since some of the trees still standing had originated previous to this time, it is evident that the area has never been completely cleared. The present stand consists largely of hemlock, with red maple, black birch, yellow birch and other hardwoods making up about ten percent of the stand volume. A few large white pine are scattered through the stand. The average height in 1944 was 65 feet, the average basal area being about 235 square feet per acre and the average board foot volume about 35,000 board feet per acre. Only among the hemlock are trees more than 110 years old to be found, and these range up to about 90 feet in height.

There is little evidence as to the composition of this stand in 1740 except that many of the large hemlock of today were small suppressed trees in the understory at that time. The earliest direct evidence of composition is provided by rotten windthrow logs of white pine and chestnut in the younger portion of the stand directly across the road in Slab City X. Increment borings of hemlock growing in the rotten wood indicate that these trees were blown down either in the hurricane of 1815 or at a subsequent date.

Figure 4. OLD GROWTH HEMLOCK ALONG HIGHWAY, SLAB CITY IX

Figure 5

INTERIOR VIEW OF OLD GROWTH HEMLOCK IN SLAB CITY IX

Analysis of increment cores of standing trees in the old growth stand indicates that the area has been culled over at least twice. In 1841 much of the stand was cut or blown down. Growth analysis of hemlocks that were left shows a marked acceleration of diameter growth beginning with this year. Of the larger white pine and hardwoods that have been bored, all originated in 1841 or within five years afterwards. In 1892, about sixty to seventy trees per acre were cut. The stumps are still discernible. These trees ranged up to two feet in diameter and consisted almost entirely of white pine together with a few chestnut. All in all, it appears unlikely that hemlock predominated in this stand in 1740. Rather it would seem that white pine, chestnut, and various hardwoods occurred at this time in mixture with the hemlock, the hemlock taking over the stand after two successive logging operations had removed its competitors.

The second existing stand in which old trees predominate is in the northeastern corner of Prospect Hill II on medium to poorly-drained glacial till bordering a peat bog. It consists of a small clump of large hemlock trees ranging up to 180 years old in 1946. On a quarter-acre permanent sample plot, volume per acre in 1944 was 8,300 cubic feet, or 36,700 board feet. The largest tree is 31 inches in diameter and 85 feet high. The stand apparently originated about 1765, probably following the first logging of the area. Growth-ring analysis shows that the stand was opened up by light cutting in 1790, by the 1815 hurricane, and that the trees were released again in 1838 and 1876. Large hemlock up to three feet in diameter were cut in 1888, and a few more trees were cut in 1894. Some release was afforded by the death of the chestnut due to the blight following 1916, and by the 1938 hurricane.

The above two cases, the only ones in the Harvard Forest where old growth trees occupy more than one-quarter acre, tell little about the composition of the original forest on those sites. Although hemlock is currently predominant in both stands, and was undoubtedly at least a minor part of the stands in the early eighteenth century, the present stands owe their composition and structure to early windthrow and subsequent logging operations which removed the overstory, thus releasing the hemlock understory. Much the same situation was found by Marshall (1927) in the southern part of Tom Swamp IX, the Adams-Fay lot.

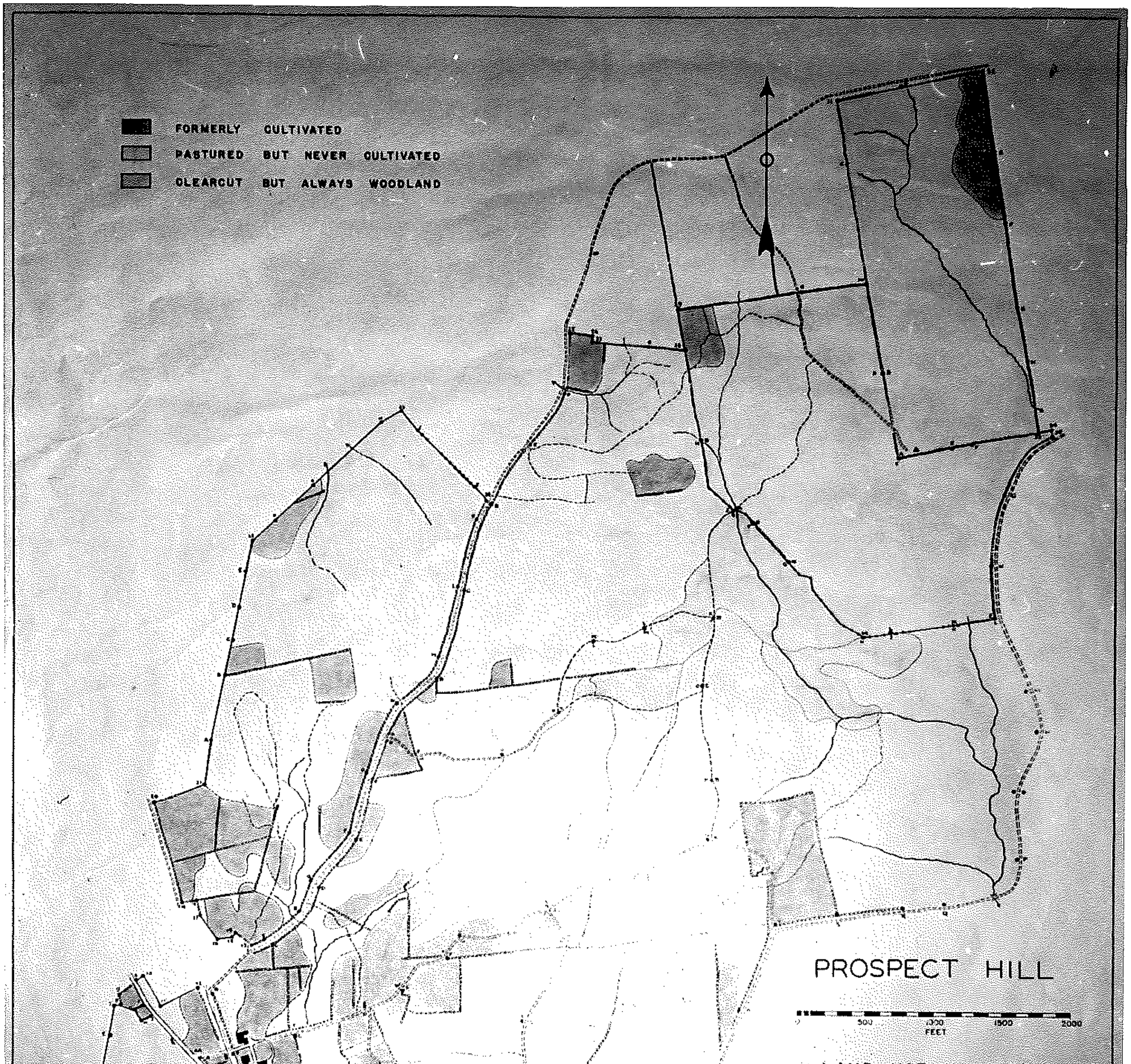
In summary, it is fairly clear that the virgin forests of central New England were made up of the same species that are common today, and that the forests were highly variable due to variations in site and catastrophic history. We have good reason to believe that white pine was an important species only on sandy and gravelly soils and on exposed ridgetops, but that it occurred either singly or in groups throughout the rest of the forest. The upland forests of the Petersham area were largely oak, chestnut, and hickory -- indicating if anything a somewhat milder and drier climate than exists today as hickory is no longer a common genus and in fact is not distant from its northern limits in the Petersham area. The position of hemlock in the virgin forest is not clear. Although theoretically an important component in the climax forest, its distribution was apparently restricted to ravines and other protected sites by fire.

THE PERIOD OF SETTLEMENT: 1733-1907

The Town of Petersham was settled in 1733. The Harvard Forest was established in 1907. The uses to which the land were put during this period of one hundred and seventy-four years have greatly influenced the forest composition. The distribution of species and forest types in the Harvard Forest in 1907 was to a large extent the function of previous use of the land, and it remains so today.

The land-use history of the area has already received considerable attention, and will be dealt with only briefly in the present study. The story in its broad outlines has been ably told by R. T. Fisher (1925, 1933) and A. C. Cline (1936), and it has been portrayed in the three-dimensional dioramas of the Harvard Forest model series. More recently, many of the details of the land-use history of Petersham and the Forest have been published by Raup and Carlson (1941).

In brief, the virgin forests were almost completely cut before the end of the eighteenth century, and much of the area cleared for farming. For a generation or two in the first portion of the nineteenth century, the area was largely agricultural. To illustrate this with a specific example, the writer prepared an agricultural land-use map of the Prospect Hill Block (Figure 6). Areas which apparently have been always forested


FORMERLY CULTIVATED
PASTURED BUT NEVER CULTIVATED
CLEARCUT BUT ALWAYS WOODLAND
PROSPECT HILL
0 500 1000 1500 2000
FEET
LAND USE HISTORY
1733—1907

were mapped out on the basis of the Raup and Carlson study and original field checks in which the ages of standing trees were determined and in which stumps and other evidence of former tree growth were noted. Nine percent of the tract fell into the continuously forested category. Less than one acre previously described is still covered with old-growth trees. The rest is occupied by hemlock, red spruce, red maple, and other species in stands less than one hundred years old, although an occasional older hemlock and spruce can be found which originated under the previous stand and which was subsequently released by logging.

The remaining ninety-one percent has been cleared for agricultural use at one time or another, but not necessarily all at one time. Much of this has obviously never been cultivated repeatedly or thoroughly, but rather has been used primarily for upland pasture. To estimate how much land has been cultivated, the stone walls were followed and studied. Stone walls made up of boulders taken from cultivated fields are typically larger and contain a greater variety of stone sizes and a greater number of stones than do simple stone walls that were erected merely to mark property lines or to fence in cattle and sheep. By correlating the nature of the stone wall with the character of the ground surface on either side, it was possible to delineate those areas that had very likely been cultivated repeatedly or thoroughly. These areas covered 16 percent of the tract, the remaining 75 percent being mapped as having been cleared for upland pasture but not having been intensively cultivated. The proportions of land in the other two tracts that have been continuously in forest, cultivated, or which have been cleared for pasture are apparently of the same general order of magnitude as in the Prospect Hill Block, but were not determined.

Following the opening of western and northern lands to settlement, much of the cleared land was abandoned, and seeded in to even-aged stands consisting largely, but by no means entirely, of white pine. These old field pine stands became characteristic of the region, and by 1900 gave rise to a substantial logging industry. However, as Thoreau first noted (1863), and as professional foresters have since rediscovered to their sorrow, these pine stands on upland soils were succeeded after logging by even-aged hardwood stands which today constitute the principal types in the region.

Thus, in but little more than two hundred years, the Petersham area has played host to four major vegetation types. One of these types was agricultural, and three predominantly forest. Each has differed widely in composition, form and structure.

Not only has the forest cover changed, but the drainage relationships of the soil have also been changed by the damming of streams and the subsequent gradual filling up of the ponds by vegetation. Benninghof has worked out the history of Tom Swamp, Harvard or Brooks Pond, and Riceville Pond. He found that, in the first part of the nineteenth century, only two small areas near the present state route 122 were ponded, each of these Meadow Water ponds covering about an acre. By 1830, the Tom Swamp causeway had been constructed across the middle of the peat bog. Riceville Pond was formed about 1856 by damming Riceville Brook. It was drained shortly after the turn of the century and restored following the 1938 hurricane. Harvard Pond was first formed sometime after 1880, and its level was raised slightly to its present position about 1900.

Similarly, the drainage of the Swift River in the Slab City Block and several of the brooks in the Prospect Hill Block, have been repeatedly modified by the construction of dams, the filling of ponds, and the destruction of dams. The ruins of the old grist mill near the Forest Cottage in Prospect Hill I are still prominent (Figure 7). This mill was powered by water stored in two artificial ponds in what is now Prospect Hill VIII.

COMPOSITION CHANGES: 1907-1947

The map series

Since 1907, the area has been managed as a research and demonstration forest, and the stand maps constructed at intervals throughout the forty-year period ending in 1947 provide a record of the composition changes during this time. Many of the composition changes are associated with silvicultural treatment of stands and will be discussed in detail in connection with a consideration of management practices. This is done in chapter 6. The general trends in forest composition, however, can be determined directly from the series of stand maps.

TANNERY HILL

Figure 7. RUINS OF OLD GRIST MILL NEAR FOREST COTTAGE PROSPECT HILL I.

The different stand maps vary greatly in quality. Up to and including the 1937 map, emphasis was placed on broad types. Only the changes in acreages occupied by these broad types can be obtained directly from the maps. Furthermore, there is considerable variation in the way the different types are defined. The distinction between hardwood and cordwood areas, in particular, has varied greatly from time to time, and these types must be grouped in the present analysis. Again, some mappers were prone to emphasize the importance of white pine, labelling stands as white pine -- hardwoods or white pine-hemlock-hardwoods even when white pine made up less than ten percent of the stand. This is particularly marked in the maps constructed between 1923 and 1937. All in all, the broad trends are well defined, but any attempt to detail the composition changes must be deferred until Chapter 6 when individual areas are taken up.

The method of analysis involved transferring all type maps to a common base map prepared in 1947 from the 1937 transit survey as amended by aerial photographic data and supplementary transit surveys by C. T. Brown, Jr. and the author. Figure 8 represents the resultant maps of 1912, 1919, 1923 and 1937 for Compartments IX and X in the Slab City block, compartments which are of particular interest because practically no cutting has been done in them since 1907 and because a minimum of damage was done to the forests by the 1938 hurricane. A general view of the area may be obtained from Choate Ledge (Figure 9). Aerial photographs of this area have been published as figures 12, 13, and 14 in "Aerial photographs in forestry" (Spurr, 1948). A soils map of the same area is included in Chapter 4.

Figure 8. HISTORICAL MAP SERIES FOR SLAB CITY IX AND X

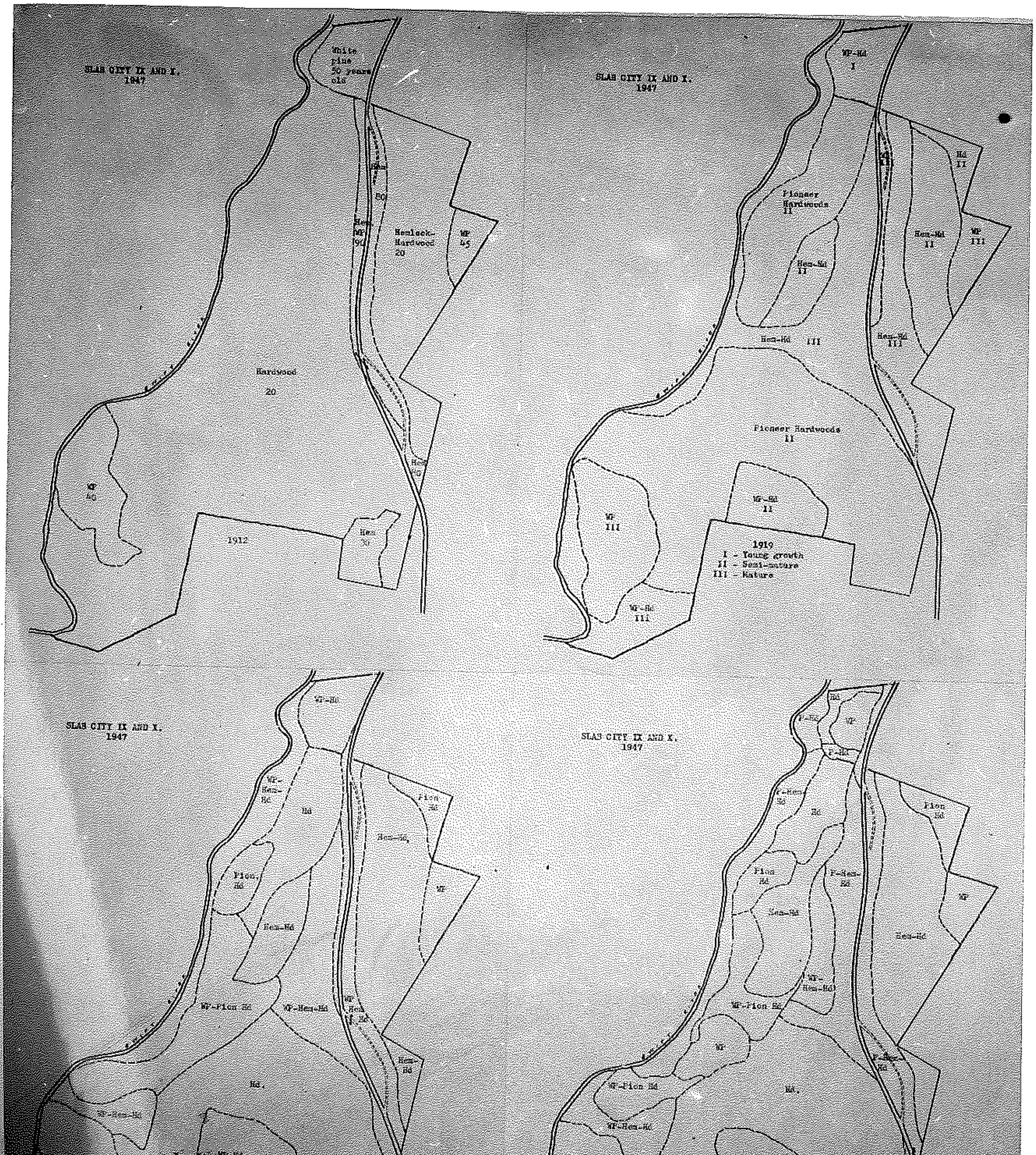


Figure 9

VIEW OF SLAB CITY IX AND X FROM CHOATE LEDGE

The number of stands mapped has increased steadily in successive years. In the Prospect Hill Block alone, containing 844 acres and including 763 acres considered in the present study, 90 forest stands were mapped in 1908. There were 120 stands mapped in 1919; 240 in 1929; and 280 in 1937. The 1946 map has 330 stands for this area, of which 163 are volunteer stands over 10 years old, 86 are undifferentiated blowdown and cut-over areas, and 81 are coniferous plantations. This increase in number of stands is due partly to the increasing complexity of the Forest during these years resulting from management and research activities, and partly to the gradual recognition of finer and finer distinctions within areas formerly mapped as a single stand.

The acreage occupied by each broad type in selected years is given in Table 1. In 1908-09, mapping was confined to the Slab City Block and to the eastern part of the Tom Swamp Block (Compartments I through VI). The acreages in these same compartments have been computed from the 1912-13 maps for the purpose of comparison. The 1912-13 maps included all of the study area except for Tom Swamp VII. Again for comparison, the comparable acreage v lues have been computed for 1919. From 1919 on, the entire 1852 acres of the study area have been mapped. No acreages were computed for the maps constructed between 1923 and 1937 as these were largely modifications of the 1923 map.

The percentage of the study area occupied by the various broad types is given in Table 2. No percentage is given for 1908-09 as less than one-third of the forest was mapped at that time. The general

Table 1

ACREAGE OF FOREST TYPES IN STUDY AREA: 1907-1947

	15 Compts.		24 Compts.		25 Compartments			
	1908	1912	1912	1919	1919	1923	1937	1946
White pine	238	217	395	394	480	431	208	38
Pine-hardwoods	120	82	115	194	208	356	287	115
Hemlock-hardwoods	34	43	79	137	164	223	306	218
Hardwoods	139	219	779	664	701	550	546	1046
Coniferous swamp	—	—	82	87	87	71	73	50
Coniferous plantings	—	—	25	67	67	81	365	330
Open	55	25	200	132	145	140	67	55
Total	586	586	1575	1575	1852	1852	1852	1852

Table 2

PERCENTAGE DISTRIBUTION OF TYPES IN STUDY AREA: 1912-1947

Forest type	1912	1919	1923	1937	1946
			(Percent)		
White pine	26	26	23	11	2
Pine-hardwood	7	11	19	15	6
Hemlock-hardwood	5	9	12	17	12
Hardwood	44	38	30	29	56
Coniferous swamp	5	5	4	4	3
Coniferous planting	1	3	4	20	18
Open	12	8	8	4	3
Total	100	100	100	100	100

trends are clear. The substantial acreages occupied by white pine and old farm land in 1912-13 have been largely taken over by coniferous plantings, hardwood, and hemlock-hardwood stands.

Finally, a somewhat more detailed analysis has been made for the 763 acres of Prospect Hill Compartments I through VIII inclusive. The 1908 stand map was reconstructed by the author in 1944 by projecting the 1913 map backwards using information supplied by the stand records. The 1929 data have been added and the forty-year trend is illustrated in Table 3. The stand maps of the Prospect Hill Block are reproduced in Figures 10 to 13 inclusive. Current stand maps of the entire forest are included in the appendix.

In general, the study of the early maps shows that the same associations have been present since 1908, but that their relative importance, distribution and exact composition has changed greatly in the intervening period. These changes will be indicated for each broad type.

<u>White pine types</u>

Two associations contain white pine as a major species. The first is a pure pine type, containing eighty percent or more white pine by volume or number of trees which are free to grow. The second contains pine in mixture with red maple, red oak, and other hardwoods. These are the old field types which follow farm abandonment. The first develops when the white pine seed supply is ample and the sod is intact; the second results when this seed supply is deficient.

Table 3

PERCENTAGE DISTRIBUTION OF TYPES IN PROSPECT HILL I-VIII: 1908-1946

Forest type	1908	1912	1919	1923	1929	1937	1946
				(Percent)			
White pine	17	17	17	19	17	4	1
Pine-hardwood	3	4	9	8	11	9	7
Upland hardwoods	42	43	36	29	27	29	42
Hardwood swamp	7	8	12	9	6	6	6
Hemlock	1	1	1	1	1	1	1
Hemlock-hardwoods	—	—	3	11	7	14	12
Conifer swamp	3	3	3	3	3	3	3
Conifer plantings	—	3	7	7	19	30	26
Open	27	21	12	13	10	5	3
Total	100	100	100	100	100	100	100

Figure 10. 1908 PROSPECT HILL STAND MAP

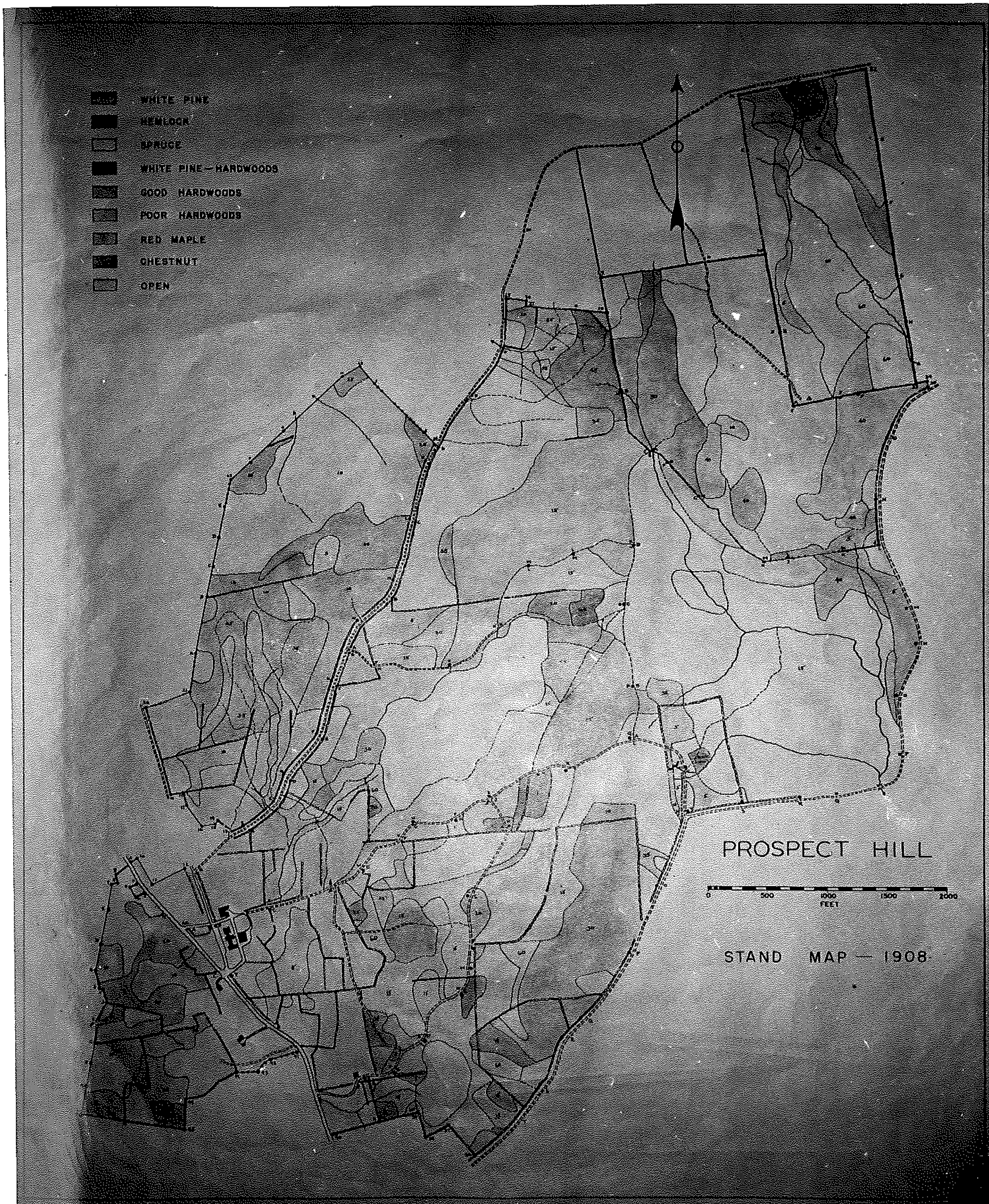


Figure 11 1919 PROSPECT HILL STAND MAP

Figure 12. 1929 PROSPECT HILL STAND MAP

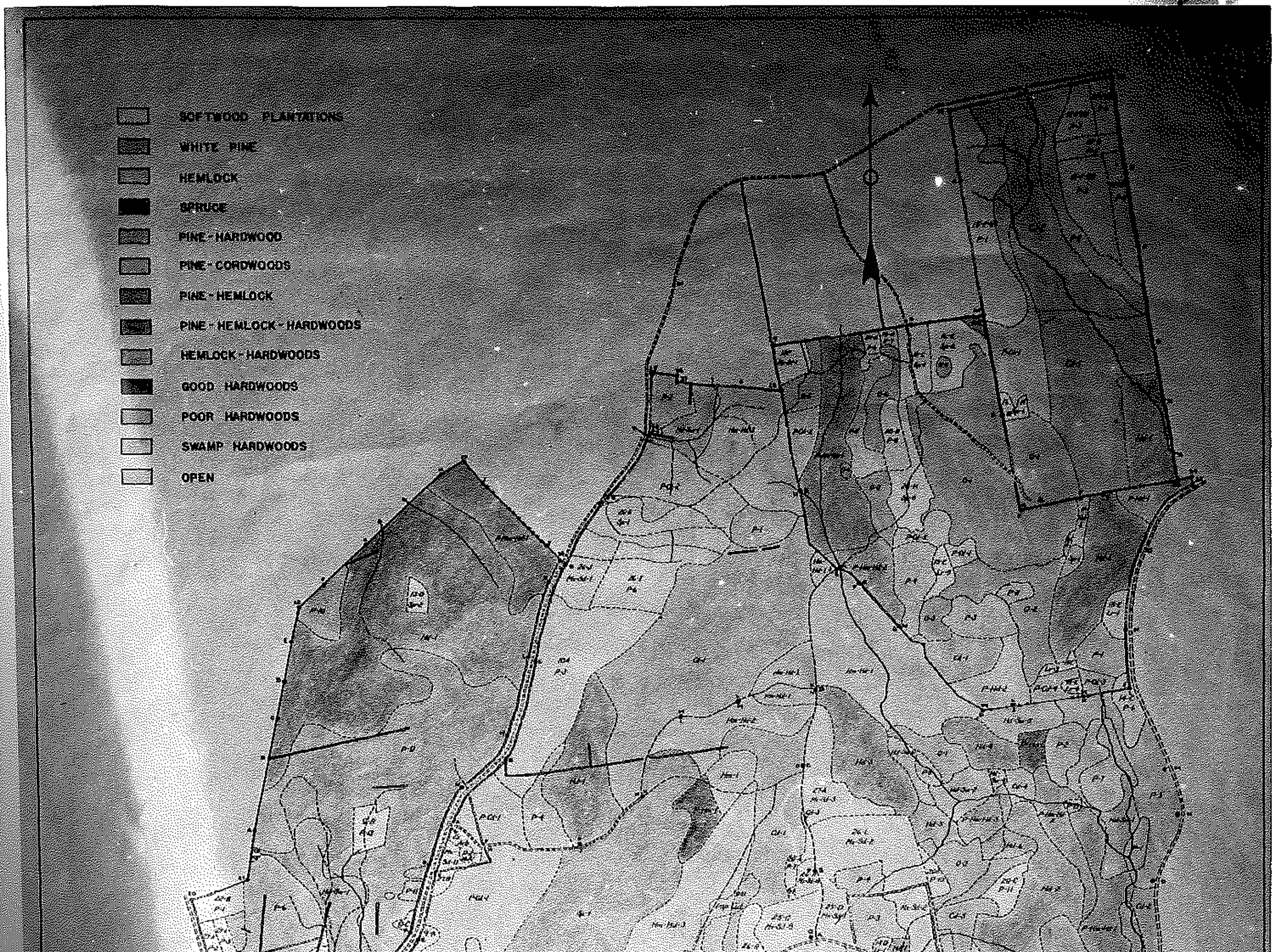
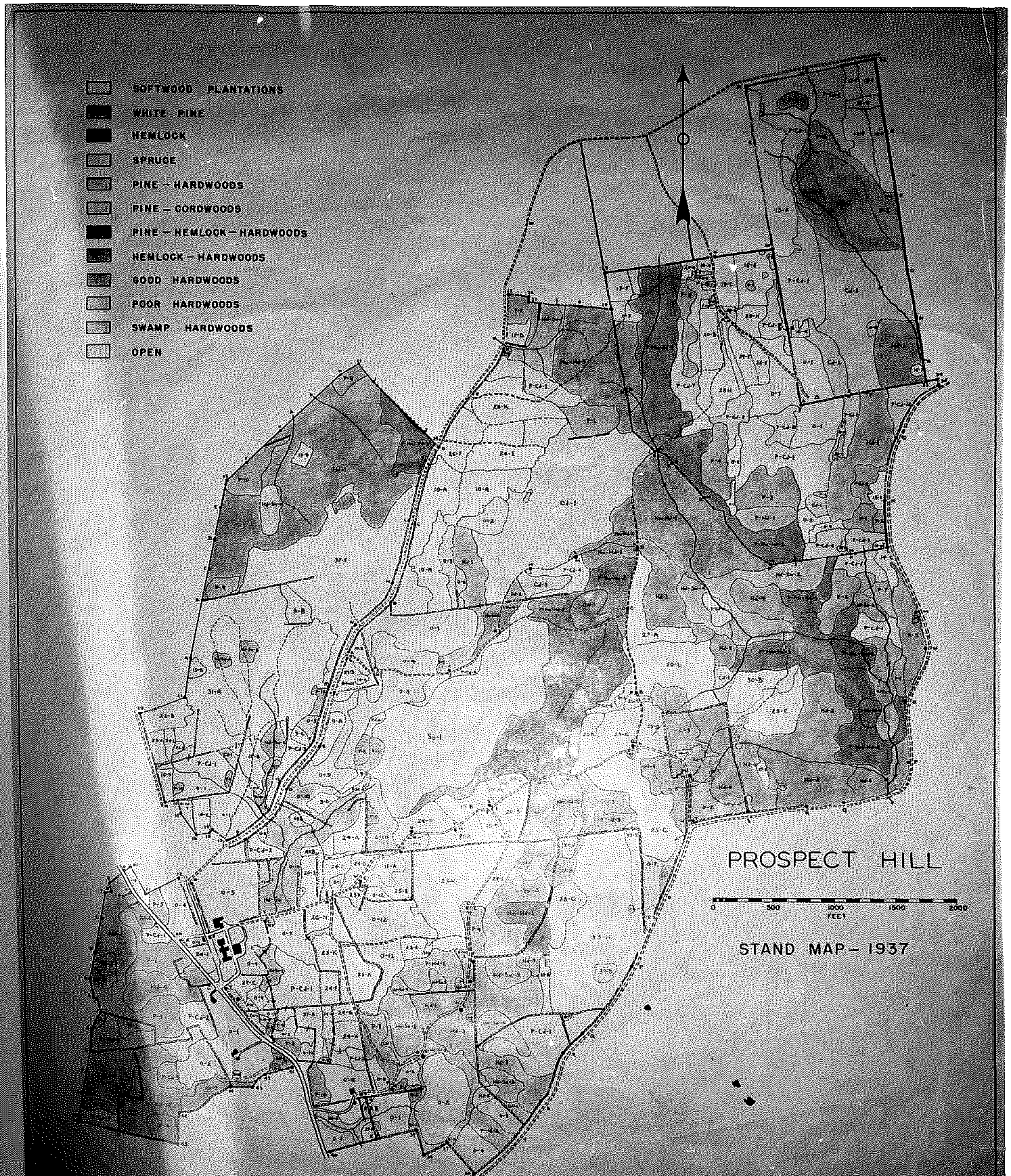


Figure 13. 1937 PROSPECT HILL STAND MAP



In 1912-13, 26 percent of the study area was in pine, and 7 percent in pine--hardwoods. In succeeding years, cutting tended to reduce the area, while natural seeding on open land tended to increase it. As late as 1923, 23 percent of the land was classified as white pine and 19 percent as pine-hardwoods, although many acres of the latter category actually contained few pine. Most of these stands have since been harvested, and the cut-over areas either planted or allowed to come back to hardwoods. Many residual stands were blown down in the 1938 hurricane so that now only two percent of the study area is in natural white pine and six percent in natural white pine-hardwoods.

Hardwood types

Three broad hardwood types were recognized in all the early type maps, these corresponding to the present day distinction between pioneer hardwoods, transition hardwoods, and swamp hardwoods. The acreage of these combined types show a decrease from 1912 to 1923. This decrease, however, is more apparent than real. With time, hemlock became sufficiently important in some areas to justify the segregation of hemlock-hardwood mixtures. Much of the apparent decrease in hardwood acreage, however, is attributable to the habit of emphasizing white pine in the nineteen-twenties, a habit leading to the frequent designation of stands containing a few white pine as pine-hardwoods or pine-hemlock-hardwoods. At any rate, the acreage occupied by hardwoods was nearly doubled by the 1938 hurricane as most of the blowdown areas have come into hardwood types (Chapter 7). At the present time, substantially more than half of the forest is in hardwood types.

Where a white pine seed source is not available at the time of land abandonment, or where mineral soil is exposed at this time, old farm land tends to come in to a mixture of weed hardwoods. These pioneer hardwoods include red maple, gray birch, and black cherry as the most abundant species. Aspen, red oak, and white ash are also common. With time, the association develops into one of the transition hardwood types.

The name, transition hardwoods, has been given to the upland hardwood complex of central New England because this complex occupies a zone between the red oak - white oak - black oak forest of southern New England and the beech - yellow birch - sugar maple region of northern New England. Red oak and red maple characterize the zone by their extreme abundance even though they also occur over a wide region outside. Paper birch, black birch, and white ash are other commonly occurring hardwood species.

On the older maps, the upland hardwoods were not subdivided into specific associations, but rather mapped as "good hardwoods" or "poor hardwoods" depending upon the commercial quality of the timber. Younger stands, in which such short-lived species as gray birch, aspen, pin cherry, and black cherry were abundant, were usually mapped as "cordwood", "poor hardwoods", or "inferior hardwoods". A few years later, after most of the short-lived species have been eliminated, the same stands were often mapped "hardwood" or "good hardwoods", or "better hardwoods".

Prior to 1916, chestnut was an important and valuable species. On the 1912-13 maps, less than 2 percent of the study area was mapped as pure chestnut, but the species occurred as a major element in the red oak -

chestnut - red maple transition hardwood type. In 1913, Kittredge noted that locally it was only exceeded in abundance by white pine and red maple. The chestnut blight disease was first noted on the Prospect Hill tract in 1910, and by 1912 the infection was uniformly distributed throughout the town (Kittredge, 1913). By 1916, practically all the trees of this species were dead or infected and consequently doomed.

In the hardwood swamps, red maple is the predominant species, although many other trees are locally abundant. In the Prospect Hill Block (Table 3), where the acreage of hardwood swamp has been segregated from that of the other hardwood types, this acreage has remained essentially constant since 1907.

Hemlock types

In 1908, less than forty acres in the Forest were mapped as containing hemlock as a major species. Prominent among the stands thus designated were the two old-growth stands discussed earlier in the present chapter. By 1946-47, hemlock occupied substantially more than two hundred acres, or twelve percent of the study area. The slightly greater hemlock acreage indicated for 1937 in Tables 1 to 3 is due to the tendency in that year to designate stands as pine-hemlock-hardwood even when hemlock was a relatively minor species.

Practically all of the present-day hemlock and hemlock-hardwood stands have developed from transition hardwood stands either in the absence of cutting or following selective cutting in which the hardwoods were removed, freeing the hemlock understory. The former process, that of natural succession, is responsible for most of the present hemlock-hardwood acreage; although the latter process, that of silvicultural control, is currently important.

The increase in acreage of the hemlock and hemlock-hardwood types is one of the most pronounced trends in forest composition in the past forty years. Hemlock was a minor species in 1907. It had become a major species by 1947. Apparently it will become increasingly abundant in the future. At one time largely confined to ravines and other protected spots (Figure 14), it is invading a wide variety of sites. A great many acres of hardwood forest are today developing a dense understory of hemlock (Figure 15).

Coniferous swamp types

Two large peat bogs in the Harvard Forest have consistently remained in coniferous swamp types. The Tom Swamp bog, of which only about fifty acres are included in the present study, is forested with a mixture containing black spruce, tamarack, hemlock, red maple, and other hardwoods. The Prospect Hill bog, containing about 25 acres, supports an uneven-aged mixture of red spruce, hemlock and red maple, with smaller amounts of black gum and yellow birch. The oldest black spruce found by the writer in the Tom Swamp bog was 125 years old, and the oldest trees found in the Prospect Hill bog were hemlock about 200 years old. Although considerable wood has been cut from the latter swamp, neither area has apparently ever been clearcut. The acreages of the coniferous types in both bogs have remained essentially constant since 1907.

Figure 14

HEMLOCK IN RAVINE OF SWIFT RIVER VALLEY, SLAB CITY X

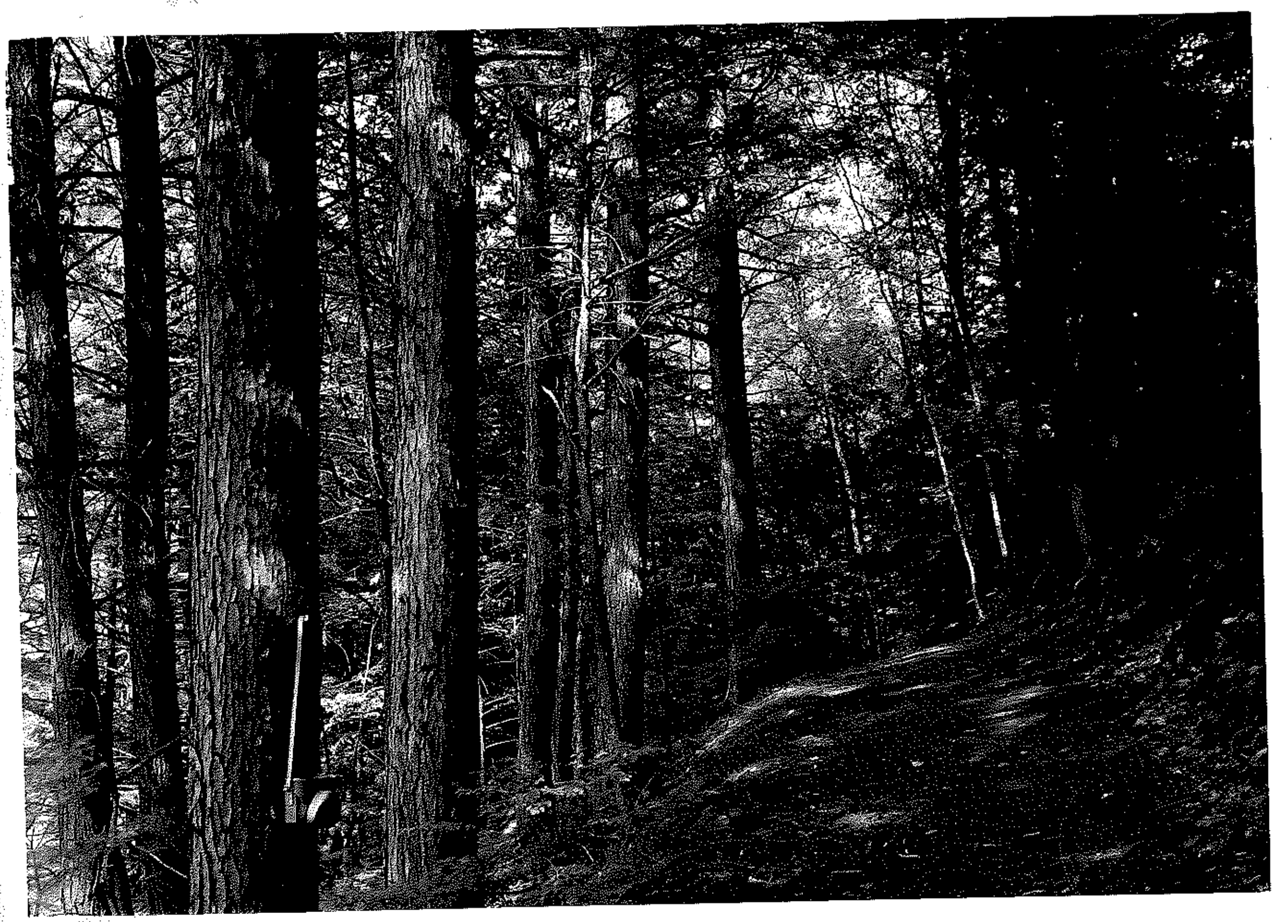


Figure 15. HEMLOCK UNDERSTORY UNDER TRANSITION HARDWOODS, SLAB CITY X.

Coniferous plantations

During the forty years of existence as an experimental forest, much planting has been done on the area. No plantations were in existence in 1907, but by 1946-47, 26 percent of the Prospect Hill Block and 18 percent of the entire forest were in coniferous plantations. The acreage in plantations has decreased in recent years, due in part to hurricane blowdown, and in part to suppression of plantings by hardwood competition. The area actually slightly exceeds 20 percent of the study area.

O en land

In 1912-13, there were 200 acres of open land, and in 1907 when the Forest was acquired by the University, this figure was at least 230 acres. Included in these values were large acreages of abandoned farm land and a lesser amount of open swamp. Systematic planting of the old farm land, coupled with the natural seeding of much of that land which was not planted, have reduced the amount of open land to 55 acres in 1946-47. Of this amount, nearly 15 acres around the Headquarters buildings have been kept open, and the remainder is largely in open swamp. Practically no open upland available for planting exists today.

Successional trends

Even the generalized picture of stand composition changes since 1907 provided by the study of old stand maps makes it apparent that the post-agricultural succession is a dominant factor determining forest composition today. Three of the naturally-occurring types -- the white pine type, the white pine - hardwoods type, and the pioneer hardwoods type, -- originated chiefly on abandoned farm land. In addition, some of the areas mapped as transition hardwoods undoubtedly originated on old fields. All in all, these old field types covered about 40 percent of the study area in 1907 and still include approximately 12 percent of the area.

In addition to the natural pioneer types, the coniferous plantations, covering 18 percent of the study area, constitute artificial pioneer associations ecologically similar to the old field white pine type. Thus, perhaps 30 percent of the present acreage is occupied with pioneer associations.

Transitional successional stages are chiefly represented by transition hardwood types, although some of the pine and hemlock stands undoubtedly fall in this category. Probably somewhat more than 50 percent of the forest is of this nature today.

Finally, the hemlock and hemlock-hardwood types, together with a small part of the hardwood and white pine types represent a later stage in succession. Somewhat less than 20 percent of the study area was in 1946-47 covered with these "late-successional stages".

At the risk of repetition, it should be emphasized that the above breakdown of successional stages is purely relative and is based upon observed changes in the composition of stands in the Harvard Forest as mapped over a forty-year period. It is not based upon theoretical considerations, nor has the nomenclature of the successional stages been equated with conventionalized ecological terminology.

Chapter 3

PRESENT-DAY FOREST ASSOCIATIONS

Although the information concerning stand composition from the older Harvard Forest stand maps is limited, the 1946-47 maps lend themselves to further analysis and provide a means whereby present-day forest associations can be isolated and described. A check on this technique is provided by the records of permanent sample plots.

Method of stand map construction

The 1946-47 stand maps were the product of aerial photographic and ground reconnaissance. Various recent aerial coverages taken with panchromatic, infrared, and color film, with various filters, and at various scales, were available for the type mapping, but particular use was made of 1:12,000 photographs, taken with infrared film and a medium red (Wratten No. 25) filter, on July 5, 1944.

First, the base map constructed from transit surveys in 1937 was corrected by using the photographs in the Multiscope set up for use as a transfer device with two semi-transparent mirrors. Some supplementary transit surveying was done by C. T. Brown, Jr. and the writer. Then, the Multiscope was converted for use as a plotting stereoscope with one semi-transparent mirror, and the boundaries of all homogeneous forest areas were transferred to the base map. All stands larger than one-quarter acre were thus segregated. From the aerial photographs, the stands were classified according to (1) broad composition classes as softwood, mixed-wood or hardwood; (2) ten-foot height classes; and (3) four density classes. Density class A included stands having 85-100 percent crown closure; B, 60-85 percent crown closure; C, 30-60 percent crown closure; and D, 0-30 percent crown closure. Heights were coded to the nearest 10 feet, class 7 for example including trees 65 to 75 feet high.

The maps were then taken into the field, and each stand checked on the ground. To replace the broad type classification, the species making up the stand were listed in order of abundance. Trees of primary or major abundance were listed in the numerator of a fraction, and trees of secondary or minor abundance were listed in the denominator. No hard and fast line was recognized between the two groups, but trees making up more than 10 percent of the basal area were generally considered of primary importance and those making up less than 10 percent were of secondary importance. Similarly, important understory trees could be designated in the denominator of the fraction when advisable, their height and density being indicated by separate height and density codings. Normally not more than four species were listed in either the numerator or the denominator of the type fraction.

The result of the typing and coding system was a flexible description of the stand composition and structure as it actually occurred on the ground without recourse to any arbitrary or preconceived classification system. Thus:

$$\frac{T - PB - RO}{YB - Be}\ 3\text{-}7\ B$$

would indicate a stand made up of hemlock (T for *Tsuga*), paper birch, and red oak in that order of abundance, with a scattering of yellow birch and beech, the trees ranging from 25 to 75 feet in height, and covering between 60 and 85 percent of the area with their crowns. Again:

$$\frac{WP\ 9\ D}{T - RM\ 4,6\ B}$$

would designate a three-story stand, the highest story consisting of a scattering of white pine, 85-95 feet high; and the lower two stories, one of which was 35-45 feet high and the other 55-65 feet high, consisting of a fairly dense stand of hemlock and red maple.

Analysis of data

In the original work on the Prospect Hill Block, the sorting of data from the stand map was based upon the primary species represented. Thus, all the white pine stands were grouped together and a frequency count made to determine the number of times each species occurred as a major and as a minor species within that group. The results were incorporated into an earlier study (Spurr, 1946). In later attempting the same technique for the stands of the Slab City Tract, however, it became apparent that the technique, although informative, was generally unsatisfactory. For instance, a stand in which white pine was the predominant species might be a young stand of post-hurricane origin on a sandy site, a middle-aged old field white pine stand, or an old-growth stand with white pine standards above a hemlock and hardwood second story. Grouping such divergent associations simply on the basis that all contained more white pine than any other species would scarcely help to define the ecological relationships and associates of white pine.

A more satisfactory approach turned out to be one adapted from a technique evolved by the writer in an earlier study (Cline and Spurr, 1942). First, the study was restricted to stands covering at least one acre, to areas of natural stocking, to stands 25 feet or more in height, and with a C stocking or better (more than 30 percent of the area covered by tree crowns). These standards could be objectively applied to the stand maps, and served to confine the study to reasonably well-developed stands of at least moderate size. The composition of younger stands following the 1938 hurricane is discussed in Chapters 4 and 7.

Second, each stand was designated on the basis of field reconnaissance according to successional stage and moisture relationships of the site. Parenthetically, it should be noted that all stands in the three major blocks of the Harvard Forest were used in this study, and not only those in the study area as defined in Chapter 1.

Three successional stages were recognized; (1) pioneer, (2) transitional, and (3) late successional. The distinction was relative rather than absolute. Pioneer stands included all those known to have originated on old fields and following clear-cutting and fire in the past twenty to thirty years. Such stands were subdivided into those of old field origin and those originating on cut-over land. Pioneer stands on cut-over sites were distinguished from transitional types by being younger and characterized by the presence of short-lived species such as gray birch, pin cherry, and aspen. Abundant black cherry was also frequently found in pioneer types. Transitional types included all middle-aged stands not segregated as pioneer or late successional. Late successional types included all old-growth remnants, and all areas in which no cutting or other disturbances have taken place over the past half-century or more. Although the segregation of successional stages was somewhat subjective, it proved surprisingly easy and apparently fairly precise.

Five soil moisture conditions were recognized, these five conditions being set up as a result of the study of the local soils and site qualities detailed in Chapter 4. The base of the classification was the Harvard Forest soils map, modified where necessary by field reconnaissance. Generally but not always, Merrimac, Hinckley and Jaffrey soils were considered very well drained; Gloucester, Charlton, and Brookfield soils were considered well drained; Acton and Sutton soils were considered imperfectly drained; Whitman soils were considered poorly drained; and peat and muck deposits were considered very poorly drained.

When all the stands were sorted according to the above criteria, it was found that each class thus set up was characterized by a distinctive stand composition. This sorting, therefore, was used as the basis for the presentation of information on the present-day forest associations.

Important species

Many writers have stressed the variability of the composition of the transition hardwood region in general and the Harvard Forest in particular. Indeed, a great many tree species do occur. Jack (1911) has listed ten commercially important softwoods and about 24 commercially important hardwoods, in addition to a long list of non-commercial woody plants.

One of the most pronounced facts to come out of the present study, however, is that relatively few tree species predominate as primary components of the local forest associations. Table 4 gives the number of stands in which each species occurs as a major or as a minor component in the 235 stands studied, together with the total occurrence reduced to a frequency percentage basis. Only two species, red maple and red oak, occur in more than 40 percent of the stands, red maple occurring in 86 percent and red oak in 75 percent of the stands. These two species may be said to characterize the region. Only two additional species, hemlock and white pine, occur as major components in more than 10 percent of the stands. These four species, -- red oak, red maple, hemlock, and white pine, -- and only these four species, may be said to constitute the major components of the local forest stands.

Six other species, -- the four native birches, white oak, and white ash, -- are locally abundant, occurring in more than 10 percent of the stands, usually as minor components. Finally, ten other species occur in more than one but less than ten percent of the stands. Black oak is

Table 4

FREQUENCY OF OCCURRENCE OF TREE SPECIES IN THE HARVARD FOREST, 1947

	Major Component	Minor Component	Total Frequency	
	Number of stands			Percent
Red maple	154	48	202	86.0
Red oak	140	36	176	74.9
Hemlock	52	34	86	36.6
White pine	48	29	77	32.8
Paper birch	19	46	65	27.7
Yellow birch	14	36	50	21.2
Black birch	9	34	43	18.3
White oak	14	24	38	16.2
White ash	11	24	35	14.9
Gray birch	9	16	25	10.6
Cherry	2	13	15	6.4
Hickory	9	5	14	6.0
Sugar maple	2	11	13	5.5
Beech	2	10	12	5.1
Elm	4	5	9	3.8
Aspen	3	3	6	2.6
Black spruce	3	2	5	2.1
Black gum	2	2	4	1.7
Red spruce	2	1	3	1.3
Tamarack	1	2	3	1.3

Based upon a total of 235 stands, 25 feet or over in height, 30 percent or better stocking, naturally restocked, and 1.0 acre or more in area.

present but not listed, as the distinction between black and red oak on the stand maps is not trustworthy.

The local forest, therefore, appears to be relatively homogeneous despite the patchwork impression that the stands present on the stand maps. Of twenty significant tree species, only four are of primary importance in that they are both abundant and widely distributed throughout the forest.

It still remains, however, to isolate and discuss the individual forest associations. This may best be done by treating separately the pioneer types, the transitional types, and the late successional types.

Pioneer types

Some 46 stands were classified as pioneer associations, 28 occurring on old field sites and 18 on cut-over sites. The sample was insufficient to permit further segregation into soil moisture classes, although the composition trends associated with soil moisture are apparently closely comparable with those described later for the transitional and late successional types.

The composition of the pioneer types is summarized in Table 5, which gives the percent frequency that each species occurs as a major and as a minor stand component. On old fields the well known white pine type emerges. White pine occurs as a major component in all but one stand, frequently forming a pure pine type. Red maple and red oak are the other two primary species, both occurring in two-thirds of the stands. Red maple occurs as a major species in slightly more than one-half of the stands, and red oak in slightly more than one-third. Of the minor species, paper birch, gray birch,

Table 5

FREQUENCY OF OCCURRENCE OF SPECIES: PIONEER TYPES

	Old field sites			Cut-over sites		
	Major	Minor	Total	Major	Minor	Total
White pine	96	4	100	—	6	6
Red maple	54	14	68	89	11	100
Red oak	36	32	68	72	11	83
Gray birch	4	18	21	45	33	78
Black cherry	—	18	18	6	33	39
White ash	—	18	18	6	6	11
Paper birch	11	7	18	—	—	—
White oak	4	7	11	6	6	11
Aspen	—	7	7	17	6	22
Hickory	7	—	7	11	—	11
Black birch	—	7	7	—	—	—
Hemlock	4	—	4	—	6	6

Based upon 28 stands on old field sites and 18 on cut-over sites.

black cherry, and white ash occur in 18 to 21 percent of the stands. The old field white pine pioneer association may, therefore, be coded as follows:

$$\frac{\text{WP - RM - RO}}{\text{YB - GB - WA - BC}}$$

The largest and oldest of these stands is illustrated in Figure 16. It covers about thirteen acres. Remeasurement of a quarter-acre permanent sample plot in 1949 located in the best part of the stand gave a total height of 91 feet, basal area of 189 square feet per acre, 140 stems of white pine and 20 stems of hemlock over six inches in diameter per acre, and a total volume of 7,600 cubic feet per acre.

In the young pioneer stands on cut-over and similar sites, red maple and red oak again appear as primary species, with gray birch being nearly as frequent. Minor components listed in order of frequency include black cherry, aspen, hickory, white ash, and white oak. This variant of the pioneer may therefore be coded as:

$$\frac{\text{RM - RO - GB}}{\text{BC - Asp}}$$

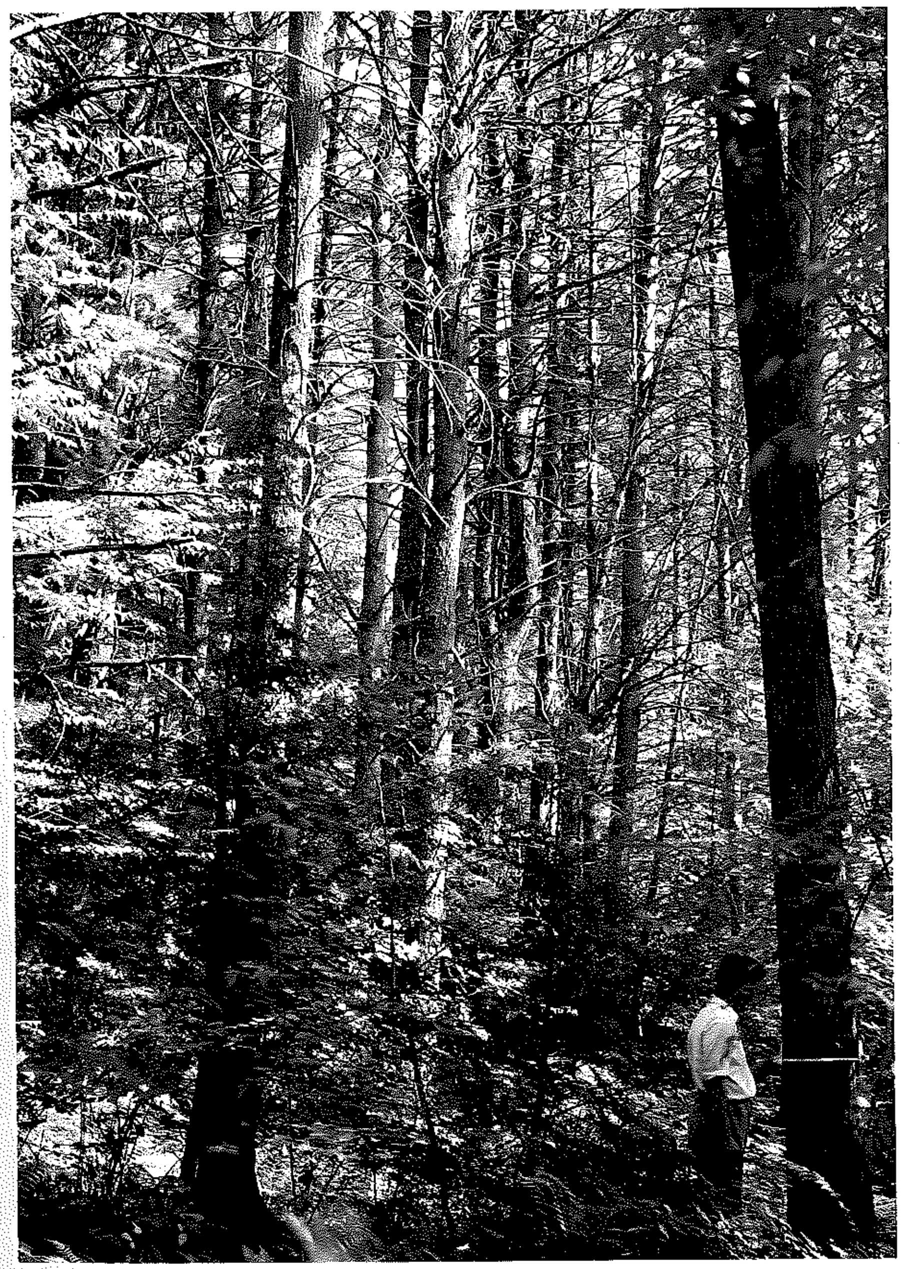
Of the two aspen species in the forest, the trembling aspen is considerably more abundant than the large-toothed aspen.

The pioneer association on cut-over land is similar in many respects to the natural restocking on hurricane blowdown areas which is discussed in some detail in Chapter 7.

<u>Transitional types</u>

A total of 139 stands on the 1946-47 maps met the requirements of

Figure 16. OLD FIELD WHITE PINE, SLAB CITY X



size, height and density of the present analysis and were classified as transitional types. These represented all sites, but nearly half of the stands occurred on well drained sites.

The frequency of occurrence of various species in the transitional types is presented in Table 6. Grouping all sites together, red maple and red oak appear as the two characteristic species, both occurring as major components in approximately three-quarters of the stands. The chief minor species is paper birch with an overall frequency of 30 percent. Six species are grouped with frequencies between 19 and 25 percent. These include in order of decreasing importance: hemlock, yellow birch, white oak, white ash, white pine, and black birch. Of these, hemlock occurs chiefly as an understory tree, presaging late successional stages characterized by that species, while the others occur in between five and ten percent of the stands as major components and in a somewhat greater number of stands as minor components. The overall transitional type, then, is predominantly a hardwood type and may be coded as:

$$\frac{RM - RO}{PB}$$

with the understanding that a number of other species occur in varying amounts.

A check on the overall composition of the transition hardwoods is provided by the records of 17 permanent sample plots in the Prospect Hill tract. These were established in 1944 by the author and C. T. Brown, Jr. for the purpose of checking aerial photographic interpretation, and

Table 6. FREQUENCY OF OCCURRENCE OF SPECIES: TRANSITIONAL TYPES 1946–47

	Very well drained			Well drained			Imperfectly drained			Poorly drained			Very poorly drained			All sites		
	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	All
Red maple	—	83	83	61	21	82	81	13	94	100	—	100	100	—	100	74	16	90
Red oak	67	17	83	95	3	98	81	13	94	42	25	67	20	—	20	73	10	83
Paper birch	—	33	33	14	26	40	9	19	28	8	13	21	—	7	7	10	20	30
Hemlock	—	33	33	3	27	30	—	12	12	4	29	33	—	13	13	2	23	25
Yellow birch	—	—	—	—	13	13	12	22	34	17	25	42	—	13	13	6	16	22
White oak	33	17	50	13	18	31	6	3	9	—	4	4	—	—	—	9	10	19
White ash	—	—	—	3	13	16	19	28	47	8	—	8	—	—	—	7	12	19
White pine	50	33	83	6	15	21	—	9	9	4	13	17	—	7	7	6	13	19
Black birch	—	—	—	5	26	31	3	6	9	4	8	12	13	—	13	5	14	19
Sugar maple	—	—	—	2	10	11	3	9	12	—	—	—	—	7	7	1	7	9
Hickory	—	—	—	6	6	13	3	3	6	—	—	—	—	—	—	4	4	7
Elm	—	—	—	—	—	—	3	3	6	—	4	4	13	—	13	2	1	4
Beech	—	—	—	—	8	8	—	—	—	—	—	—	—	—	—	—	4	4
No. of stands		6			62			32			24			15			139	

consist of a series of plots, mostly one-quarter acre in size, located in practically all the natural stands of timber in this largest of the Harvard Forest blocks. In the largest stands, more than one plot was established. Most of the plots were located in protected areas, as the stands on the more exposed sites had suffered greatly from hurricane blowdown and cutting. Therefore, the average site was somewhat better than would normally be the case.

The average basal area per acre by species of the 17 plots in the transition hardwood stands is given in Table 7. Red oak and red maple are by all odds the characteristic species as in the preceding analysis. Of the secondary species, sugar maple has the largest basal area, primarily because two of the sample plots were arbitrarily placed in small stands characterized by this species. Otherwise, the relative importance of species is much the same as for the frequency study of the entire forest; yellow birch, white ash, paper birch, white pine and hemlock each making up a minor proportion of the forest.

The transitional types, however, vary greatly according to the moisture relationships of the soil. The contrast in the distribution of red oak and red maple is especially well marked. Both occur on all sites. Red maple, however, occurs only as a minor constitutent on the very well drained sites and becomes increasingly important with increasing soil moisture, being of major importance in all the stands on poorly drained and very poorly drained sites. Red oak has diametrically opposite habits. It is of minor importance on the very poorly drained sites, becomes

Table 7

PROSPECT HILL TRANSITION HARDWOOD STANDS
(17 plots)

	Free trees	Overtopped trees	All trees
	Basal area per acre (square feet)		
Major components			
Red oak	22.7	1.5	24.2
Red maple	18.9	4.0	22.9
Minor components			
Sugar maple	4.4	1.2	5.6
Yellow birch	3.5	0.7	4.2
White ash	2.8	0.3	3.1
Paper birch	2.9	0.1	3.0
White pine	2.5	0.4	2.9
Hemlock	1.1	1.0	2.1
Black birch	1.5	0.2	1.7
White oak	1.2	0.4	1.6
Black cherry	1.3	0.2	1.5
Others (GB, Be, Basswood)	1.2	0.4	1.6
Total	64.0	10.4	74.4

increasingly important with decreasing soil moisture, and is of major importance on well drained and very well drained sites.

The other species exhibit just as pronounced adaptation to site although none are as abundant as red maple and red oak. Only hemlock appears to be about equally frequent on all sites. White pine is a major species only on very well drained soils, and apparently decreases in importance with increasing soil moisture. Paper birch has much the same distribution except that it is most important on well drained sites. White oak is important only on the very well drained sites, decreases with increasing soil moisture and is not found on the very wettest sites. Since only these species are found on the very well drained sites, the transitional forest on these dry soils may be described as:

$$\frac{RO - WP}{WO - RM}$$

In contrast, the transitional forest on the well drained sites is considerably more complex. Twelve species have frequencies of 8 percent or greater on these sites. Beech is apparently confined to well drained soils and hickory and sugar maple to well drained and imperfectly drained soils. The transitional forest on well drained sites is basically:

$$\frac{RO - RM}{PB - WO - BB}$$

Hemlock occurs primarily as an understory tree, again foreshadowing late successional stages. White pine, white ash, hickory, and sugar maple also occur more or less frequently as major components.

On the imperfectly drained soils, red oak and red maple are of equal importance. White ash is the third most frequent species, being very largely confined to these soils. Considering the minor components, the transitional forest on imperfectly drained sites may be summarized as:

$$\frac{RO - RM}{WA - YB - PB}$$

On the poorly drained sites, fewer species are found, and the stand structure is somewhat simpler. Red maple is by all odds the characteristic species with red oak being clearly second in importance. Yellow birch is more abundant on these sites than on any others, while all the other species show a general decline in abundance from the imperfectly drained soils. The association on poorly drained soils, then, may be generalized as:

$$\frac{RM - RO}{YB}$$

As in the previous cases, hemlock occurs primarily as an understory tree. White pine, paper birch, black birch, and white ash are locally of some importance. Figure 17 is of a red maple swale directly behind the Headquarters building. This stand has been thinned once.

Finally, on the very poorly drained soils, red maple is the only tree that occurs in more than 20 percent of the stands, and it occurs in all of the fifteen cases. Chief among the minor components are red oak, American elm, and black birch, with yellow birch and hemlock being nearly as frequent but occurring only as minor components. The transitional type on very poorly drained soils is basically:

$$\frac{RM}{RO - BB - Elm}$$

From the above discussion, it can readily be seen that the transitional types are highly interrelated and form a continuous and gradual gradational

Figure 17. RED MAPLE SWALE, PROSPECT HILL I.

series from the driest to the wettest types. The transitional associations are characterized by red oak and red maple, the relative importance of each being determined almost perfectly by soil drainage. All the other components occur less frequently, and serve to indicate soil moisture conditions. Thus, white pine in the transitional associations is prominent only on the very well drained or dry sites; white oak only on the very well drained or well drained sites; black birch on the well drained to very poorly drained soils; paper birch on the well drained and imperfectly drained soils; white ash on the imperfectly drained soils; yellow birch on the imperfectly drained and poorly drained soils; and finally elm only on the very poorly drained soils. The actual range of each species, is, of course, somewhat greater than that indicated above, but their range as a characteristic species is largely as stated.

Late successional types

Fifty stands were classified as belonging to the more maturely developed or late successional stages. None of these stands approach the nature of the theoretical climax association as few are apparently stable in composition and all show clearly the effect of past land use and management practices. Relative to the transitional stages, however, they do represent a later stage in forest succession.

Hemlock is the characteristic species of late successional associations, occurring as a major stand component in 96 percent of the stands (Table 8). Red maple and red oak are the other two species with frequencies greater than 50 percent. Of the other species, only white pine and three of the

Table 8. FREQUENCY OF OCCURRENCE OF SPECIES: LATE SUCCESSIONAL TYPES
1946-47

	Very well drained			Well drained			Imperfectly drained			Poorly drained			Very poorly drained			All sites		
	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum	Maj.	Min.	Sum
Hemlock	100	—	100	100	—	100	88	12	100	100	—	100	91	—	91	96	2	98
Red maple	—	44	44	29	47	76	75	25	100	40	40	80	64	36	100	40	40	80
Red oak	33	44	77	47	41	88	38	—	38	20	20	40	—	—	—	30	24	54
White pine	67	22	89	24	—	24	—	50	50	20	20	40	18	18	36	26	18	44
Paper birch	11	11	22	6	47	53	—	62	62	—	40	40	—	—	—	4	32	36
Yellow birch	—	11	11	18	12	29	12	38	50	40	40	80	—	27	27	12	22	34
Black birch	—	33	33	—	53	53	—	—	—	40	—	40	—	—	—	4	24	28
Spruce	—	—	—	—	—	—	—	—	—	—	—	—	36	27	64	8	6	14
Beech	—	11	11	—	18	18	25	—	25	—	20	20	—	—	—	4	10	14
White oak	—	33	33	—	18	18	—	—	—	—	—	—	—	9	9	—	14	14
Elm	—	—	—	—	—	—	—	—	—	—	40	40	9	—	9	2	4	6
Tamarack	—	—	—	—	—	—	—	—	—	—	—	—	9	18	27	2	4	6
Black gum	—	—	—	—	—	—	—	—	—	—	—	—	9	9	18	2	2	4
No. of stands		9			17			8			5			11			50	

birches occur in more than fifteen percent of the stands. The overall late successional association may be characterized as:

$$\frac{T - RM - RO}{WP - YB - PB - BB}$$

Considering variations in composition with relation to variation in soil moisture, both red oak and red maple behave much as they do in the transitional types, the former species tending to predominate on the drier soils and the latter on the wetter soils. The only reason that red maple occurs more frequently than red oak in the late successional stands appears to be that a higher percentage of the stands on the more poorly drained sites reach this stage of development, as these sites are the more protected locations.

An insight into the average composition of late successional stands on a basal area basis is given by the average values from six permanent sample plots in the Prospect Hill Block established and measured in 1944 (Table 9). Hemlock makes up nearly 70 percent of the basal area of these stands, with red maple and red oak being the other common species. White pine and the three longer-lived birches are the other chief components.

On the very well drained sites, white pine is a major species. Black birch, white oak, and paper birch occur frequently as minor stand components. The late successional forest on the very well drained sites consists of :

$$\frac{T - WP - RO}{RM - WO - BB}$$

This association differs from the comparable transitional association in that hemlock is a major species and that white pine has become somewhat

Table 9

PROSPECT HILL HEMLOCK STANDS
(6 plots)

	Free trees	Overtopped trees	All trees
	Basal area per acre (square feet)		
Major components			
Hemlock	60.8	8.6	69.4
Red maple	12.6	0.8	13.4
Red oak	9.0	0.7	9.7
Minor components			
White pine	3.2	0.3	3.5
Black birch	3.0	0.1	3.1
Yellow birch	2.6	0.3	2.9
Paper birch	2.4	0.1	2.5
Others (RS, Be, WA, BO)	2.5	0.8	3.3
Total	96.1	11.7	107.8

more prominent. Figure 18 illustrates the pine-hemlock-hardwood stand in the upper part of Slab City X on a well drained to very well drained Hinckley soil.

On the well drained sites, white pine is less important and various hardwoods are more frequent. The average composition obtained from the frequency study is similar to that obtained from the basal area study of the Prospect Hill sample plots in Table 9. Coded, it is:

$$\frac{\text{T - RO - RM}}{\text{WP - YB - PB - BB}}$$

White oak and beech are also important constituents locally. Again, in contrast to the comparable transitional type, this late successional association is distinguished by the predominance of hemlock and the greater importance of white pine and yellow birch.

A similar late successional association is found in the eight stands growing on imperfectly drained sites. Their average composition is:

$$\frac{\text{T - RM}}{\text{YB - PB - WP - RO}}$$

As in the corresponding transitional type, red maple is more common and red oak less common than on the drier sites. Hemlock and white pine are again more important than in the related transitional types. Beech also occurs as a somewhat less frequent stand component than the other species.

On the poorly drained sites, hemlock is still the most frequently occurring species, followed closely by red maple and yellow birch. The sample is too small to permit accurate analysis of the minor species, but black birch, red oak and white pine are the only ones occurring as major

Figure 18

WHITE PINE-HEMLOCK-HARDWOOD TYPE, SLAB CITY X

stand components. Elm and paper birch, however, occur as minor stand components in two out of the five stands. Tentatively, the stand may be described as:

$$\frac{T - RM - YB}{BB - RO - WP}$$

Finally, on the very poorly drained sites, hemlock and red maple are again the characteristic species. Here, however, spruce (red on the Prospect Hill Tract and presumably black on the Tom Swamp Tract) are prominent, along with white pine, tamarack, black gum, and yellow birch. We are, therefore, dealing with the softwood swamp type. Two plots in the Prospect Hill peat bog give basal area data typical of that bog, but not of the Tom Swamp bog (Table 10). In these values, red spruce is the most abundant tree, followed by red maple and black birch, with the other species only making up a total of five square feet of basal area per acre. This bog is pictured in figure 19. The late successional association on very poorly drained soils varies widely from spot to spot, but may be generalized as:

$$\frac{T - RM - Sp}{WP - Tam - YB - BG}$$

All in all, the late successional associations bear a strong resemblance to the corresponding transitional associations. The most striking differences are the predominance of hemlock and the greater importance of white pine in the former stands. Hemlock arrives at its position by coming up through the understory, while white pine does not increase in numbers over the years, but rather maintains itself by the

Table 10

PROSPECT HILL PEAT BOG
(2 plots)

	Free trees	Overtopped trees	All trees
	Basal area per acre (square feet)		
Red spruce	30.4	5.0	35.4
Hemlock	25.0	1.1	26.1
Red maple	12.8	1.1	13.9
Others (YB,GB,WP,BG)	4.9	0.3	5.2
Total	73.1	7.5	80.6

Figure 19. PEAT BOG, PROSPECT HILL II

persistence of those few stems which managed to survive early hardwood competition and thereby reaches a position of dominance over the rest of the stand.

As with the other associations described, red oak and red maple are present in most cases, the former being more frequent on the drier and the latter on the wetter sites. White ash does not occur noticably in the late successional stands, but whether this is due to inherent inability to meet long-term competition, or merely to inadequate sampling cannot be specified at this time.

Summary

Apparently, then, the associations in the Harvard Forest, far from being made up of a hodge-podge of species scattered indeterminatly over the area, constitute a regular series of interrelated types, composed predominantly of surprisingly few species, and closely correlated to successional stage and site as expressed in terms of soil drainage.

Two species are practically omnipresent. Red oak and red maple are equally prominent in all successional stages and one or the other is prominent on all sites. As stated previously, however, both exhibit marked relationship to soil moisture, red oak being most frequent on the drier and red maple on the wetter sites.

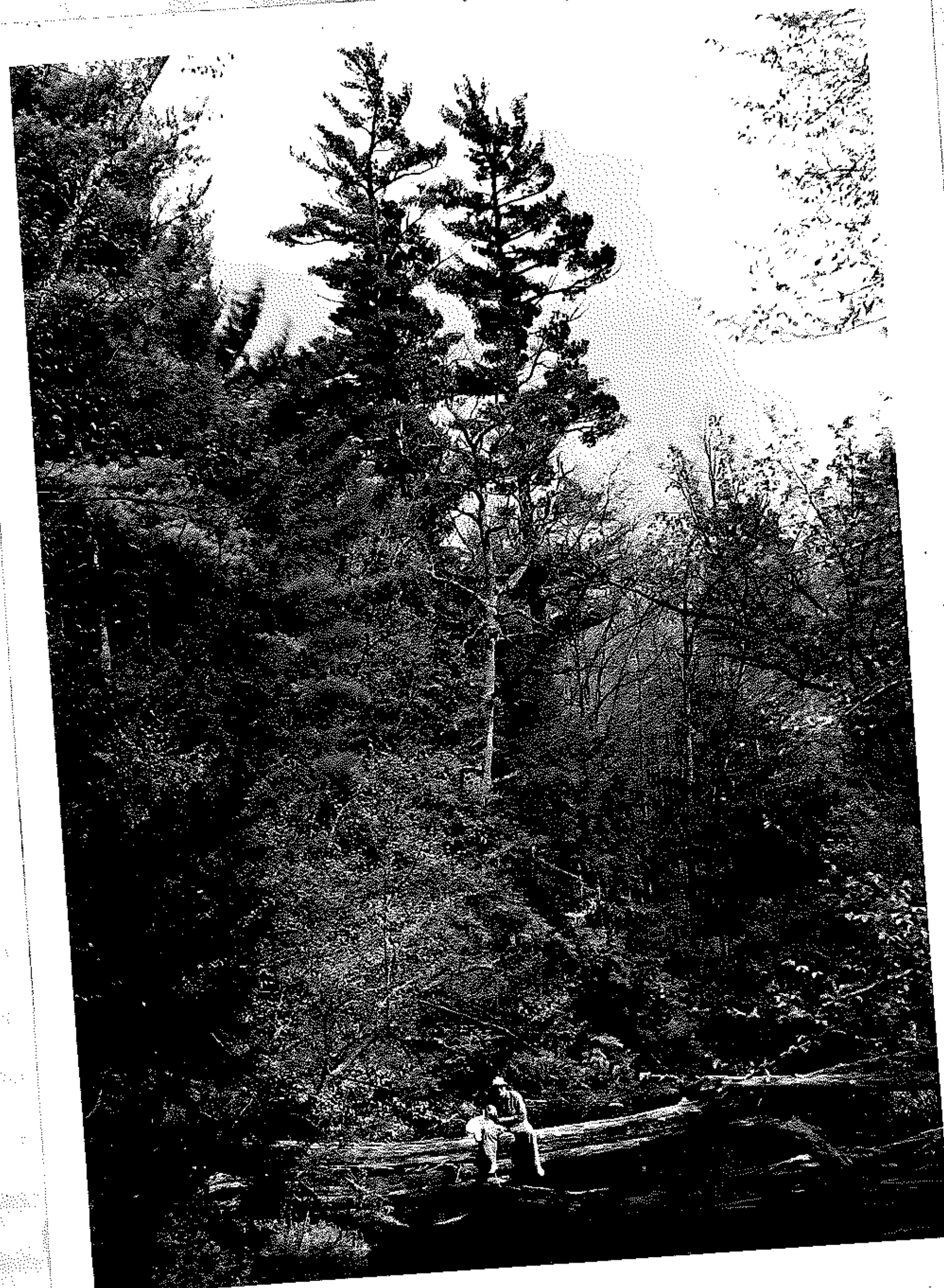
White pine appears to be both less important than assumed by earlier white pine enthusiasts and more important than assumed by latter hardwood enthusiasts. It is, of course, the characteristic old field tree. Furthermore, as has previously been well established by many investigators, it is the characteristic tree of very well drained sites in all successional stages. Regionally, it occurs on somewhat better sites than those frequented by pitch pine and on slightly better sites than those where red pine is found, chiefly to the north of the Petersham area. On the typical Merrimac and Hinckley soils as well as on the dry ridges of the Pisgah Tract (Cline and Spurr, 1942) and similar sites in the Harvard Forest, white pine is a tree of major importance in all successional stages.

The present data further indicate, however, that scattered white pines persist into the transitional stages on all sites, and make up an increasingly percentage of the stand volume in the late successional stages as a few trees reach the overstory and become dominant over the rest of the stand (Figure 20). White pine thus appears to be a minor but important and characteristic component of late successional stages on all sites from the wettest to the driest.

Hemlock occurs in more or less equal numbers in late successional stands on all sites. It occurs but infrequently in pioneer and transitional associations, but is the characteristic species of late successional stands. As the period since farm abandonment increases in length and as clearcutting is supplanted by partial cutting, hemlock is becoming increasingly important. Already one of the most frequent species on the forest, it should become more abundant as partial cutting is practiced in the future.

Figure 20

WHITE PINE STANDARDS NEAR SWIFT RIVER, SLAB CITY X



Of the other species, the various birches are the most important. Paper birch is best adapted to the drier sites, black birch to the average well drained sites, and yellow birch to the wetter sites. White ash is locally important on the imperfectly drained soils, but shows little persistence into late successional stages. White oak is important in all successional stages on the drier soils, while hickories are somewhat less xerophytic, being found on the well drained as well as on the very well drained sites. Beech and sugar maple are occasionally found on the intermediate sites; while red and black spruce, tamarack, elm, and black gum are found on the wettest sites.

Everything considered, all the forest associations found in the Harvard Forest seem to represent a continuous gradational series correlated with successional stage and soil moisture. Thus, the old field white pine and the pioneer hardwood types are pioneer associations which vary in composition according to the site where they occur. Among the transitional types, the white pine-hardwoods type on the driest sites grades into the transition hardwoods type on the intermediate sites which in turn grades into the swale and swamp hardwoods types on the wettest sites. Among the late successional types, the white pine-hemlock-hardwoods type on the driest sites grades into the hemlock-hardwood type on the intermediate sites which grades into the softwood swamp type on the wettest sites. A similar gradational series is found on each site as between the different successional stages.

It may be mentioned that the associations here described bear little resemblance to the standardized forest cover types as described by the Society of American Foresters (1940).

It has already been noted that few if any of the stands described approach the condition of a theoretical climax in that their present composition and structure would persist unchanged indefinitely in the absence of disturbance or climatic change. None the less, it is of interest to project the successional trends noted. The regional climax as described by Nichols (1935) is a hemlock-white pine-northern hardwoods association; beech, sugar maple, and yellow birch being the prevalent hardwood species. On the basis of the present study, the local climax might well be a hemlock-white pine-hardwood forest. White pine, however, would be a prominent member of the association only on the drier sites. The hardwoods would be quite different from those named by Nichols, being chiefly red oak and red maple. Certain of the other hardwoods, particularly yellow and black birch, would apparently be constituents of any climax community; but there is no evidence in the present study of any trend toward greater numbers of the northern hardwood species. Apparently, the physiographic climax on the drier sites is basically a hemlock-white pine-red oak association; the climatic climax on the intermediate sites is a hemlock-red oak-red maple association; and the physiographic climax in the swamps, a hemlock-red maple-spruce association. Together with the key species listed above, white pine, yellow birch, and black birch would occur in lesser numbers on a variety of sites. Such an ensemble of climax associations would not only be in accord with the successional trends here described, but would also agree with the conclusions reached in the study of the virgin upland forest of central New England (Cline and Spurr, 1942).

The forest associations in the Harvard Forest, therefore, appear to be closely related to site as expressed in terms of soil drainage and to forest history as expressed in terms of successional stage. It remains to examine in detail the effect of site as expressed more specifically in terms of soils and local climate, and the effect of forest history as expressed in terms of silvicultural operations and natural restocking after the 1938 hurricane.

Chapter 4

GEOLOGY AND SOILS

As the medium in which plants obtain their support, nutrition, and water, soils must be expected to exert considerable influence upon forest composition.

In the Harvard Forest, the soils are almost entirely of one age, that of the last Wisconsin glaciation. About 92 percent of the area is overlain with glacial till and 8 percent with deposits laid down by glacial melt water. It would seem at first glance that a knowledge of glacial deposition coupled with a mapping of the actual soil types would suffice for an understanding of the soils of the area.

Appearances are deceiving, however, for the glacial deposits prove to be very thin. Bedrock is exposed in each of the three blocks of the Forest at several points. The glacial till throughout central New England varies up to only a few tens of feet in thickness and probably averages less than ten feet in depth (Alden, 1924; Flint, 1930). Although the glaciers modified the surface of the land to some extent by erosion, and the melting of the ice left a veneer of deposits, yet the major features of the landscape are essentially pre-glacial in origin.

Furthermore, probably more than 90 percent of the drift is derived from the local bedrock, much of it having been moved only a few feet from its source (Flint, 1930). Thus, the petrology of the bedrock determines in large part the chemical composition of the soil and influences greatly its physical nature. Both from the standpoint of topography and soil composition, therefore, the pre-glacial geology of the area is highly important and should be examined in some detail along with the glacial geology of the area before discussing the problem of soil classification, the nature and distribution of the local soils, the relation of soils to site, and the relation of soils to natural reproduction.

PRE-GLACIAL GEOLOGY

The Harvard Forest lies entirely within the eastern upland of New England. It is within the type locale of the peneplane as defined by Davis in 1889. His description of the terrain in 1895 as the product of long-term erosion and subsequent rejuvenation through uplift has long been accepted as the classic illustration of this major geological process. Despite the concentration of geologists at New England centers for several generations, however, the bedrock geology and the geological history of the eastern upland of Massachusetts are still little known. The exceeding complexity of the problem coupled with the lack of fossils and other means of attacking the problem have led most workers to shun the problem for more attractive and promising areas. By bringing together what little has been done, however, we can at least obtain a general idea of the bedrock geology of the Petersham area.

We may well start with Davis's concepts which were based largely upon observation of the landforms rather than upon a detailed study of the rocks themselves. He conceived of ancient New England as being a very mountainous country. Quoting his 1895 work:

> "The New England rocks are not only deformed in mass: they exhibit also at many places the minute internal deformities so characteristic of regions that have been crushed under a great overlying load, and so prevalent in regions that are mountainous today."

These "New England Alps" were in his view gradually reduced over long geologic time to a penplane of denudation:

> "...a kind of plain that results from the destructive action of weather and water, by which any land area, whatever its original form, is worn down so smooth, and so close to sea level, that it cannot be worn any lower."

Standing above this plain are left residuals which owe their altitude according to Davis to the resistance of their rock to erosion. The classic example is Mount Monadnock, only twenty-five miles north of the Harvard Forest Headquarters. Finally, uplift subsequent to the peneplanation resulted in dissection of the more or less level surface. Davis illustrates the nature of the valleys formed by this dissection with reference to Millers River, which flows only four and one-half miles north of the Forest Headquarters.

> "Millers River offers another kind of illustration of the general principle by which the breadth of our valleys is governed. Its course leads westward near the northern boundary of Massachusetts for about thirty miles to its mouth in the Connecticut. On the way, the river crosses successive belts of harder and weaker crystalline rocks, trending about north and south. Where the rocks are weak, as between Athol and Orange, the valley is wide-opened; where the rocks are hard, as above Athol and below Orange, especially the latter, the valley is much narrower. Southward from Athol, towards Brookfield and Palmer, the peneplain is much dissected by valleys that follow the belts of weaker rocks; and, instead of resembling a continuous plateau, the upland consists of a number of dissevered hills."

The concepts presented by Davis have received widespread acceptance (Fenneman, 1938). Such fragmentary work as has been done in the bedrock geology of central Massachusetts (Emerson, 1898, 1917; Callaghan, 1931) is insufficient to prove or disprove Davis's views, although recent geological studies of west-central New Hampshire are rapidly adding to our knowledge of closely related geological conditions.

The geology of the Petersham area has been mapped and described in some detail by Emerson (1917). His general description is that:

> "The central upland, or Worcester County plateau, is made up of alternate broad bands of carboniferous granite and narrower bands of older schists, repeating in part the structure and lithology of the western upland. The northern part of the westernmost range of granite is rather resistant and forms monadnocks like Mount Grace, but its southern part has been deeply eroded in the Wilbraham valley. The granite belt next east is made up of less resistant rock and forms the Monson valley and the broad, relatively low strip that stretches from Orange to Palmer. The third granite belt is more resistant again and forms monadnocks as Wachusett and Asnebumskit.

The oldest rocks in the area are Paleozoic sedimentary deposits which were strongly metamorphosed by late Paleozoic pegmatic igneous intrusives. Originally, these sedimentaries apparently consisted of "a calcareous sandstone below and a great mass of carbonaceous and pyritous shale and subordinate beds of conglomerate and limestone above." In the Petersham area, these have been metomorphosed into schists, particularly the Brimfield, Paxton, and Ware schists.

The most marked and widely distributed schist is the Brimfield. As described by Emerson (1917), it is:

> "A uniform coarse red-brown muscovite schist containing much biotite, fibrolite (commonly derived from an antecedent andalusite), and graphite, and so much pyrite that it is wholly rusted in many of

the deepest openings. West of the Worcester phyllite, it is very generally so soaked with granitic material in small lenses, veins, and filaments that it has become a composite rock or a gneiss which still retains largely the aspect of the schist from which it was derived."

Quartz occurs in lenses while beds of meta-limestone occur in layers in the shale. This rock occupied nearly the entire surface of the western part of the country. It was subsequently thrown into great north-south synclines which are folded into the Paxton quartz schist. Callaghan (1931), on the basis of evidence in the fourteen mile tunnel normal to the strike constructed by the Metropolitan District Water Commission southeast of Petersham, has designated that part of the Brimfield schist below the Paxton as the Ware schist.

The Paxton schist lies below the more narrowly defined Brimfield schist. It thins towards the west and is not as abundant as the latter in the Petersham area. Again according to Emerson, it differs from that rock in being distinctly quartzitic, less rusty, and lacking in graphite, garnet, and the alumino-silicates. It is much intruded by granite and includes much biotite, small beds of mica schist, and limestone. Callaghan gives quartz, feldspar, biotite, and minor amounts of muscovite (chiefly andesine) as the principal mineral components.

These schists were thought by Emerson to be Carboniferous. Callaghan, while not rejecting this, states that west of the Fitchburg granite, "the greater degree of metamorphism and igneous intrusion of the

schists suggests that they belong to a different and possibly older series."
Generally similar schists in southwestern New Hampshire are currently thought to be Devonian.

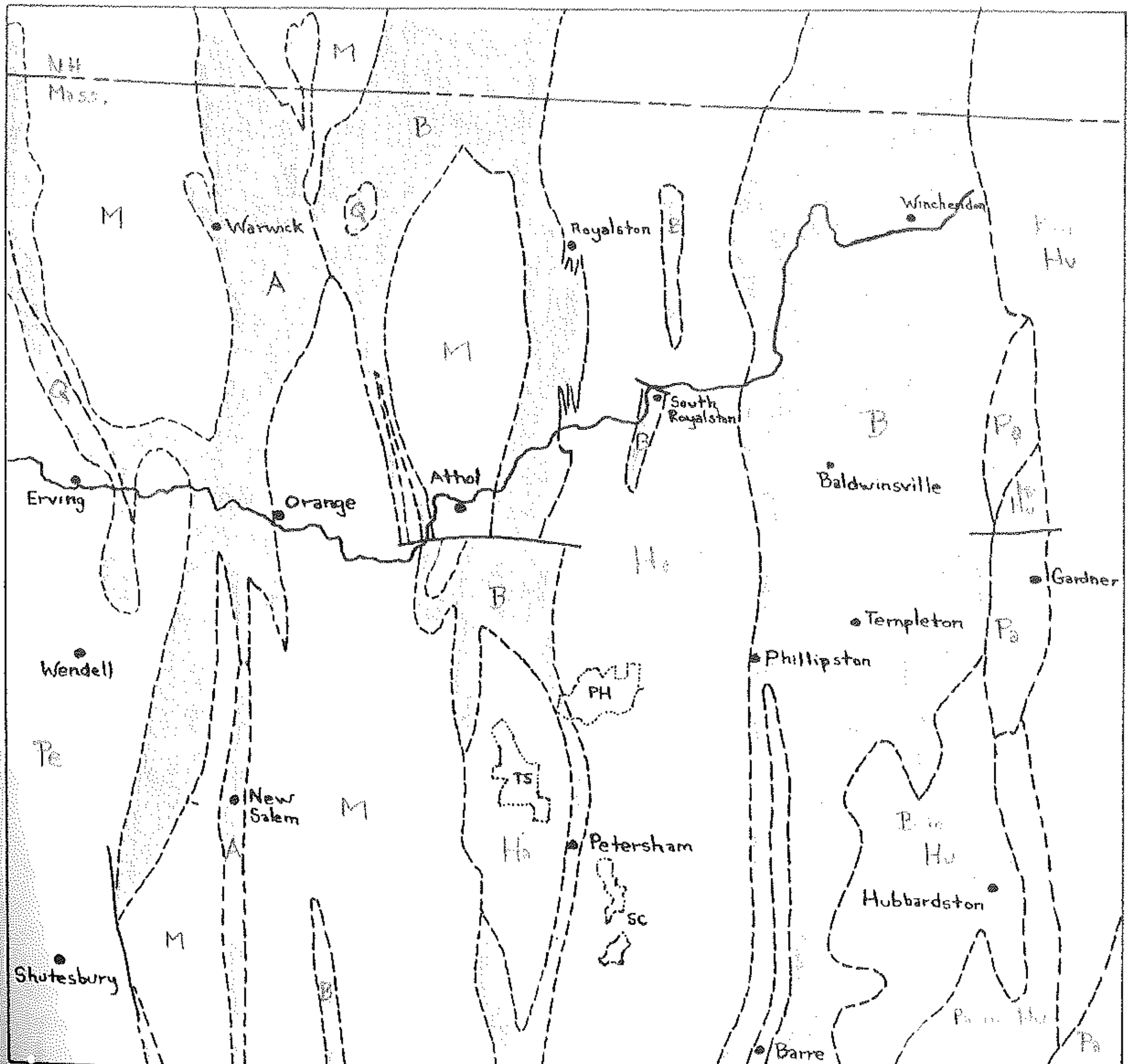
Much of the present-day surface is mapped as granite rather than schist as shown in Figure 21, adapted from Emerson (1917). Petersham lies over the center of a very symmetrical batholith which extends from Marlboro, New Hampshire to Monson, Massachusetts and is about four miles wide and fifty miles long. The exposed rock according to Emerson is:

> "Almost everywhere a dark granite gneiss, but in several small central areas which seem clearly to be a deep-seated core is exposed. Thus in Petersham, sheets of a black fine and even grained rock pass with low inclinations east and west beneath the inclosing sheets. Next inwardly broad bands of a dark small porphyritic rock pass outward beneath the fine-grained sheets, and in the central area this porphyritic rock is itself cut through in the deep valleys, exposing a very light-colored granite.

Where pure, this granite is termed the Fitzwilliam and was formerly quarried extensively in that town in the southernmost tier of New Hampshire townships. Where contaminated with the older schists, it is termed the Hardwick granite.

The other granitic intrusions lie east and west of the Petersham batholith. Although they have contributed little or nothing to the Harvard Forest soil mantle, a brief mention of them will help complete the geological picture. Extending east from Gardner and Hubbardston is the central batholith composed of the Fitchburg (uncontaminated phase) and Hubbardston (contaminated phase) granites. Underlying the Quabbin valley to the west of Petersham, the Tully valley to the north of Athol, and

Figure 21. BEDROCK GEOLOGY OF CENTRAL MASSACHUSETTS
Generalized from Emerson, 1917



Igneous intrusives

Pelham granite (Pe)
Monson granodiorite (M)
Hardwick granite (Ha)
Hubbardston granite (with Brimfield schist) (Hu)

Metamorphic sedimentaries

Amherst schist (A)
Quabbin quartzite (Q)
Brimfield schist (B)
Paxton schist (Pa)

the highlands northwest of Orange, is the Monson granodiorite, described by Emerson as a "clear gray granite or granite gneiss of rather fine grain, generally pure biotitic." Along its eastern border in Athol and Petersham, he adds that the rock becomes potassic, and a band a mile wide is porphyritic. Here the rock rises to high ground. Finally, the upland west of the Quabbin valley and supporting the towns of Wendell and Shutesbury is mapped as Pelham granite. This granite is dissected by the deep valley of the Millers River in the area around Erving.

From the above description of the rocks and formations in the Petersham area, it is apparent that the bedrock geology of the Petersham area is exceedingly complex and confusing. Perry, writing of the area around Mt. Monadnock (1904) has well described the general situation.

> "It is difficult to decide, in some parts of this area, where to draw the boundary between granite and schist, because there is frequently a zone of alternating bands extending in the direction of the strike. Such an area is represented in the extreme western part of the (Monadnock) geologic map, and also in cross-section. The meaning of such an area is that the surface of contact between schist and granite batholite was a ragged surface -- the granite having penetrated the schist at intervals, and pushed apart the vertical laminae. The erosion has brought the land surface down so as to make a section through this alternation. If the land surface had been lowered somewhat less, the rock at the surface would have been schist; whereas if the land surface had been lowered somewhat more, the rock would have been then all granite. As it is, the extension of the batholite is but a short distance below the surface."

Having examined the present state of knowledge concerning the bedrock geology, we are now in a position to raise certain questions about the broad sweep of geologic history of the area as envisioned by Davis.

First, the monadnocks of the area, including Mt. Monadnock itself, have been demonstrated by Perry to "owe their survival to their position rather than to the rocks of which they are composed." The one probable exception is Mt. Grace in the town of Warwick which is composed of more resistant rocks (amphibolite). Mt. Monadnock is the remnant of a syncline of andalusite mica schist, induced by the intrusion of granite, which modified the schist already metamorphosed. Asnebumskit in Paxton and Wachusett in Princeton are composed of Brimfield schist and some granite, similar to the rock of the rest of the plateau.

Second, the hypothesis of an old "New England Alps" mountain range does not seem at all essential. The presence of Paleozoic sedimentary deposits in the form of schists over much of the surface today suggest that such ancient highlands as did exist need not have greatly exceeded in height the depth of these sediments, whatever they may have been. Furthermore, the general accordance of the volcanic intrusives suggests the rasing of a rough plateau-like upland rather than rugged mountains.

Third, it isn't at all necessary to assume that the present accordance of hill-top levels is due entirely to peneplanation controlled by a base level much higher than that of today. Rather, it may well be that structure may account for much of this accordance. A good deal of the topography is clearly structurally controlled. The erosional fault scarp bounding the western limit of the upland is an example. The drainage system is generally well adjusted to lithology and structure, as witness the agreement between the present Quabbin valley and the lower portion of the Monson granodiorite. The present accordance of hill-top levels might well be at least partially controlled by the pre-existing accordance of the batholithic intrusions. It would be interesting to ascertain whether the Monson granodiorite is actually less resistant to erosion than the Pelham granite to the west and the Hardwick granite to the east, or whether it simply did not well up as high and thus created a broad structural valley.

Finally, if we accept the possibility of a late Paleozoic upland that has gradually been eroded down to the present upland, producing a terrain molded to lithology and structure, it then becomes no longer necessary to presume a former high base level at an altitude approximating 1000 feet in the Petersham area today. Certainly the ocean has often been higher since late Paleozoic times than it is today. Nevertheless, the scarcity of sedimentary deposits since Triassic time and the general stability of the New England Province since that time (except for the depression of the land under Pleistocene ice and its subsequent recovery) might well be used as arguments against a long-existing high base level coupled with subsequent uplift being responsible for the present topography.

There is no doubt that erosion has played a major part in the formation of the present landscape, and that evidences of peneplanation are abundant (Figure 22). At the same time, the concepts of Davis concerning the central New England region seem more based upon subjective judgment than upon facts. Rather than being an uplifted, dissected

Figure 22

WESTWARD VIEW OF NEW ENGLAND PENEPLANE FROM PROSPECT HILL

peneplane, the present upland may equally well owe its character to the nature of the batholithic intrusion and to subsequent erosion. Neither rugged mountains nor a highly developed peneplane are essential prerequisites to the present landscape. In futhre geological work, the importance of structural and lithological control of the present topography should be more carefully investigated.

GLACIAL GEOLOGY

Although the long period of geological history prior to the Pleistocene epoch was entirely responsible for the local bedrock and very largely responsible for the present-day land forms and topography, yet Pleistocene glaciation, by modifying the surficial topography and by providing a mantle of deposits from which nearly all of the present soils have developed, is also of great importance.

Little is known of the precise history of Pleistocene glaciation in New England. The region was glaciated several times, the last glaciation being of the Wisconsin series, but the stratigraphy and correlation of the deposits has not been worked out. All the soils in the Petersham area, however, are presumably the product of the last of these glaciations.

Actually, the evidence of prior glaciation is scanty, but it is provided by two similar sections east of the village of Petersham. In digging the foundation and drilling a deep well for the Fiske house on East Street, thre-quarters of a mile east of the village, it was found that the till deposit on the surf ce is about nine feet thick. The surficial layer of three feet is a brown stony fine sandy loam typical of the Gloucester soil series. This is underlain by a six-inch layer of a much coarser deposit, made up largely of coarse sand and gravel, but including pebles up to four inches in diameter. Under this, extending from three and one-half to nine feet is a very compact basal till, a fine sandy loam somewhat less stony and finer-grained than the top layer. Beneath this, however, is more than one hundred feet of a uniform gray medium sand, laminated and highly compact. From the position of the site on the west bank of the Swift River valley, 120 feet higher than the present stream, and from the form of the bench, it appears highly probable that this sand represents a kame terrace laid down in the latter stages of a prior advance of the ice. Substantiating sections are exposed in a large gravel pit opened in 1948 three-quarters of a mile north of the Fiske house, at a lower elevation in the Swift River valley just north of Brown Pond. Here the till is thinner, but everywhere covers a complex of sands and gravels which appears to be stratified drift dating from a prior ice sheet or at least an earlier stage of the same ice sheet.

The glacial deposits of central New England have been studied by Tarr (1892), Emerson (1898), Alden (1924), and Flint (1930, 1933). Tarr attempted to identify and map terminal moraines in central Massachusetts, but beyond stating that the moraine is typically developed at Winchendon, Gardner, and south of Athol and Orange, had to admit that:

"In the region between Ayer Junction and the Connecticut River the morainal accumulations are quite puzzling. The country is hilly and deeply scored by both east and west and north and south valleys. The result has been a complicated distribution of the morainal deposits which renders exact statements concerning the detailed history of their formation quite impossible at present. The distribution is in more or less continuous patches; but distinct lines of moraine cannot be traced for any considerable distance, their continuity being interrupted by the irregularity of the topography. As a result of this, we find a series of scalloped, serrated lines in the general moraine. These lines and the entire moraine are somewhat broken, yet the general continuity of the deposit is undoubted for the breaks are rarely a mile in width.

"A vacillating condition at this place is indicated by the great width of the morainal deposits. The moraine covered tract is often eight or ten miles in width and isolated patches of "shoved" moraine are found both to the north and south of this."

Tarr's inability to locate a definite terminal moraine presaged Flint (1929) who concluded that the last ice melted largely <u>in situ</u> as a stagnant mass, rather than withdrew to the north. This concept is now generally accepted, as has been the concept that the ice over central Massachusetts was quite thin even at its maximum, probably being not more than one or two thousand feet thick over the top of the upland.

The ground till or ground moraine has been described by Alden (1924) as averaging ten to fifteen feet thick over central Massachusetts. Flint (1930) gives similar values for Connecticut, and his description of the deposits could well have been written for the Petersham area:

"The thickness of the till is variable. In not a few places, notably on cliffs, steep hillslopes, and many hilltops, it is lacking altogether. In general it is thicker on stoss slopes, where apparently a kind of plastering process took place, than in the lee of obstructions, where plucking was active. In a few places, notably in the Connecticut Valley, it is penetrated by wells to depths of more than 80 feet. Thickness of over 30 feet are not exposed and are uncommon even in borings. The average for Connecticut is probably not more than 10 feet. Even this figure may be too great.

"An examination of almost any exposure of till shows that considerably more than 90 per cent of the component materials are locally derived. The rock types found in the fragments are identical either with the immediately underlying rock or with the bedrock a short distance to the north. Pebbles and boulders of definitely foreign origin are rare enough to cause remark.

"The small volume of the till points to weak erosion by the ice; the close correlation between the composition of the till and that of the underlying bedrock points to weak transportation. It is evident that the glacier accomplished little work as far as rock material was concerned.

Considering the Harvard Forest itself, about 92 percent of the area is covered with ground moraine. A few small drumlins or drumlin-shaped hills occur, among them being one immediately south of the peat bog in Prospect Hill VIII, another along Brooks Pond in Tom Swamp VI, and a third in the northern portion of Slab City X.

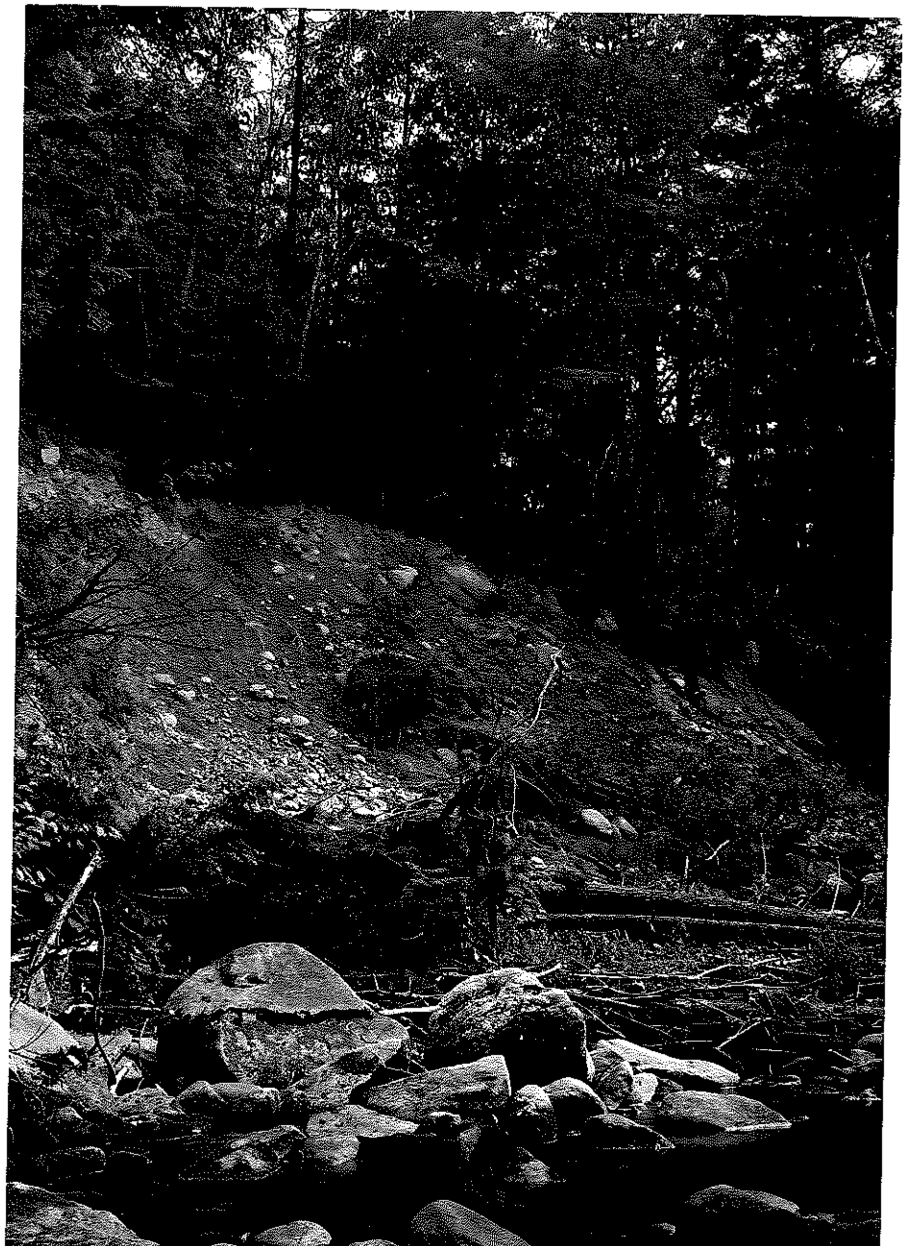
Only 8 percent of the Harvard Forest is covered by stratified drift. This area is largely localized in the Swift River Valley in the Slab City tract, and in the valley now occupied by Brooks Pond, Tom Swamp, and Riceville Pond in the Tom Swamp tract. An occasional small esker is found such as the one north of Conner Pond in Slab City VI, and the one east of the beat bog in Prospect Hill II. Most of the stratified drift occurs as kames or kame terraces mapped as Hinckley and Jaffrey soils, or as outwash deposits mapped as Merrimac or Barnsted soils. Figure 23 is of a cut in glacial stratified drift along the Swift River in Slab City X.

THE PROBLEM OF SOIL CLASSIFICATION

It may be inferred from the discussion of the geology of the Petersham area, and it is actually the case, that the soils of the locality are highly complex and vary widely within short distances.

Figure 23

GLACIAL STRATIFIED DRIFT ALONG SWIFT RIVER, SLAB CITY X



Under such conditions, the problem of how to map soils is a difficult one. Although a detailed general discussion of this problem in New England has recently appeared (Lunt, 1948), a brief discussion of its general aspects will help to explain and clarify the classification system and the techniques actually used in preparing the soil map of the Harvard Forest.

The soil consists of that upper part of the earth's mantle which is affected by biological agencies and which supports plant growth. The parent material, discussed in the preceding sections, thus plays an important part in determining the character of the soil, but so also do the factors of time, topographic relief, living organisms, and climate (Muckenhirn, Whiteside, Templin, Chandler, and Alexander, 1949).

American soil classification attempts to organize, name, and define soils into categories based upon the interaction of these five factors. The purpose is to be able to name given soil samples, to provide a means for reducing data into usable form, and to formulate generalizations about soils and their importance (Cline, 1949). Of the various criteria used, the number, color, and texture of the various soil horizons are the most commonly employed.

Starting with the broadest categories, the upland soils of the Petersham region fall within the order of <u>zonal soils</u>, the suborder of <u>light-colored podzolized soils of the timbered regions</u>, and the great soil group of the <u>brown podzolic soils</u> (Thorp and Smith, 1949). In other words, the regional effect of the interaction of parent material, time, topographic relief, living organisms, and climate is such to produce brown-colored soils with a tendency towards the development of a leached layer under long continued forest cover. Within the same region, intrazonal soils which develop in poorly drained or undrained areas are termed hydromorphic soils and are likewise recognized.

In classifying the soils of a limited area, however, we are concerned only with the lower categories of soil clasification, especially the soil series. A given soil series must have definite soil profile features and occupy an area on the landscape (Riecken and Smith, 1949). Soil series are based primarily upon the type of parent material. Thus, the Gloucester series consists of soils developed from late Wisconsin glacial till made up largely of granite or granite gneiss. The series is subdivided into types based upon the texture of the surface or plow layer. Thus Gloucester fine sandy loam is differentiated from Gloucester sandy loam and Gloucester clay loam. Finally, the type may be broken down into phases based upon characteristics significant to the use of the soil by man. For example, Gloucester very stony fine sandy loam may be distinguished from Gloucester stony fine sandy loam, and from Gloucester fine sandy loam.

Of the five groups of factors principally affecting soil formation, only three enter into the differentiation of the local soils of the Petersham area, and only two into the classification system. Climate is sufficiently uniform throughout the area that it has no effect in differentiating local soils. The time factor may be similarly dismissed as all the soils are very young geologically speaking and all are of the same age, dating from the last Wisconsin glaciation of the area.

Parent material, topographic relief, and living organisms are thus the soil-forming factors chiefly responsible for the local variation in soils. Of these, the first two enter into the naming of the mapped units. The living-organism factor also affects the soils, but not sufficiently so in the Petersham area to affect soil nomenclature. The type of forest vegetation influences markedly the development of forest humus layers (Lutz and Chandler, 1946), and over a period of time affects the formation and the thickness of a leached layer in the soil horizon (Fisher, 1928; Griffith, Hartwell and Shaw, 1930; Gast, 1937; Cline and Spurr, 1942). Nevertheless, due to the lack of major differences in the vegetation in the Harvard Forest and to the disturbances of the vegetation attendant upon a long period of land-use by man, the effects of forest cover and other living organisms on vegetation do not seem to be sufficiently important or distinct to justify their being mapped or classified.

The local problem of soil classification, therefore, may be reduced to the problem of recognizing areas of uniform parent-material and relief, the latter factor being interpreted to cover variations in moisture relations as well as variations in the surface topography. A group of soils developed from a single parent material but differing in relief and in moisture relations constitutes a <u>catena</u>. Winters (1949) has emphasized that the catena is a genetic grouping consisting of soils with differences in properties assumed to be attributable to differences in topography and soil moisture, rather than a natural taxonomic grouping which consists of soils with similar rather than different properties. A major value of the catena concept is that it emphasizes the continuous and gradual variation of soils of the same parent material from an undrained bog to dry ridgetop.

The catena is often named for the zonal soil of the group. Thus, the Gloucester catena, developed from granite and granite gneiss parent material, consists of the Shapleigh series on excessively drained sites, the Gloucester series in well-drained situations, the Acton series in moderately well drained locations, the Leicester series in poorly drained areas, and the Whitman series in very poorly drained localities.

Logical though the taxonomy of soil classification may be, in practice great difficulty is experienced in soil mapping. As implied by the catena concept, soils vary continuously in make-up due to variation in any one of the soil-forming factors. Any effort to draw sharp boundary lines and to force samples into set pigeon-holes leads inevitably to difficulties.

Furthermore, so many mappable characteristics might conceivably be important in forest site valuation that the choice of basic variables is difficult. For instance, Lunt and Swanson (1948) believe that, -- in addition to soil series and texture, -- slope, aspect, moisture relations, humus type and degree of stoniness are important in forest soil mapping. Granting the importance of these characteristics, it is easy to see how an attempt to evaluate all of them would lead to the delineation of small mapping units, a long-term and expensive mapping program, and the production of a complex map difficult to use.

Finally, the soils can be seen, and studied only by means of arduous digging of pits or auger sampling. In order to cover the ground, the soil surveyor must generalize his soil boundaries on the basis of inferred relationships between soils and super-surface evidence. Vegetation is frequently used for a guide. Thus Muckenhirn et al. (1949) state:

> "Vegetation can be used as an aid in the delineation of field boundaries in soil survey work in certain regions, especially in reconnaissance surveys in some non-agricultural regions. Lightly cutover forested areas in the Adirondack Mountains of New York State, the northeastern part of Maine, the White Mountains of New Hampshire, and many areas in eastern Canada are examples of this relationship. Nearly pure spruce stands on steep mountain slopes often indicate Lithosols. The mixed forest types usually denote Podzols. Pure hardwood forests are usually growing on Brown Podzolic soils. Low-lying pure coniferous types are associated with sandy outwash or may represent soils of poor drainage ranging from Ground-Water Podzols to Half-Bog and Bog soils. To use this distribution of vegetation effectively in locating soil boundaries, the surveryor must have intimate knowledge of the soil-vegetation relationships of the region. He may even determine the distribution of forest types from aerial photographs and deduce therefrom the distribution of the soils."

The general truth of such soil-vegetation relationships as are illustrated above is undoubted. At the same time, however, we must realize that if soil types are deduced from the vegetation, then any subsequent attempt to correlate vegetation with the mapped soil types is meaningless, since the identical correlation was presumed in the construction of the soils map.

All in all, no really satisfactory classification of forest soils has been devised, nor have really workable field surveying techniques been developed. Nevertheless, we cannot deny the basic importance of forest soils in determining forest site quality and in affecting the distribution of species. At the same time that we realize the weaknesses and limitations of present soil mapping methods, we may make the best possible use of the detailed soils maps that are available. Therefore, a consideration of the detailed soils maps of the Harvard Forest is in order as an essential prelude to the consideration of forest site quality in that area.

HAVARD FOREST SOILS

The soils of the Harvard Forest were mapped during the summers of 1939, 1940 and 1941 by Charles S. Simmons of the Division of Soil Survey, Bureau of Plant Industry, U. S. Department of Agriculture. This present discussion is based largely upon his report on the Tom Swamp block in 1939, the Slab City block in 1940 and the Prospect Hill block in 1941, supplemented by soils series descriptions and other material furnished by Walter H. Lyford, Jr., Senior Soil Correlator, Division of Soil Survey, and by personal observations.

In working with the soil maps of the Forest over a period of years, in accompanying the soil surveyor in his work, and in trying to correlate forest composition and growth with established soil types, it became evident to the author that hard and fast distinctions between the various soil types are difficult if not impossible to make, and that soil classifications must frequently be taken with a grain of salt. Parts of three summers were spent in preparing the soils map of the Harvard Forest. Nevertheless, despite this large amount of time spent only on about two thousand acres, the distinctions between many soil types are by no means clearcut and the resultant soil maps cannot be considered by any means as definitive. Upland soils derived from glacial till on the Harvard Forest intergrade freely from Gloucester to Charlton to Brookfield. None of the soils mapped as belonging to these series in the Forest are typical or classic examples. Distinction between Acton and Sutton soils is similarly hazy.

The safest and most useful classification of the soils of the Harvard Forest, therefore, might well be a generalized one based solely upon mode of deposition of the parent material and upon moisture relations. In practice, such a classification proves quite satisfactory.

Two modes of origin were recognized: (1) soils developed from glacial till, and (2) soils developed from stratified drift, particularly glaciefluvial sands and gravels laid down in kames, eskers, and outwash plains.

Five drainage classes were set up, based largely upon the effect of soil moisture on profile development and permitting the correlation of soils series with drainage classes in so far as possible. Very well drained soils are those zonal soils with a low water table. Under this category come most Hinckley and Merrimac soils and those Gloucester, Charlton and Brookfield soils so located topographically as to be unusually dry (i.e. typically on high, dry ridges). Well drained soils include most Gloucester, Charlton and Brookfield soils and occasional areas of low-lying Merrimac and Hinckley soils with better moisture relations. Imperfect drainage (termed moderately well drained in current Soil Survey nomenclature) refers to soils developed under a water table sufficiently high to cause a mottled soil profile reaching close to the surface. Sutton and Acton soils are thus imperfectly drained. Poorly drained soils belong largely to the Whitman series and include soils with such a high water table that essentially the entire mineral soil profile is colored dark or is heavily mottled up to the surface. Finally, very poorly drained soils are those in which there is a surface layer of organic matter in the form of muck or peat at least ten inches thick.

As is shown in Table 11, well drained soils are predominant on the part of the Harvard Forest covered by the present study, with soils of extreme conditions of drainage making up less than one-sixth of the total.

It is of interest, nevertheless, to examine the characteristics of the various named soil series which have been mapped on the Harvard Forest and to consider their importance. The soils maps of Slab City IX and X (Figure 24) and of the Prospect Hill Block (Figure 25) cover the same area as do the stand maps in Chapter 2, and are representative of the Harvard Forest soils maps. The major soil series occurring in the Harvard Forest are classified in Table 12 according to parent material, mode of deposition, and drainage. This catena key is based upon the three-membered

Table 11

ACREAGES OF SOILS UNDER DIFFERENT

DRAINAGE CONDITIONS IN THE HARVARD FOREST[1]

Drainage Condition	Acres	Percent
Excessively drained	144	7.8
Well drained	1,083	58.5
Imperfectly drained	223	12.0
Poorly drained	265	14.3
Very poorly drained	137	7.4
Total	1,852	100.0

[1] Excluding PH IX, Higgins addition to PH IV, TS IX, and SC I (formerly SO XI).

Table 12

CATENA KEY TO MAJOR SOIL SERIES
IN THE HARVARD FOREST

	Well to excessively drained	Imperfectly drained	Poorly drained
Late Wisconsin till			
Mainly from granite or granitic gneiss	1. Gloucester	8. Acton	11. Whitman
Mainly from gray mica schist	2. Charlton	9. Sutton	11. Whitman
Mainly from brown rusty pyritiferous schist	3. Brookfield	9. Sutton	11. Whitman
Glaciofluvial sands and gravels developed on kames and eskers			
Mainly from granite or gray mica schist	4. Hinckley	10. Sudbury	12. Scarboro
From granite, gray mica schist, and some rusty pyritiferous schist	5. Jaffrey	10. Sudbury	12. Scarboro
Glaciofluvial sands and gravels developed on outwash plains and terraces			
Mainly from granite or gray mica schist	6. Merrimac	10. Sudbury	12. Scarboro
From granite, gray mica schist and some rusty pyritiferous schist	7. Barnstead	10. Sudbury	12. Scarboro

Figure 24

SOIL TYPES

SLAB CITY IX AND X.
1947

Well to very well drained
- C Charlton stony loam
- Cs Charlton stony fine sandy loam
- G Gloucester stony fine sandy loam
- Hs Hinckley stony fine sandy loam
- Mfs Merrimac fine sandy loam

Imperfectly drained
- Al Acton stony loam
- Sl Sudbury loam
- Sb Sudbury fine sandy loam

Poorly to very poorly drained
- Ws Whitman stony silt loam
- Wf Scarboro fine sandy loam
- Ms Muck, shallow phase

Others
- A Recent alluvium
- Rv Riverwash

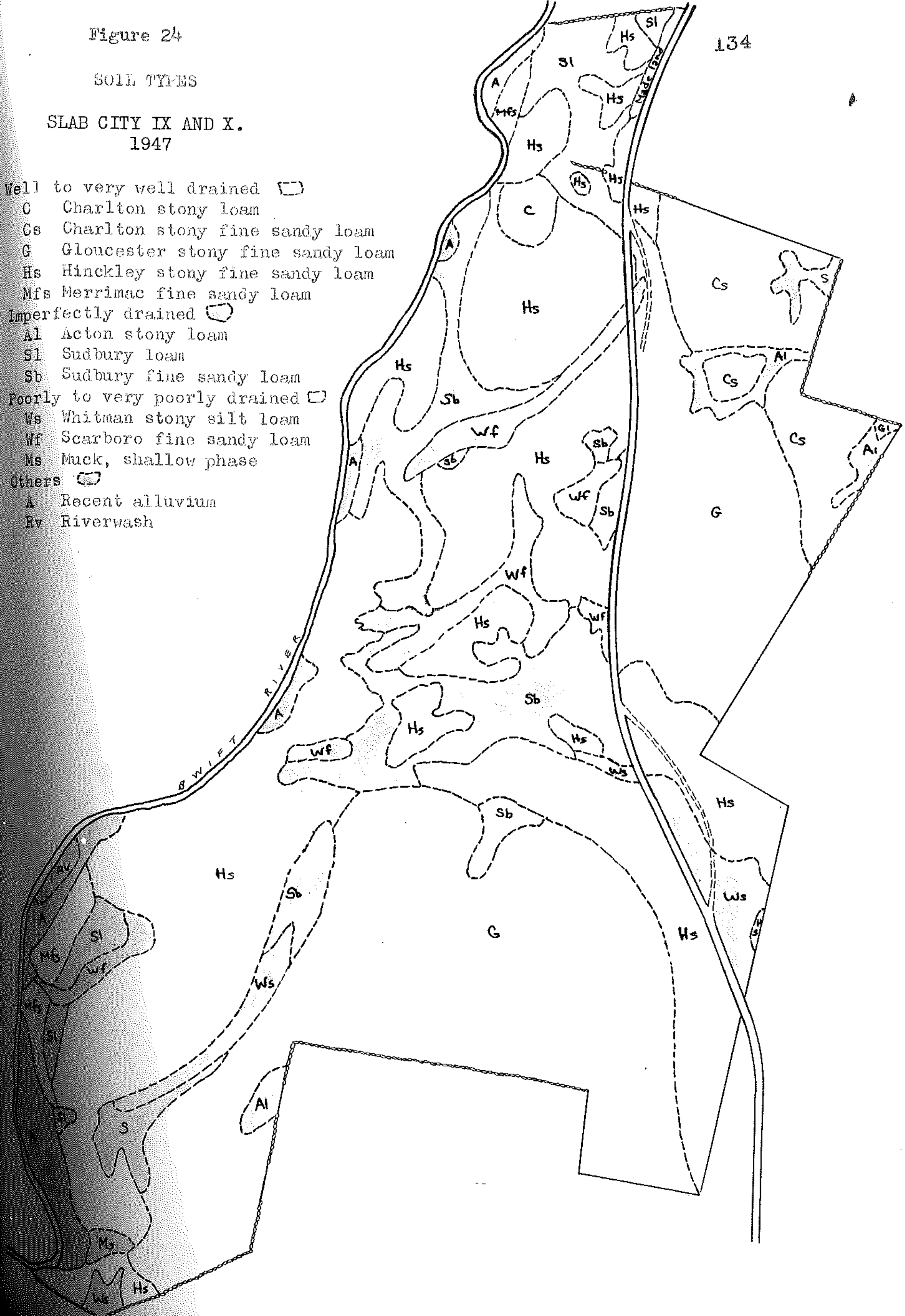
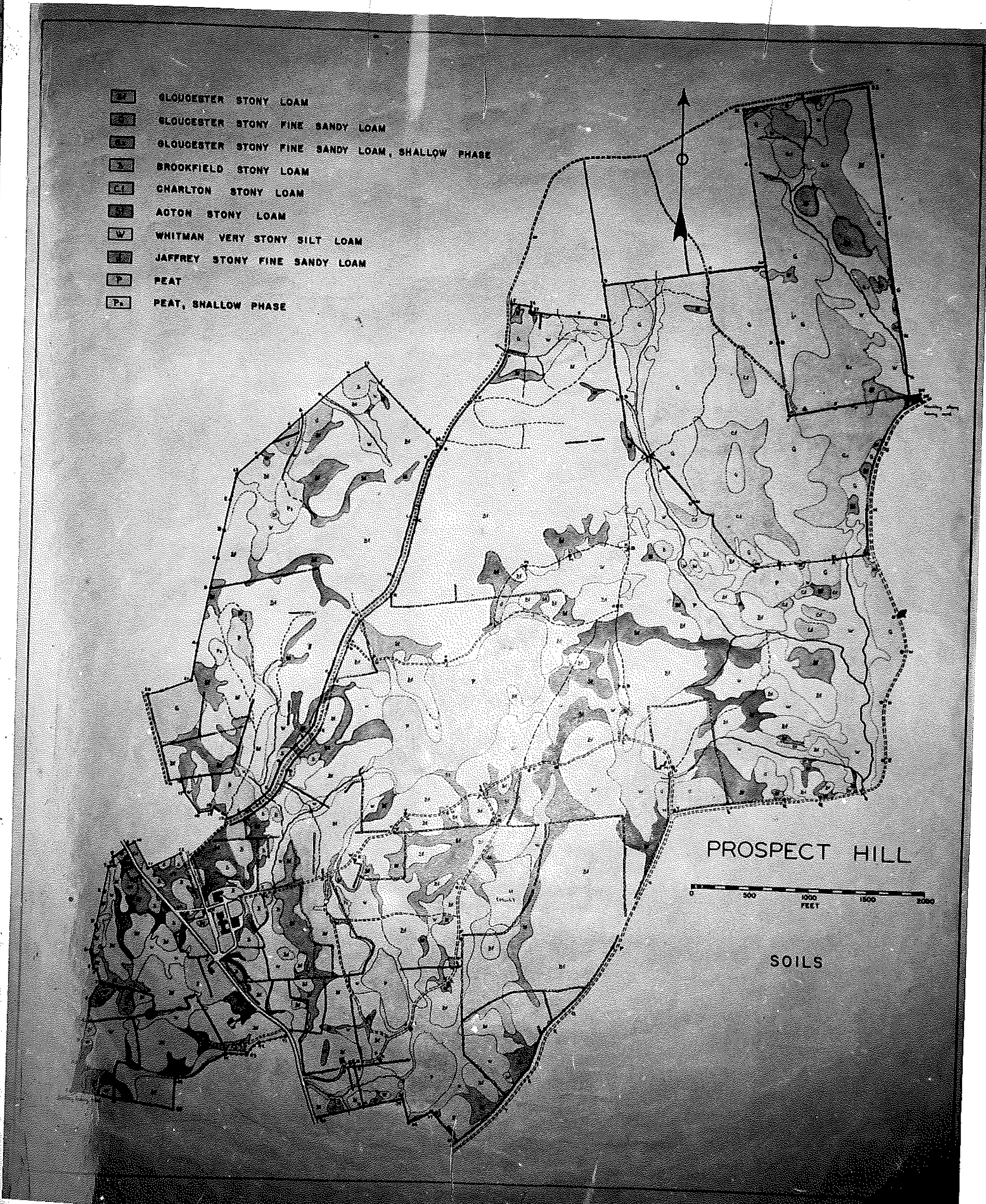


Figure 25, SOILS MAP, PROSPECT HILL BLOCK



grouping used in the original soil survey of the area rather than upon the four- and five-membered groupings subsequently adopted by the Division of Soil Survey. In Table 13, the acreage of each series is given for that part of the Forest covered by the present study.

1. GLOUCESTER SERIES: The most common upland soils on the Harvard Forest belong to the Gloucester series. As mapped and described by Simmons, these Gloucester soils are not typical of the established series. The large areas of Gloucester stony loam are intermediate in character between the typical Gloucester and typical Brookfield soils. Whereas the typical Gloucester soil is developed from granite with relatively little mica, the local soils are developed not only from granite and gneiss, but also contain a relatively large amount of reddish brown schist or thinly banded gneiss (Brimfield schist). This latter material is the parent material of the Brookfield series. Gloucester stony loam, then, resembles Brookfield but contains less mica and less pyrites, is less greasy and more gritty, and has a gray rather than a gray-yellow parent rock.

Whereas the Gloucester stony loam resembles Brookfield, the Gloucester fine sandy loam more closely resembles the Charlton. It contains more sand than the typical Charlton, but is finer textured than the typical Gloucester. Developed from granitic debris, it has a lighter gray substratum than the Charlton. The shallow phase is mapped when the bedrock averages less than 3 feet from the surface.

Table 13

ACREAGES OF SOIL SERIES
IN THE HARVARD FOREST[1]

Soil Series	Prospect Hill	Tom Swamp	Slab City	Total	Percent of total
1. Gloucester	448	61	100	609	32.9
2. Charlton	18	73	104	195	10.5
3. Brookfield	18	247	0	265	14.3
4. Hinckley	0	0	66	66	3.6
5. Jaffrey	4	20	0	24	1.3
6. Merrimac	0	0	14	14	0.8
7. Barnstead	0	40	0	40	2.2
8. Acton	95	0	28	123	6.6
9. Sutton	0	31	35	66	3.6
10. Sudbury	0	2	30	32	1.7
11. Whitman	129	87	23	239	12.9
12. Scarboro	0	3	6	9	0.5
13. Other mineral					
Peru	0	2	0	2	0.1
Buxton	0	1	0	1	0.0
Essex	0	0	1	1	0.0
Grafton	0	0	13	13	0.7
Alluvial	0	0	16	16	0.9
14. Organic					
Peat	47	52	3	102	5.5
Muck	4	23	8	35	1.9
Total	763	642	447	1852	100.0

[1]Excluding PH IX, Higgins addition to PH IV, TS II, and SC I (formerly SC XI).

2. CHARLTON SERIES: Of the three upland soils developed from late Wisconsin till in the Petersham area, the Charlton soils are generally the finest textured and therefore may be expected to have the best water relations. The typical Charlton soil is a deep, friable to firm soil developed from gray mica schist. In the Harvard Forest, however, the soils mapped as Charlton are not typical of the series, ordinarily having more sand and less colloid than the typical soil, and not as brown a subsoil. Charlton stony loam is considered a good upland soil. The stony fine sandy loam is similar, but has some sand in all of the horizons. These soils resemble both the Brookfield and the Gloucester, and are ordinarily distinguished by having a grayer substratum than the former and being somewhat finer in texture than the latter. The Charlton soils on the Harvard Forest, however, are difficult to distinguish from the Brookfield and the Gloucester.

3. BROOKFIELD SERIES: The third of the three major upland soils on the Harvard Forest is the Brookfield. Developed from late Wisconsin till, as are the Gloucester and Charlton soils, the Brookfield is distinguished by containing relatively large amounts of mica together with some pyrites, both derived from Brimfield schist. On the Harvard Forest, however, there is apparently less pyrites than is typical to the series, and more granite. The local Brookfield soils, therefore, grade toward the Gloucester.

To sum up the differences between the three major upland soils on well drained locations that have been derived from late Wisconsin till, the Gloucester soil is typically derived mainly from granite or granitic gneiss, the Charlton soil is derived mainly from gray mica schist, while the Brookfield soil is derived chiefly from brown, rusty pyritiferous schist. On the Harvard Forest, however, none of these soils are typical, and then tend to grade one toward the other. In the course of mapping the Harvard Forest between 1939 and 1941, areas mapped into one series in the field were frequently changed to another series after correlation by the Division of Soil Survey. While theoretically the Charlton and Brookfield soils are slightly more fertile than the Gloucester soils, differences in composition and growth on the three soils are not marked, as discussed in the following section, and for the time being we may consider these three soils to be approximately equal in their effect upon the forest trees.

4. HINCKLEY SERIES: Whereas the Gloucester, Charlton and Brookfield soils are developed from glacial till, the Hinckley, Jaffrey, Merrimac, and Barnstead soils are developed from sand and gravel which were laid down in glacial streams and lakes and similar water action. The Hinckley soils are developed from generally the same parent materials as the Gloucester and Charlton soils, but were laid down on kames and eskers. They therefore contain large quantities of sand and gravel which is in many places poorly assorted. The soil differs widely in texture, therefore, but is ordinarily excessively drained and relatively infertile. In the Prospect Hill block, it occurs only as a very small area of stony sandy loam in a small kame. In the Tom Swamp block, it covers sizable acreage in Compartment IX on gently rolling to hilly land bordering Riceville Pond. In the Slab City tract, it occurs as fine sandy loam, developed from assorted sand and gravel deposited in the kames, and has stony fine sandy loam where large stones and boulders occur on the surface and in

the soil. Where the stony type is mapped, the deposit of gravel is shallow and over-lays a finely grained till similar to substrate of the Charlton soil. This latter soil, therefore, appears to have a higher moisture content than the typical Hinckley soil and probably can be classified as well drained rather than excessively drained.

5. JAFFREY SERIES: Originating from sands and gravels deposited in kames and eskers, but differing from the Hinckley soils in that the parent material contains some rusty pyritiferous schist are the Jaffrey soils. These soils, therefore, bear the same relation to the Brookfield series as the Hinckley bears to the Gloucester and Charlton. In the Harvard Forest, the sand and gravel deposits giving rise to Jaffrey soils are poorly assorted, so that the type of soil varies greatly within small areas. In general, though, the Jaffrey soils are excessively drained and relatively infertile.

6. MERRIMAC SERIES: Merrimac soils are developed from much the same material as the Hinckley series, but are ordinarly laid down outwash plains or terraces, and result in a generally flatter plain than the deposits left by the Hinckley soils. This soil does not occur in the Prospect Hill tract. In the Tom Swamp tract it occurs as an excessively drained loamy sand in Compartment IX. In the Slab City tract, however, the Merrimac soils occur as fine sandy loam whose parent material may have been deposited by a post-glacial stream rather than by a glacial river in the case of true Merrimac soils. In this tract, there is very little gravel in the soil or substrate, and in places the water table is fairly high. Whereas the Merrimac soils in the Tom Swamp tract may be characterized as excessively

drained, those in the Slab City tract are therefore only moderately well drained to well drained.

7. BARNSTEAD SERIES: What was mapped as Berwick soils on the Harvard Forest have since been renamed Barnstead. Forty acres in the Tom Swamp block are mapped as either Berwick fine sandy loam or Berwick loamy sand. These Barnstead soils are developed from the same glaciefluvial sands and gravels containing some rust pyritiferous schist as are the Jaffrey. They differ, however, in that they were laid down on outwash plains or terraces rather than on kames or eskers. Barnstead soils are therefore analogous to the Merrimac soils, except that their parent material includes Brimfield schist. Like the Merrimac, they are apt to be excessively drained and relatively infertile.

8. ACTON SERIES: Where soils of the Gloucester type have developed under imperfectly drained conditions and have thus acquired a mottled rather than a stratified profile, they are classified as members of the Acton series. Such soils occupy a transitional zone between the poorly drained Whitman soils and the well drained Gloucester soils. The mottled profile results from imperfect drainage and the consequent incorporation of partially decomposed organic matter in the upper horizons. Acton soils are mapped in the Prospect Hill and Slab City blocks. While not mapped in the Tom Swamp block, it is probable that some of the areas mapped as Sutton in this block more closely resemble the Acton in characteristics.

9. SUTTON SERIES: Analogous to the Acton series is the Sutton series which is also developed under imperfectly drained conditions, but from the same parent materials as the Charlton and Brookfield soils. In other words it is similar to the Acton soils in that it is imperfectly drained and is therefore characterized by a mottled profile. It differs from the former series, however, in that the parent material is schist rather than granite or granitic gneiss. Because of the incorporation of organic matter, and because of the high water table causing frost heaving of stones and boulders, it generally occurs as a stony silt loam. In a small area in the Tom Swamp tract, however, it occurs as a stony fine sandy loam. There seems to be no clearcut distinction in the Harvard Forest between the Acton and Sutton series. Soils mapped as one series in the field were changed to the other during the preparation of the soil report. Since preliminary efforts have failed to show any distinctions between forest composition and growth on the two series, they may be tentatively grouped and considered as one in so far as they affect the forest.

10. SUDBURY SERIES: Wherever soils are developed from glaciofluvial sands and gravels under imperfectly drained conditions, the Sudbury series is recognized. This series, therfore, may be developed from the same parent material as the Hinckley, Jaffrey, Merrimac or Barnstead soils. Sudbury soils are not common on the Harvard Forest, being restricted to about five acres in the Tom Swamp block and thirty acres in the Slab City block. In most places the soil is covered by a mat of organic matter, and has a mottled structure in the upper part of the horizon with the brownish-yellow fraction predominant, with the gray fraction increasing as the depth

increases. Sudbury soils contain ample moisture for tree growth but are considered less fertile than their Acton and Sutton analogues.

11. WHITMAN SERIES: As mapped on the Harvard Forest, the Whitman series includes all poorly drained and very poorly drained soils developed from glacial till. They are developed from the same parent material as are the Gloucester, Charlton, Brookfield, Acton and Sutton soils, but occur where there is very little water drainage, and therefore have a very gray to black mucky silt loam on the surface. The substratum is gray or mottled gray. These soils are ordinarily very stony inasmuch as the freezing and the thawing of such a wet soils inevitably heaves many stones and boulders toward the surface. Whitman stony loam as mapped in the Tom Swamp block is considered by Simmons to be the same as Whitman very stony silt loam mapped in the Prospect Hill and Slab City blocks.

Since the Harvard Forest soil survey was undertaken by the U. S. Division of Soil Survey, this agency has found it desirable to establish four-membered catena rather than a three-membered catena as was done in the Harvard Forest. Current-day practice, then, according to Walter H. Lyford, Jr., Senior Soil Correlator, is to restrict the Sutton and Acton series to soils that start out like a well drained soils but show definite mottling at 18 to 24 inches or so. The Whitman series is now held to soils that are half bogs, and that have an accumulation of muck or peat on the surface. In between these two soils is now mapped the Leicester series. Mr. Lyford suggests that most of the Whitman soils mapped on the Harvard Forest would currently be mapped as Leicester, and would include only smaller areas of Whitman as now defined, these being in the very wettest portions.

12. SCARBORO SERIES: Although restricted to a very small area on the Harvard Forest, the Scarboro series is of interest in that it is developed from glaciofluvial sands and gravels under poorly drained conditions. It therefore, resembles the Whitman soils, but has more sand at all horizons, and is poorly drained equivalent of the Merrimac, Jaffrey, Hinckley, and Barnstead soils.

13. OTHER MINERAL SOILS: Most of the soils in the Harvard Forest fall into the soils series described above. Small areas, however, were mapped by Simmons as belonging to the Peru, Buxton, Essex, and Gorham series. In addition, Simmons mapped limited areas along the Swift River as being soils derived from undifferentiated alluvial deposits.

None of these latter soils are important in the Harvard Forest. Peru stony loam is restricted to two acres in the Tom Swamp block, and is similar to Sutton, except that it is more podzolized, and therefore belongs in the podzolic group rather than the brown podzolic group.

Buxton loam confined to a fraction of an acre on the Tom Swamp block. It is similar to Sudbury, but in this instance is probably developed from wash from adjoining areas of Charlton soil, rather than from glaciofluvial sands and gravels. It may be grouped with the Sudbury.

Essex soils are similar to Gloucester, but are compact and platy rather than loose and friable to firm. Only one area of this soil is mapped in the northern portion of the Slab City tract. This soil is practically impervious to penetration to water, and occurs on the slopes of a smooth rounded hill. Despite its distinct differences from Gloucester, it may be grouped with that soil because of its limited occurence in the forest.

What was mapped as Gorham soils on the Harvard Forest soils maps have since been renamed Grafton. These soils are similar to Charlton, but have a looser structure. Some thirteen acres in the Slab City block were mapped in this series. Whereas the Charlton soil originated solely from glacial till, the parent material of the Grafton series was glacial till that was slightly influenced by running water at the time of deposition and therefore contains sand and gravel intermixed.

Limited areas in the flood plain of the Swift River are classified as undifferentiated alluvial soils. The texture varies within short distances from sand to loam, and the color is grayish-brown, generally mottled with rusty-brown and gray.

14. ORGANIC SOILS: Where sizable accumulations of organic matter overlay the soil, the areas are mapped as muck or peat. In the peat bogs, the soil is only partially decomposed so that many plant remains are still identifiable. Muck is mapped where the organic matter is fairly well decomposed and fragments of plants are not identifiable. Peat soils are ordinarily developed under a higher water table and frequently under more acid conditions. Shallow phases of peat and muck are mapped where the depth of the organic matter ranges from 10 to 24 inches, and deep phases are classified where the depth of the organic matter is greater than 24 inches. Where the organic matter is less than 10 inches, Whitman and Scarboro soils are mapped.

RELATION OF SOILS TO SITE

The problem of relating soil to site has attracted many investigators, especially within the last fifteen years. Of principal concern has been the determination of site quality for areas which are either unstocked or stocked with unwanted species as a result of cutting and fire. Good summaries of previous work have been prepared by Lutz and Chandler (1946), Coile (1948), and Gardner and Retzer (1949).

A number of workers have correlated soil series with site index. Roe (1935) published general relationships between site index and soil type for the various cover types of the Lake States. Cooper (1942) found that for loblolly pine in the southeast, site was closely related to both soil type and sheet erosion class. Thus, for sheet erosion class 2, the site index of loblolly ranged from 103-104 on Lloyd silt loam down to 69-83 on Appling silt loam. Very similar results for different soil series were obtained by Chandler, Schoen and Anderson (1943). They found that the mean site index ranged from 103 to 58 for loblolly and from 100 to 62 for shortleaf pine on seven soil types. The best sites were on Ocklockonee fine sandy loam, a soil derived from recent alluvium with water within a few feet of the surface; and the poorest sites on Segno fine sand, a soil with a very low water table and low water-retaining capacity. The middle five soils did not differ significantly in site quality. In the Lake States, Stoeckeler (1948) was able to assign site indices for aspen on different soils, ranging from 82 on Superior silt loam, a soil originally supporting a hemlock-white pine forest down to 53 on Plainfield sand, an original red pine soil.

In the various studies in which soils have been correlated with site, two general trends are discernible. In the first place, many investigators were able to obtain significant trends only by grouping soil types and soil profiles. Thus, Hicock, Morgan, Lutz, Bull and Lunt (1931), in a study of the relation of forest composition and rate of growth to certain soil characteristics, found that stand composition was not clearly related to individual soil types but that it was related to a broad grouping based on soil moisture. Thus on the lighter well drained soils, chestnut oak and scarlet oak were the most abundant species followed by hickory, black oak, and red oak. On the heaver well drained soils, yellow poplar was relatively abundant. On the imperfectly drained soils blue beech (Carpinus), basswood, and yellow birch were the most common species along with sugar maple and red maple. Finally, on the organic soils, elm and red maple were characteristic together with black ash, yellow birch and alder. The grouping finally arrived at in the Connecticut study is closely comparable to that worked out earlier in this chapter and used as the basis for discussing the present-day forest associations in Chapter 3.

In the aspen community of the Lake States, Kittredge (1938) correlated soil texture, geological formation group, and soil profile group separately with site index. The best results were obtained with soil profile groups, but twelve broad groups provided almost as high a correlation as did ninteen more narrowly defined groups.

Another example of the necessity of grouping soil types is provided by Hill, Arnst and Bond (1948) who worked with Douglas-fir in the Pacific northwest. Significant correlations of soil with site were obtained only when the soils were grouped according to broad classes, each based on depth of the soil, soil texture, and the nature of the subsoil.

The second noticable trend is towards the recognition that soil moisture is in many cases the one soil characteristic most closely related to site and forest composition. This is most noticable in areas where the parent material is more or less uniform as in the 1931 Connecticut study by Hicock et al. and the present paper. It is, moreover, inferred by many of the other papers cited. Thus, Hill, Arnst and Bond (1948) state that:

"In the case of Douglas-fir in Lewis County, site quality appears to be determined by the moisture relationships of the soil. On the same soil, an area of higher rainfall has a higher site-index.

In contrast, Tarrant (1949), who also worked with Douglas fir in the Northwest, was unable to find any significant correlation between various measures of nutrient availability and forest site class.

Soil moisture is, of course, determined in large part by the texture and depth of the soil; and it might be expected that site quality would be related to these factors. Frequently this is the case. Coile (1935) successfully correlated site index for 48 shortleaf pine stands with a measure of the silt and clay content of the B_1 horizon. Similarly, Auten (1937) used the depth of the A_1 horizon to evaluate site quality for yellow poplar. Lunt (1939) was unable to find a correlation between site index and kind of soil for second-growth oak stands in Connecticut, but he did find that the lower the site index, the greater was the percentage of the soil that was made up of colloids (silt and clay); and presumably a high mineral colloid content could indicate little leaching and therefore less available water. Donahue (1940) in the Adirondacks found that the best sites were associated with a perched moving-water table. Lunt (1948) found that both white pine and Norway spruce grew better in Connecticut on a Manchester sandy loam, than they did on the better drained Merrimac sandy loam.

All in all, every indication points to soil moisture being a controlling factor of forest vegetation in the Petersham region, with other soil characteristics being locally at least, of relatively little importance. That soil drainage greatly affects forest composition has been demonstrated in Chapter 3. That parent materials of the local soils are relatively uniform, or at least so mixed as to form a single upland zonal complex of Gloucester-Brookfield-Charlton soils has been indicated in the earlier part of this chapter. That in other regions, soil moisture is of the greatest importance in determining composition even where parent materials vary greatly may be inferred from practically every one of the references cited above.

Outside of the present study, there is little information dealing specifically with the soil-site relationships in central New England. Griffith, Hartwell and Shaw (1930), in their study of soil changes associated with the old field white pine-mixed hardwood succession, found it advisable to group the three upland soils of the Harvard Forest in the same way as has been done here. Several graduate students at Clark University (Cunningham, 1928; Brierly, 1936; and Beishlag, 1938) have studied the relation of forest succession to the major soil types of the Worcester County region, but their findings were general in nature and do not provide the specific data needed in the intensive study of a small area. Cunningham (1928) found that within the Charlton series, white pine, paper birch, juniper and gray birch were apt to be found on the lighter textured soils with less soil moisture and nutritive value; while the oaks, hickory, yellow birch, beech, maple and hemlock were more commonly found on the heavier textured soils of the same series. Brierly (1936) worked with Paxton and Sutton soils and noted especially that the amount of white oak present was directly related to dryness of the soil. Finally, Beishlag (1938) reported that on Charlton soils, white pine and hickory were both much more common on the warmer and drier south slopes than on the cooler and moister north slopes.

In the present study, although excellent correlations were obtained between soil drainage and forest composition, the available data does not permit a careful analysis of the differences between the various soil types of the same soil drainage class, such as between Gloucester, Brookfield and Charlton soils. In the first place, the soils maps are not reliable as to the distinctions and boundaries between these soils. Even more limiting is the difficulty in distinguishing between them in the field. Finally, the distribution of upland soil types is confounded with other factors, making it difficult to attribute any composition differences found to any one factor. For instance, the Charlton soils in the Harvard Forest are largely confined to the southeast part of the Tom Swamp Block. The transition hardwood stands in this area are similar to those of the rest of the Forest in being composed predominantly of red maple and red oak, but they do contain somewhat more white ash than is found elsewhere. While it might be inferred that this indicates that Charlton soil is characterized by more white ash than are the other upland soils, it might equally be true that greater importance of white ash in this area is due to chance, or even to the fact that the stands there are younger than comparable transition hardwood stands elsewhere in the forest and to the inference stated in the previous chapter that white ash becomes less abundant with age in such stands.

Despite the inherent limitation of the study, an effort was made to see if the hardwood stands in the southeast part of the Tom Swamp Block, an area composed largely of Charlton soil, are growing on better sites than the hardwood stands in the Prospect Hill Block, an area composed largely of Gloucester soil. The permanent sample plots in the Prospect Hill Block drawn upon in Chapter 3 provide site index data for that area. Thirteen sets of measurements taken during the summer of 1947 by graduate students working under the author's direction in eight stands in the Tom Swamp Block give comparable data for that area. In working up the site index values, Schnur's site index curves for upland oak (1937) were used. The thirteen sample stands in the Prospect Hill Block had site indices ranging from 53 to 72 and averaging 62. The thirteen samples in the Tom Swamp Block had site indices ranging from 50 to 70 and averaging 64. Very apparently, there is no significant difference indicated in this comparison of the two areas.

RELATION OF SOILS TO NATURAL REPRODUCTION

So many factors affect the composition and growth of the semi-mature stands in the Harvard Forest that, as we have seen, little can be done in isolating composition differences due to specific soil types. In order to eliminate as many variables as possible, a study was made of available data on post-hurricane regeneration, with the thought that the ability of seedlings of various species to establish themselves on blowdown areas after the 1938 hurricane would be more dependent upon soil qualities than on other factors. The other conditions were kept as uniform as possible. All the timber was of course destroyed at one time, on September 21, 1938 in the late afternoon. The previous cover in all cases was predominantly white pine. In all cases, the white pine had been salvaged subsequent to the hurricane. Finally, the sampling was undertaken after two and three growing seasons, so as to provide sufficient time for the new growth to become established, and yet not enough time for competition to greatly reduce the number of seedlings.

Two groups of data were available. The first consisted of 3,400 mil-acre plots taken in 137 former white pine stands in northern Worcester county by Brake and Post in 1941 and used by them as the basis for their master's thesis. The second consisted of 600 mil-acre plots taken in 23 stands in Tom Swamp III by Larson, Yoder, Gill and Frahar in 1942 as part of their master's work under the direction of the writer and R. J. Lutz. In each case, the original field notes were reanalyzed by the present worker to determine what differences in composition could be attributed to soils type. The results were compiled for seedlings only, leaving out seedling-sprouts, stump sprouts, and root suckers, all of which owe their presence to the preceding stand. Results were compiled on both abundancy and frequency bases. These measures are discussed in detail in Chapter 7. Briefly, abundance is defined as the number of seedlings per acre; and frequency as the percent of mil-acre plots which contain at least one seedling of a given species.

Of the stands sampled by Brake and Post, 131 were found to be on Charlton, Gloucester, Merrimac and Hinckley soils on the basis of the soils map published by Latimer et al. (1927). Tables 14 and 15 give the abundance and frequency respectively of seedlings of various species on these soil types. That the Charlton and Gloucester soils were better stocked than the Merrimac and Hinckley soils and contained a better representation of the mesophytic species can readily be seen. There is little significant difference in stocking between the Charlton and Gloucester soils, however. The Charlton soil had more seedlings per acre, but the difference is entirely attributable to the great number of pin cherry seedlings. On the frequency basis, the soils have closely comparable restocking. Likewise, there is little if any significant difference in composition of restocking# between the Merrimac and Hinckley soils. Although several species are more abundant on the Merrimac soils, the same species are more frequent on the Hinckley soils.

The 82 plots on the Gloucester soil type were further sorted according to aspect and the results presented in Tables 16 and 17 in terms of abundance and frequency respectively. Here again, no pronounced differences in composition can be discerned although a few minor differences are of interest. For instance, white ash and black birch are noticably less common on the level, high sites than elsewhere.

The 1942 study of Tom Swamp III gives much information about a small tract. All the blowdown areas in one of the smaller compartments were heavily sampled. Five soil types were included: Gloucester stony fine

Table 14

1941 NATURAL REPRODUCTION STUDY
SOIL TYPES AND SEEDLING ABUNDANCE

(Seedlings per acre)

Species	Charlton	Gloucester	Merrimac	Hinckley	All
Gray birch	1830	2200	720	620	1820
Pin cherry	2840	520	740	600	940
Black cherry	800	720	790	400	710
White pine	660	640	1060	850	710
Red maple	510	720	620	230	620
Red oak	250	150	80	60	160
Paper birch	330	60	20	10	90
White ash	40	120	20	20	90
Aspen	100	80	110	20	80
Black birch	40	50	20	10	40
Sugar maple	10	40	—	20	30
Hemlock	130	10	—	10	30
White oak	10	20	20	10	20
Balsam fir	10	10	—	—	10
Yellow birch	40	10	—	—	10
Hickory	10	10	10	—	10
Red spruce	20	10	—	—	10
Beech	10	10	—	—	10
Basswood	10	10	—	—	10
Scrub oak	—	—	20	—	10
All species	7650	5390	4230	2560	5410
Number of stands	22	82	12	15	131

Table 15

1941 NATURAL REPRODUCTION STUDY
SOIL TYPES AND SEEDLING FREQUENCY

(Percent of stands in which the species occurs)

Species	Charlton	Gloucester	Merrimac	Hinckley	All
Red maple	100	99	67	87	95
Pin cherry	100	88	83	87	89
Black cherry	86	93	75	87	89
White pine	86	89	83	100	89
Gray birch	100	82	67	73	82
Red oak	77	77	25	40	68
Aspen	27	38	33	20	34
Paper birch	50	31	17	7	30
White ash	32	23	17	13	23
Sugar maple	14	21	—	7	16
Black birch	14	20	8	7	16
White oak	9	17	17	13	15
Hemlock	27	7	—	13	11
Hickory	5	10	8	—	8
Yellow birch	23	5	—	—	7
Balsam fir	5	5	—	—	4
Beech	5	5	—	—	4
Red spruce	5	1	—	—	2
Basswood	2	1	—	—	2
Scrub oak	—	—	8	—	1
Number of stands	22	82	12	15	131

Table 16

1941 NATURAL REPRODUCTION STUDY
ASPECT AND SEEDLING ABUNDANCE ON GLOUCESTER SOILS

(Seedlings per acre)

Species	Northerly aspect[1]	Southerly aspect[2]	Level high[3]	Level low[4]	All
Gray birch	1580	630	4350	1030	2200
Black cherry	840	570	720	850	720
Red maple	690	500	930	650	720
White pine	660	460	640	580	640
Pin cherry	440	590	500	530	520
Red oak	120	160	180	130	150
White ash	190	170	40	140	120
Aspen	70	80	90	50	80
Paper birch	20	80	90	10	60
Black birch	20	100	10	50	50
Sugar maple	50	30	30	70	40
White oak	10	20	10	60	20
Hemlock	10	10	10	10	10
Balsam fir	—	40	20	—	10
Yellow birch	—	10	10	—	10
Hickory	10	10	10	20	10
Red spruce	—	—	10	—	10
Beech	10	10	10	—	10
Basswood	—	10	—	—	10
All species	4720	3680	7660	4180	5390
Number of stands	16	22	29	15	82

[1] North and east facing slopes of more than 10 percent.
[2] South and west facing slopes of more than 10 percent.
[3] Slopes less than 10 percent and above 900 feet elevation.
[4] Slopes less than 10 percent and below 900 feet elevation.

Table 17

1941 NATURAL REPRODUCTION STUDY
ASPECT AND SEEDLING FREQUENCY ON GLOUCESTER SOILS

(Percent of stands in which the species occurs)

Species	Northerly aspect[1]	Southerly aspect[2]	Level high[3]	Level low[4]	All
Red maple	100	95	100	100	99
Black cherry	88	91	93	100	93
White pine	88	86	90	93	89
Pin cherry	81	86	90	93	88
Gray birch	81	73	86	87	82
Red oak	69	77	76	87	77
Aspen	37	32	38	47	38
Paper birch	19	27	48	13	31
White ash	25	27	10	40	23
Sugar maple	19	27	10	33	21
Black birch	25	27	7	27	20
White oak	12	23	3	40	17
Hickory	12	9	3	20	10
Hemlock	12	9	3	7	7
Yellow birch	—	5	10	—	5
Balsam fir	—	14	3	—	5
Beech	6	5	7	—	5
Red spruce	—	—	3	—	1
Basswood	—	5	—	—	1
Number of stands	16	22	29	15	82

[1]North and east facing slopes of more than 10 percent.
[2]South and west facing slopes of more than 10 percent.
[3]Slopes less than 10 percent and above 900 feet elevation.
[4]Slopes less than 10 percent and below 900 feet elevation.

sandy loam, shallow phase, on the top of the low ridge in the southeast corner of the compartment; Gloucester stony fine sandy loam a little lower on the ridge, Charlton stony fine sandy loam, Sutton stony silt loam, and Whitman stony silt loam. The Charlton soils occupied somewhat lower and moister sites than the Gloucester soils so that differences in composition attributable to these two series may be as much due to moisture differences as to fertility differences.

From Table 18, it can be seen that natural restocking after the hurricane by seedlings of all species did not differ appreciably between the three upland soils, but that restocking was somewhat poorer on the imperfectly drained Sutton soil, and markedly poorer on the poorly drained Whitman soil.

The abundance and frequency of seedlings of the various tree species are given in Tables 19 and 20 respectively. Very little difference is apparent between the restocking on the three upland soils. Perhaps the most obvious correlations between composition and soil are provided by white pine and yellow birch. The former is most common on the driest soils and decreases with increasing soil moisture, while the latter is most common on the Sutton soil and decreases with decreasing soil moisture. White ash is actually both more frequent and abundant on the Gloucester soil than on the Charlton, thus tending to further substantiate the view that it has little preference for the latter soil over other upland soil types. Several of the light-seeded species, including black birch, paper birch and gray birch, had apparently become established in greater numbers on the drier soils.

Table 18.

FREQUENCY AND ABUNDANCE OF SEEDLINGS BY SOIL TYPES IN TOM SWAMP III, 1962

Soil type	No. of stands	No. of plots	Frequency percent	Abundance stems/A.
Gloucester stony phase	2	70	92.4	5400
Gloucester	6	170	92.3	8200
Charlton	6	140	93.6	5600
Sutton	2	50	86.0	4900
Whitman	4	110	62.7	2600
All soils	20	540	85.9	5700

Table 19

SEEDLING ABUNDANCE IN TOM SWAMP III, 1942

Species	Gloucester stony phase	Gloucester	Charlton	Sutton	Whitman	All
Red maple	908	2139	1668	558	519	1392
Yellow birch	204	671	508	1692	1046	753
White pine	1029	1030	643	525	106	679
Black cherry	158	994	822	616	125	647
Redoak	662	250	778	616	236	483
Pin cherry	150	1168	116	158	19	420
Gray birch	1054	675	92	300	125	390
White ash	558	539	236	176	206	346
Black birch	404	369	421	100	92	303
Paper birch	129	204	77	41	86	118
Sugar maple	46	16	114	25	25	51
White oak	—	46	39	33	—	29
Hemlock	—	—	72	25	8	26
Aspen	16	41	17	—	—	19
Hickory	46	25	—	—	—	12
Basswood	—	—	—	—	38	8
Total	5364	8167	5593	4865	2631	5676

Table 20

SEEDLING FREQUENCY IN TOM SWAMP III, 1942

Species	Gloucester stony phase	Gloucester	Charlton	Sutton	Whitman	All
Red maple	49	53	52	29	20	43
Black cherry	14	38	40	26	14	30
Red oak	46	20	41	24	19	29
White pine	41	32	32	24	8	27
White ash	44	27	16	11	16	19
Yellow birch	9	17	18	25	18	18
Pin cherry	8	32	11	12	2	15
Black birch	28	16	14	9	8	14
Gray birch	14	23	3	24	8	13
Paper birch	6	11	6	4	3	7
Sugar maple	4	2	9	2	3	5
White oak	—	6	3	—	—	3
Hemlock	—	—	6	5	1	2
Aspen	2	4	—	—	—	2
Hickory	8	2	—	—	—	1
Basswood	—	—	—	—	2	1

SUMMARY

From the mass of data concerning the geology and soils of the Harvard Forest Region, gathered from many diverse sources, it is apparent that although the soils derive much of their character from the local bedrock-- and the complexity of the bedrock geology engenders a similar complexity of soil, -- yet the mixture of parent materials is on such an intimate scale that soil types representing a given parent rock material cannot be mapped out readily and have little real significance. No evidence has turned up to indicate any real difference between the effect of Charlton, Brookfield and Gloucester soils on stand composition.

Although the character of the bedrock may thus be ignored in correlating soil with site in the study of a small area in central Massachusetts, there is a real difference between soils derived from stratified drift deposits of glacio-fluvial origin, and soils derived from glacial ground moraine or till. The former are apt to be sandy and gravelly and are largely classed as very well drained; while the latter are commonly fine sandy loams and are mostly classified as well drained when occurring as upland soils. Although the two basic types of parent material commonly differ in their drainage characteristics, they also undoubtedly differ markedly in their other chemical and physical properties. In this area the very well drained soils are probably considerably less fertile from the standpoint of available nutrients than are the well drained soils.

Other than this difference in fertility, soil moisture appears to be the major soil character which markedly affects forest composition. By segregating sites on the basis of soil drainage alone, an excellent stratifica-

tion can be obtained. Sites thus recognized are highly correlated with stand composition. The recognition in the preceding chapter of different forest associations for the same successional stage but on different soil moisture sites is apparently fully justified, and represents about the maximum breakdown of forest site on the basis of soil conditions alone that is practicable in the area studied.

Site quality, the capacity of an area to produce vegetation, is the sum total of the soil factors, biologic factors, and climatic factors affecting the plant or plants. Although the forest soil is thus an important consideration in determining sites, the forest climate must equally be considered, as the crowns and other [illegible] live in the air and are affected by it.

The interrelationships between trees on the one hand and solar radiation, air temperature, atmospheric moisture, and other climatic factors on the other are basic considerations in forest ecology. Yet, the study of micro-climates in and about the forest has not been exhaustive. A few investigations have dealt primarily with the problem (among them being Geiger, 1927, 1936; Pallmann and Frei, 1943; and Wolfe, Wareham, and Scofield, 1943, 1949), and many ecological studies have touched upon it. Even so, [illegible] the influence of the local or micro-climate upon the local distribution and growth of forest trees is but poorly understood.

The present study provides preliminary information on the climatic variation within the Harvard Forest, based largely on data collected by the writer from 1947 to 1949. Subsequently, [illegible]

Chapter 5

CLIMATE AND ITS LOCAL VARIATION

Site quality, the capacity of an area to produce vegetation, is the sum total of the soil factors, biologic factors, and climatic factors affecting the plant or plants. Although the forest soil is thus an important consideration in determining site, the forest climate must equally be considered, as the crowns and boles live in the air and are affected by it.

The interrelationships between trees on one hand and solar radiation, air temperature, atmospheric moisture, and other climatic factors on the other are basic considerations in forest ecology. Yet, the study of micro-climates in and about the forest has not been exhaustive. A few investigations have dealt primarily with the problem (among them being Geiger, 1927, 1930; Pallman and Frei, 1934; and Wolfe, Wareham, and Scofield, 1943, 1949), and many ecological studies have touched upon it. None the less, the influence of the local or micro-climate upon the local distribution and growth of forest trees is but poorly understood.

The present study provides preliminary information on the climatic variation within the Harvard Forest, based largely upon data collected by the writer from 1943 to 1945. Subsequently, a more intensive study was undertaken by Herbert H. Rasche as a subject for his doctoral dissertation. To avoid unnecessary duplication, therefore, the present discussion will be confined to a presentation of the preliminary data and to the broader aspects of local climate as a factor affecting stand composition.

Method of study

Weather information has been gathered at the Harvard Forest intermittently for many years. Precipitation records have been taken since 1913 in cooperation with the Metropolitan District Water Supply Commission and more recently in cooperation with the U. S. Weather Bureau which supplies and maintains a weighing-bucket gauge equipped with wind collar southeast of the Headquarters building. From time to time, special weather studies have been carried on, such as the work on the relation of weather to forest fire hazard (Stickel, 1928), and on solar radiation (Gast, 1930). Hygro-thermograph records, checked weekly by Weather Bureau type maximum and minimum thermometers, have been obtained intermittently at the Headquarters building since 1936 and regularly since 1939. Anemometers were installed in 1946.

For two years beginning in the fall of 1943, the author studied the variation of temperature and certain other climatic factors at key spots throughout the forest. Ten home-made louvered shelters, large enough to hold maximum and minimum thermometers, were constructed and placed about three feet from the ground at various points. With the exception of three stations in a plantation thinning experiment, all were placed in the open, generally in hurricane blowdown areas. Instruments used were of the Weather Bureau type and of the Six's or U-type. During the 1944 growing season, Livingston white bulb atmometers were maintained at each of the ten temperature stations. All instruments were serviced every Monday morning. Finally, current soil temperatures were obtained every Monday morning at various depths in the plantation thinning experiment at the time the maximum and minimum recording thermometers in the plantation were serviced.

In 1943-44, eight stations were maintained in the Prospect Hill Block and two in Slab City. In addition to the base station at the Headquarters, and the three in the thinning experiment, one was established at the summit of Prospect Hill, the highest point in the Forest; three were placed at the top, mid-slope, and bottom of Little Prospect Hill in a south-facing cut-over area; one in a shallow frost pocket in Slab City II; and one at Burns Bridge over the Swift River in the Slab City Tract, one of the lowest points in the Forest. After one year of measurement, the stations on Prospect Hill, Little Prospect Hill, and in the thinning experiment were discontinued, and new ones were established at the Headquarters area, and on an east-facing slope in Slab City II leading down to the Swift River. These new stations, along with the three continued from the previous year, were operated for a full year. The various local climate stations are located in Figure 1 and described in Table 21.

The Petersham Climate

The broad features of the New England climate are detailed by the U. S. Department of Agriculture Yearbook for 1941, "Climate and Man",

Table 21

HARVARD FOREST WEATHER STATIONS
1943-45

Station	Location	Description	Elevation
1A	Headquarters	Large shelter	1090
1B	"	Small shelter - Six's type	1090
1C	"	Small shelter - 6 feet above gr.	1090
1D	"	Small shelter - 3 feet above gr.	1090
1E	"	Small shelter - 1 foot above gr.	1090
2	PH II, 24-C	WP-WS plant. light thinning	1120
3	"	WP-WS plant. reserve	1120
4	"	WP-WS plant. heavy thinning	1120
5	PH IV	Little Prospect: ridgetop	1310
6	"	Little Prospect: mid-slope	1250
7	"	Little Prospect: slope bottom	1190
8	PH VI	Prospect Hill summit	1383
9	SC II	Flat near Route 32	960
10	SC IV	Burns Bridge	745
11	SC II	Swift River Valley: top of slope	940
12	"	Swift River Valley: mid-slope	860
13	"	Swift River Valley: along river	810

which gives climatic summaries for such central New England weather stations as Amherst, Fitchburg, Rutland, and Worcester in Massachusetts; Keene and Nashua in New Hampshire; and Brattleboro and Vernon in Vermont. As these stations, with the exception of Rutland, Massachusetts, are located in valleys, their climate is not necessarily representative of that of the Harvard Forest. The local records, therefore, although spotty in character and not of overly long duration, may be taken as presenting the best data on the Petersham climate.

The annual precipitation as recorded at the Headquarters over a period of 36 years from 1913 through 1948 averages 42.36 inches. June is generally the wettest month (4.26 inches), and October the driest (2.97 inches), but the precipitation is generally well distributed throughout the year. In any one year, however, any month may be characterised by high rainfall or drought. Monthly rainfall values of around seven inches or more have been recorded for every month, as have droughty periods bringing only about an inch or less (Table 22). Yearly rainfall also fluctuates considerably. In 28 out of the 36 years recorded, the rainfall has been between 35 and 50 inches, but for 3 years a smaller amount of precipitation and for 5 years a larger amount has been measured. The driest year on record was 1941 with 27.3 inches, followed by 1914 and 1930 with 30.9 and 32.2 inches respectively. The wettest year was 1938 with 60.1 inches, of which 15.78 fell in September immediately preceding the hurricane of September 21, and an additional 15.62 fell in June and July. Other wet years were 1933, 1937, 1920, and 1936 with 53.6, 51.8, 51.8, and 50.8 inches of precipitation respectively.

Table 22

MONTHLY PRECIPITATION AT HARVARD FOREST HEADQUARTERS
1913–1949

Month	Maximum Year	Maximum Inches	Minimum Year	Minimum Inches	Average Inches
January	1936	7.51	1944	1.09	3.53
February	1920	7.44	1949	1.34	3.14
March	1942	6.48	1915	0.07	3.21
April	1933	7.69	1941	0.67	3.49
May	1943	6.01	1944	0.91	3.39
June	1922	11.17	1913	0.89	4.27
July	1915	9.81	1939	0.97	4.02
August	1928	7.70	1944	0.66	3.52
September	1938	15.70	1914	0.29	3.92
October	1917	5.84	1924	0.00	2.97
November	1940	6.96	1939	0.99	3.79
December	1936	6.91	1949	0.72	3.11
Total	1938	60.11	1941	27.33	42.36

Temperature values are obtained from a nine-year record at the Headquarters area. The mean annual temperature, as computed from the weekly maximum and minimum readings, is 44.0 degrees Fahrenheit, ranging from 20.4 in January to 67.6 in July. The trend of mean weekly maximum and minimum temperatures is shown in Figure 26. The coldest weather occurs in the middle of January and the hottest in the middle of July, with the minima lagging slightly behind the maxima. The maximums remain high for a longer period than do the minima. The maximum averages above 70 from the end of April to the latter half of October, while the minimum averages above 32 only from the middle of May to the end of September. The warmest recorded temperature from 1937 through 1947 is 97 degrees, and the coldest at the Headquarters was 29 degrees below zero.

The frost-free season may be taken as an approximation of the growing season. For the 11 years from 1936 through 1947, it has varied at the Headquarters building from 103 days in 1944 to 154 days in 1940 and 1942. The average frost-free season for this period was 137 days.

Finally, forest fire danger records kept during the summer of 1947 provide some information about the cloudiness, wind velocity, and wind direction for the months of July, August, and September. For this 92 day period, less than one-third of the sky was cloudy on 40 days, while more than two-thirds were cloudy on another 40 days, leaving 12 days of intermediate cloudiness. The winds were from the west or southwest three-quarters of the time, east winds making up most of the other cases. The wind velocity measured at noon averaged 4 miles per

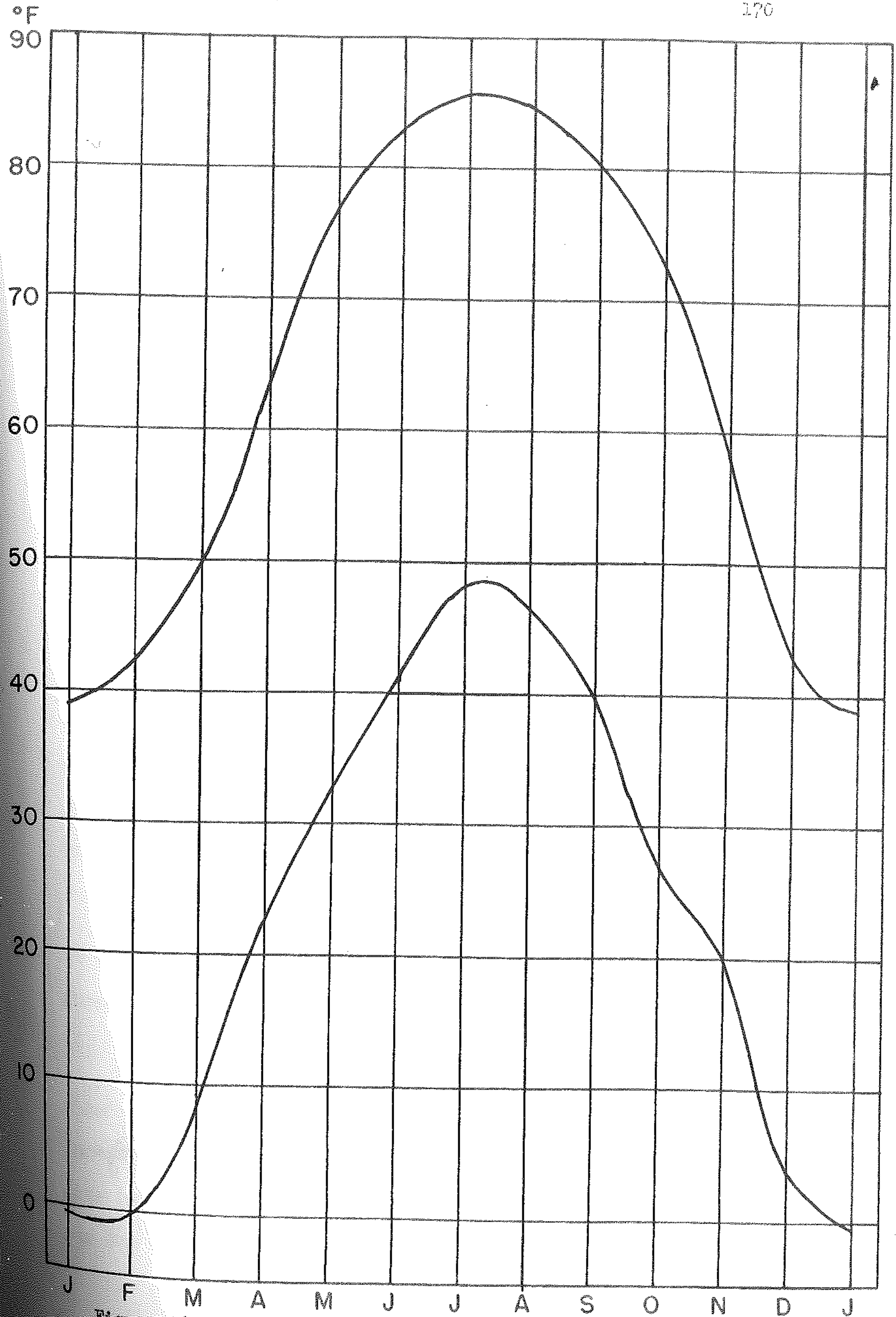


Figure 26. WEEKLY MAXIMUM AND MINIMUM TEMPERATURES
Headquarters. 1939-1947

hour, while the maximum recorded at this time of day was 10 miles per hour although occasional stronger winds were noted at other times.

Local temperature variation

In the local climate study, chief emphasis was placed on maximum and minimum air temperatures. The results confirmed studies by others elsewhere in demonstrating that the local climate varies markedly and is largely controlled by local topography and type of vegetative cover. The mean weekly maximum, minimum, and mean temperatures are given in Table 23 for the four seasons. In this table, each seasonal mean is based upon 13 weekly temperatures. The seasons begin on December 21, March 21, June 21, and September 21. The winter temperatures for stations 4 and 9 are based upon the last nine and eight weeks of the season only, and the mean temperatures covering the same period at station 1A are given for comparison. The 1943-44 records include the period from October 25, 1943 to the same date in 1944, while the 1944-45 records likewise begin and end on October 25th.

The stations may be considered in three groups: (1) the stations at the Headquarters, (2) the stations in the open throughout the Forest, and (3) the three stations in the thinning experiment.

The first year's results indicated that higher maxima were obtained during the warm weather in the small stations around the forest than were recorded in the large shelter at the headquarters area (station 1). In order to determine how much of this variation was due to the size of the stations, and also to evaluate the effect

Table 23. MEAN SEASONAL TEMPERATURES AT LOCAL WEATHER STATIONS

Station	Winter Max.	Winter Min.	Winter Mean	Spring Max.	Spring Min.	Spring Mean	Summer Max.	Summer Min.	Summer Mean	Fall Max.	Fall Min.	Fall Mean
1943-44												
1A	41.1	-1.2	20.0	73.1	28.1	50.7	85.4	46.6	66.0	57.5	16.8	38.2
2	39.1	1.8	19.9	70.2	30.9	50.6	79.9	49.8	64.8	53.0	22.1	37.5
3	36.8	1.9	19.3	67.9	31.5	49.7	78.0	49.4	63.8	51.6	21.8	36.8
4	(38.7)[1]	(3.1)[1]	(21.0)[1]	68.8	30.5	49.6	79.7	48.4	64.0	52.1	22.0	37.0
1A	(42.9)[1]	(0.8)[1]	(21.8)[1]									
5	40.6	1.9	21.3	75.1	31.5	53.3	90.0	51.0	70.5	58.5	21.3	39.9
6	42.8	0.8	21.8	77.0	30.8	53.9	93.4	49.4	71.5	61.5	20.3	40.9
7	43.3	-1.3	21.0	76.0	26.9	51.5	89.9	45.0	67.5	60.3	17.7	39.0
8	40.8	2.7	21.8	75.9	33.4	54.7	92.1	52.1	72.1	59.6	21.9	40.8
9	(46.5)[2]	(-4.0)[2]	(21.2)[2]	79.2	22.9	51.0	92.5	40.8	66.7	—	—	—
1A	(43.1)[2]	(-0.2)[2]	(21.4)[2]									
10	46.8	-6.3	20.3	80.5	23.6	52.0	94.3	42.7	68.4	64.0	15.5	39.7
1944-45												
1A	42.4	-1.3	20.5	73.6	30.7	52.2	84.7	45.8	65.3	62.7	19.8	41.3
1C	43.3	0.2	21.8	73.8	31.5	52.7	86.9	46.5	66.7	61.2	20.8	41.0
1D	43.0	-0.5	21.3	74.3	31.4	52.8	86.8	46.5	66.7	61.3	20.7	41.0
1E	42.5	-0.9	20.8	76.7	30.4	53.5	89.3	45.8	67.6	63.0	19.9	41.5
9	47.8	-8.8	19.5	78.2	26.5	52.4	91.8	41.2	66.5	67.2	16.2	41.9
10	47.8	-9.2	19.3	80.4	26.5	53.4	94.6	43.3	69.0	67.8	15.8	41.8
11	48.1	-4.4	21.8	79.9	28.2	54.1	93.2	42.2	67.7	67.7	16.2	41.9
12	46.5	-5.5	20.5	80.5	27.8	54.1	90.2	42.8	66.5	64.5	16.4	40.4
13	44.2	-6.2	19.0	77.3	27.8	52.5	90.1	43.2	66.6	64.5	16.8	40.7

[1] Last 9 out of 13 weeks only. [2] Last 8 out of 13 weeks only.

Table 23. MEAN SEASONAL TEMPERATURES AT LOCAL WEATHER STATIONS

of height of shelter above the ground on temperature, a series of small shelters were placed next to the large shelter at the Headquarters during the second year. Of these, one was a small upright shelter with a U-type (Six's) maximum-minimum thermometer, while three were small horizontal shelters with Weather Bureau type instruments placed at 6, 3, and 1 feet above the ground. The small Six's type instrument and shelter (station 1B) was found to give comparable results to the Weather Bureau type instruments in a small shelter at the same distance from the ground (station 1D) and was discontinued after several months.

Readings in the small shelter at 6 feet (station 1C) yielded hot weather maxima averaging 2.2 degrees higher than were obtained in the large shelter, but under other conditions yielded fairly comparable results. Practically identical readings were obtained in the small shelters at the 3- and 6-foot heights, indicating that the practice of placing the instruments in the field at a 3-foot height did not produce any large error. The 1-foot readings (station 1E), though, were quite different, the hot weather maxima being 2.5 degrees higher and the minima throughout the year averaging three-quarters of a degree lower than at the 3-foot level.

The stations at the Headquarters area thus provided information showing that the small shelters used in the field tended to result in excessive maximum temperatures in hot weather, but that otherwise they provided results comparable with those obtained from a standard shelter.

Significant differences in both maximum and minimum temperatures were obtained between the various field stations. The highest maxima and the lowest minima were obtained at stations 9 and 10, the former representing a shallow frost pocket at a high relative elevation, and the latter a deep frost pocket at a low relative elevation. The other low stations, 7 and 13, recorded consistently low minima. Maxima at these latter stations, however, were not consistently high, a phenomenon apparently correlated with the partial shade from nearby trees at these points.

In contrast, the high stations 8 and 5 were characterized by high minimum temperatures throughout the year and low maxima. The weekly minimum at the top of Prospect Hill (station 8) was 9 or 10 degrees higher than at Burns Bridge (station 10) throughout most of the year, while the weekly maximum was 5 to 6 degrees lower.

The intermediate stations (1B, 6, and 12) proved to be intermediate in temperature range. The relatively high maxima at station 6 were found to be related to the pocket formed around that station by rapidly growing hardwood sprouts which sheltered the instrument from winds without providing shade.

Although highly significant differences were found between maximum and minimum temperature readings at various points, the high maxima and low minima found in frost pockets tended to compensate so that relatively little variation in mean annual temperature was found. The maximum difference between mean annual temperature at comparable open stations in 1943-44 was 0.9 degrees and in 1944-45 was 1.5 degrees.

It thus appears that mean annual temperatures are fairly free of topographic influence and that their values may safely be compared in determining the influence of latitude and altitude on climate. This finding was drawn upon in the determination of long-term climatic trends in Chapter 2.

The length of frost-free season proved to be much shorter in the frost pockets than at points of good air drainage. The length of frost-free season is a highly variable quantity and the present study is sufficient to give only an indication and not to supply any valid averages. In 1943-44, the longest frost-free period was 161 days at the tops of Prospect and Little Prospect Hills and also at station 6. At the Headquarters, the period was 156 days; at the edge of the peat bog (station 7), it was only 126 days; at Burns Bridge, 104 days; and at station 9, it was only 77 days, a frost occurring on August 25 at that point. The following year, the frost-free period was shortened by two late frosts in June, but the variation in length of the period at the different stations was generally consistent with the previous year's finding. The longest season, 119 days, was at the Headquarters; while at the various Slab City stations, the period ranged from 91 to 112 days.

The three stations in Plantation 240, a 20-year old white pine and white spruce plantation (see case history in appendix), provide some data on temperatures under dense conifers, and on changes in temperatures brought about by thinning. In general, lower maxima and higher minima were obtained throughout the year under the softwoods than in the open. The mean temperatures were a little lower at all seasons than at the nearby Headquarters, never by more than two degrees, and usually by less. In other words, the conifer overstory greatly modified the temperature extremes, but exerted relatively little effect on average temperatures. Very little difference was observable between the reserve stand, light thinning and heavy thinning. Maxima in the reserve stand were somewhat lower than under the thinned stands, but minima did not differ significantly.

Soil temperatures were made directly every Monday morning and at other times during the 1943-44 period in the reserve stand, the heavily thinned stand, and in a nearby semi-open area. Readings were taken from laboratory type thermometers imbedded horizontally into the earth from a square shaft set into the ground and lined with lumber. The shaft was sealed between readings with an excelsior filling and a heavy insulated lid. Readings were taken above the mineral soil at 12, 6, and 2 inches, at the top of the mineral soil, and 2, 6, and 10 inches below the mineral soil. Throughout the fall and winter, the soil remained warmer than the air, and the air temperatures increased toward the ground. The surface of the soil at all three stations fell below freezing for the first time about December 12, while the temperature at the 10-inch depth fell below freezing on January 3. At no time did the temperature at the 10-inch depth fall below 31 at any station. The minimum winter temperature at the 2-inch depth was 28 in the reserve stand, and 26 in the semi-open station.

The main difference in soil temperature between stations occurred at the time of the spring thaw. At the semi-open station, the ground thawed quickly, being still frozen to the surface on April 17, and thawed down through the 10-inch depth by April 24. Under the heavy thinning, the thaw began after April 24, and reached the 10-inch depth on May 4. Under the reserve stand, the thaw began again after April 24, but did not reach the 10-inch depth until May 8. The length of time the soil was frozen, therefore, was 4 days longer in the reserve stand than in the thinned stand, and between one and two weeks longer in the thinned stand than at the semi-open station.

Local evaporation variation

During the first season (1943-44), Livingston white bulb atmometer readings were taken at the open stations. Weekly evaporation was thus recorded for a period beginning on May 22 and ending September 18. The evaporation at the Headquarters (station 1) was taken as the base of 100. The only station showing higher evaporation was number 5 on the top of Little Prospect Hill in a grassy clearing formerly used to turn around logging trucks. The reading here was 103.5. Halfway down Little Prospect at station 6, where the hardwood sprouts had surrounded the station, the evaporation was 85.0; while at the bottom of the slope in a somewhat more open spot, the reading was 94.4. At Slab City stations 9 and 10, evaporation was 77.0 and 78.2 percent of that at the Headquarters. Evidently, the protection from the wind afforded by adjacent vegetation had a greater effect on relative evaporation than did the topographic location. Nevertheless, the two stations (9 and 10) characterized by the greatest temperature extremes were the two that had the least evaporation and presumably the least air motion.

Frost damage in May, 1944

The local effects of frost on the tree cover were graphically illustrated by a damaging frost that occurred on May 19, 1944 after 16 days of unseasonably warm weather. Notes on the damage around the various local weather stations were taken by the author and Karl A. Grossenbacher immediately after the frost.

Cool spring weather with temperatures seldom higher than the fifties ended abruptly on May 3rd of that year, after which warm temperatures prevailed daily. Beginning May 4, buds began bursting into leaf, and by May 19, all trees were well leaved out. Beginning at 4:00 P.M. on the 17th, the temperature fell continuously from a high of 79 degrees Fahrenheit to a low of 22 at the Headquarters at 6:00 A.M. on the 19th, reaching freezing at 11:00 P.M. on the 18th, and remaining below freezing for nine hours. At the top of Prospect Hill (station 8), the minimum was only 30 and at the top of Little Prospect (station 5), it was 26. On the mid-slope of Little Prospect (station 6), it was 24, and at the bottom of the slope (station 7), 19. The Slab City II frost pocket (station 9) recorded a low of 17, while 19 was reached at Burns Bridge (station 10).

Thus, the minimum temperature ranged from 17 degrees to 30 at a time when the leaves were out. Frost damage varied accordingly. At the top of Prospect Hill, no damage was noted to any of the 11 species observed except for two small red oaks, about 20 percent of whose leaves were injured. At the other extreme around station 9, the red oak, chestnut, sumac, white oak, red maple, and yellow birch were 90 percent or more defoliated; choke cherry and pin cherry were 35 percent defoliated; and gray birch, paper birch, black cherry, Norway spruce, and aspen exhibited 10 to 20 percent injury. The other stations provided intermediate results. The severe frost injury of red oak and chestnut was at least partly due to the fact that the leaves of these species were at a much earlier stage of development than those of the other species. They were light yellow green and less than one-half of normal length.

As a result of these observations, it was possible to construct a tentative list of species as to frost susceptibility. Class A, the most resistant species, included hawthorn, black cherry, aspen, and gray birch; species which showed less than 10 percent leaf injury following long exposure to 20 degrees F. Class B, including paper birch and pin cherry, showed slight injury at 26 degrees but less than 40 percent defoliation at 17 degrees. Class C, comprising red maple and large-toothed aspen, was highly variable, but showed less than 50 percent defoliation following long exposure to 20 degrees. Finally, class E consisted of species largely or completely defoliated at 26 degrees. These were red oak, chestnut, hickory, and white ash.

Influence of climate on composition

The data presented above indicates that the local climates differ significantly from place to place throughout the Harvard Forest. In concave areas, both high and low in relative elevation, where air drainage is poor, the maximum temperatures are higher, the minimum temperatures are lower, and the frost-free season is a great deal shorter than in convex areas characterized by good cold air drainage.

Vegetation modifies the local climate even to a greater extent than does topography, although this factor is treated but briefly here. It might be expected, therefore, that forest composition is influenced by local climate to a major extent.

Actual proof of the interrelationships between local climate and stand composition, however, is not at all ample. Other variables such as land-use history, forest management history, and forest soils all exert obvious and masking effects, and an extremely detailed study would be needed to isolate the importance of the local climatic factor. That local climate is highly important in influencing plant distribution, however, cannot be doubted. A few illustrations will suffice.

First, the soils classification evolved in chapter 4 and utilized in the study of present-day associations in chapter 3 carries with it an implication of variation in local climate. The same factors that make a soil very well drained are apt to insure good drainage of cold air and to indicate a site with lower maximum and higher minimum temperatures than would be indicated by a regional climatic average. Thus, a very well drained site is apt to have a moderated climate suitable to plants of a generally southern distribution. Likewise, a very poorly drained soil is apt to result from a topography that inhibits the drainage of cold air as well as of water. Thus, the very poorly drained sites are apt to be characterized by temperature extremes and a short growing season, and thus might prove suitable for plants of a generally northern distribution.

Of the species that occur near the southern limit of their range in the Harvard Forest, red spruce, black spruce, and tamarack are all largely confined to peat bog sites, sites which incidentally are characterized by low minimum temperatures throughout the year and a very short growing season. The implication is strong that these trees are localized in the Petersham region in localities where the climate is colder than the regional average.

On the other hand, there is relatively little evidence that species occurring near the northern edge of their range are found on the high slopes with good cold air drainage. The most common such species are the hickories and black gum. The former occur on the hills, but also on imperfectly drained sites. They are not found in the Forest on the poorly drained or very poorly drained sites. The latter is found chiefly in the Prospect Hill peat bog in close association with red spruce.

The climatic data, however, do tend to explain why white ash is found only infrequently on the poorly drained and very poorly drained sites. As noted above, white ash is extremely susceptible to frost injury, a fact frequently observed in connection with the many small white ash plantings in the Forest. Apparently, the late spring and early fall frosts of the low-lying poorly drained soils are sufficient to inhibit the successful development of white ash past the juvenile stage on these sites, even though the species may be abundant in the reproduction.

Chapter 6

SILVICULTURE

Importance in changing composition

The Harvard Forest has been a research and demonstration forest since 1907. In a broad sense, all cutting operations and other management activities designed to affect forest establishment, composition and growth that have been undertaken since that time come under the designation of silviculture.

The silvicultural history of the first thirty years of the Forest, emphasizing selected case histories, has been prepared by R. J. Lutz and A. C. Cline, and Part I of this study dealing with fourteen cases of the conversion of stands of old field origin by various methods of cutting and subsequent cultural treatments has already appeared (1947). The present chapter deals with the effects of silviculture in quite a different way. First, we are here concerned only with the influence of silviculture on forest composition, and not with its influence on growth or stem quality. Second, the present study deals with general trends over that part of the Forest that has belonged to the University for the entire forty year period. Every case of silvicultural treatment on these 1852 acres will be considered briefly as it bears upon stand composition, but none will be given the detailed attention characteristic of Bulletin 23 by Lutz and Cline.

The Harvard Forest stand records are voluminous and remarkably complete. By going through them Compartment by Compartment and page by page, it is possible to construct case histories of individual areas detailing all silvicultural treatment over a forty year period. This was done as the basis for the present discussion. In order to reduce the wealth of material to usable shape, it was found necessary to follow certain arbitrary rules.

First, an arbitrary decision had to be made defining the area covered by an individual silvicultural case. Successive treatments rarely covered precisely the same area. For instance, a ten-acre stand might have been clearcut in 1910. Two years later, six acres of it might have been planted. Successive weedings in both the planted and unplanted portions might have covered various portions of the tract ranging from 1 to the entire 10 acres. Finally, a recent thinning operation might have covered only one-half the planted and one-half the unplanted area. Obviously, the whole record might be grouped into one case, or broken down into as many cases as there exist areas which have received different treatment. The practice followed by the present study has been to group the treatments as much as possible and yet to preserve the distinction between natural reproduction and reproduction through planting. Thus, in the hypothetical example above, two cases would be set up, one for the planted and one for the unplanted areas.

Second, many of the silvicultural treatments have been restricted to very small areas. Since little of a definitive nature can be learned from "postage-stamp forestry", cases involving less than one-half acre have in most cases been omitted.

Finally, the period involved extends from the summer of 1907 to the summer of 1947. Cutting operations made prior to the purchase of the tract by the University are not considered except as information concerning them has become available through land-use studies. Operations subsequent to the summer of 1947 are ignored.

Having constructed case histories for the entire study area of 1852 acres (the three main blocks of the Forest excluding PH IX, TS IX, SC I, and the Higgins Lot), we are in a position to compute for the first time the number of acres affected by cutting operations during the first forty years of the Harvard Forest.

In all, 196 cases were constructed, involving 697 acres or 37 percent of the study area. Of these, 125 cases covering 396 acres deal with softwood planting; and 71 cases covering 301 acres deal entirely with natural restocking. The acreages involved must remain more or less approximate as the case lines are not always clearly defined. Also, the boundary between cases of natural restocking and cases of softwood planting is frequently indistinct. In the present study, cases where planting was clearly of a supplementary nature, as in several areas in the southeastern part of the Tom Swamp Block, are classed with the cases of natural restocking. The many small hardwood plantings have been almost completely unsuccessful and are not included in the above tabulation although they are later discussed.

Cases involving softwood planting are located on the stand maps included in the appendix. The code number refers to the year of planting. Thus, plantation 24A was the first planting put out in the spring of 1924. Cases involving natural restocking, including those with supplementary planting are identified on the map in Figure 27. The code number for these cases refers to the block and compartment in which they occur. Thus case 1-1 is the first case in Prospect Hill I; case 24-6 is the sixth case in Tom Swamp IV; and cases 39-2 and 40-2 refer to the second case in Slab City IX and X respectively. The color code in Figure 27 provides a rough distinction between cases involving clearcutting only, those involving only extensive silviculture of a rather crude nature, and those involving more or less intensive silviculture.

Of the softwood plantings, 54 cases covering 102 acres involve the planting of open and semi-open lands without prior cutting. The remaining 71 cases covering 294 acres deal with planting following cutting operations.

Of the natural reproduction cases, 30 covering 148 acres deal with the cutting of hardwoods and to a very limited extent with hemlock-hardwoods; while 41 cases covering 153 acres deal with the cutting of white pine and pine-hardwood types. Of these, however, 19 cases covering 88 acres (8 in hardwoods covering 43 acres, and 11 cases in pine and pine-hardwoods covering 45 acres) deal with clearcutting alone and can only be considered as silvicultural cases in the very broadest sense. Some of the cases discussed as instances of natural regeneration had been previously unsuccessfully planted, and their areas are therefore included in the acreage planted, rather than in the acreage of natural reproduction cases.

Summarizing the acreage affected by silviculture then, 102 acres of open and semi-open land, constituting 6 percent of the study area, have been planted. The forest on 595 acres, or 31 percent of the study area, has been cut in one way or another. Of this latter figure, 88 acres have been clearcut only, 294 have been clearcut and planted, and 213 have been regenerated naturally by methods other than clearcutting, or have received intermediate cuttings only.

The amount of wood cut each year on the study area of 1852 acres is given in Table 24. Up to the hurricane, the cut was largely in the form of saw-logs, an average of 291,000 board feet being removed yearly. The salvage from the hurricane is recorded under the 1938-39 period and approximates 4,250,000 board feet. Subsequent saw-log cutting has been on a very minor scale, being scarcely 22,000 board feet per year. Over the entire period, 7,260 board feet per acre have been cut or 182 board feet per acre per year. Cordwood cutting was on a relatively small scale until 1923, and since that time has varied considerably. Over the entire period, an average of 3.8 cords have been cut per acre, or 0.1 cord per acre per year. Due largely to the hurricane, the cut per acre exceeds growth per acre as the 1947 growing stock was much less than that of 1907.

Silvicultural policy

No one can work with the records of silvicultural operations on the Forest for long without realizing the great extent to which the personality and philosophy of the individuals concerned with the actual operations have influenced the method and type of cutting. A consideration of the silvicultural policies in vogue at various times in the history of the Forest is therefore essential if one is to understand the case histories and the present status of the Forest. The forty years involved can conveniently be broken down into ten year periods, especially as 1907 marks the beginning of silvicultural operations in the Forest; 1917 marks

Table 24

FOREST PRODUCTS CUT IN THE STUDY AREA

Year	Saw-timber (M board feet)	Cordwood (cords)
1907-08	0	0
08-09	217	220
09-10	148	208
1910-11	231	238
11-12	248	c35
12-13	281	c50
13-14	185	c50
14-15	294	c30
15-16	51	c50
16-17	350	c50
17-18	176	c50
18-19	285	75
19-20	140	28
1920-21	754	30
21-22	50	100
22-23	422	39
23-24	423	388
24-25	0	222
25-26	438	273
26-27	254	188
27-28	519	278
28-29	587	209
29-30	0	48
1930-31	369	99
31-32	458	32
32-33	c360	138
33-34	388	85
34-35	446	111
35-36	300	148
36-37	306	662
37-38	346	46
38-39	c4250	304
39-40	40	606
1940-41	18	446
41-42	21	591
42-43	24	298
43-44	39	296
44-45	0	137
45-46	11	167
46-47	20	53
Total	13449	7078
Average cut per acre	7260 board feet	3.82 cords
Average cut per acre per year	182 board feet	0.10 cords

both World War I and the start of a major change in silvicultural attitude at the Harvard Forest; 1927 marks the approximate culmination of the new attitude; 1937 is the last year of normal operations preceding the 1938 hurricane and the 1939 start of World War II; and 1947 marks the assumption of the silvicultural burden by Director Hugh M. Raup.

During the first ten years, from 1907 to 1917, the Forest was an adjunct to the work in forestry centered in Cambridge. Relatively little silvicultural work was carried out, and relatively little silvicultural research was published. The first operations on the Forest in 1908-09 were summarized by Fisher (1911). These included a thinning of old field white pine (6.5 acres), a clearcutting of a pine-hardwood mixture (3.8 acres), and a light improvement cutting of mixed hardwoods in which aspen and other weeds were taken out (20.0 acres). In this report, Fisher favored clear-cutting to reproduce old field white pine stands because of the low cost of operation, the necessary burning of slash, and the form of the stand, making any method by partial cutting almost impractical. He felt that group or shelterwood cuttings would tend to increase the percentage of hard-woods unduly. Other publications of the first ten-year period deal primarily with planting problems such as the influence of shade on survival (Kimball and Carter, 1913), and the relative merits of mattock and silt planting (Carter, 1915). The dangers of forest pests were emphasized by the depredations of the chestnut blight (Kittredge, 1913), and the damage to white pine reproduction wrought by the pales weevil (Carter, 1916).

The second ten-year period from 1918 to 1927 marked the gradual recognition of the impermance of the old field white pine type, the importance of the old field-pine-hardwood succession, and increasing interest in hardwood types. In 1918, Fisher recognized that, following the cutting of pine, a substantial percentage of the new stand would be made up of hardwoods, and that a good pine-hardwood mixture could be brought about by weeding or cleaning the young growth (Fisher, 1918, 1921; Fisher and Terry, 1920; Cline, 1924a; Cline and Lockard, 1925). For the first time, critical attention was focused upon the hardwoods, particularly upon the growth yield of red oak, white ash and other species that followed the clear-cutting of old field pine (Spaeth, 1920; Patton, 1922). Although it was realized that white pine on old fields could successfully be released from an overstory of gray birch (Spaeth, 1922), and although continued attention was given to the growth of white pine (Tarbox, 1924), the current attitude toward that species was summarized by Cline (1924b) as follows:

> "White pine in the unevenaged form is found growing as a relatively permanent type on light, sand and gravel soils of north central Massachusetts and southern New Hampshire. The permanent character of this type is due to the impossibility of hardwoods of vigorous growth coming in sufficient numbers to crowd out the pine..... On the heavy upland soils white pine is commonly found in the evenaged form growing on abandoned farms. While no system of reproducing the "old-field" type has yet been devised which will effectually check the determined ingress of hardwoods both before and during the reproduction period, the clear cutting and shelterwood methods, following by weedings, have given the best results."

Also during this period, early success with red pine in plantations drew attention to the possibilities of this species (Reed, 1926); while Marshall (1927) ably documented the great ability of hemlock to respond to release from suppression. Finally, the two worst insect pests of white pine, the pales weevil and the white pine weevil, were studied in detail with a view to their control by forest management (Peirson, 1921, 1922).

Silvicultural policy in the third decade (1928-37) followed closely that of the second (Fisher, 1928, 1931; Anonymous, 1935). The pine-hardwood mixtures of the preceding period had largely evolved into pure hardwood stands, and the composition and treatment of these transition hardwood stands were studied in detail (Cline, 1929, 1935; McKinnon, Hyde and Cline, 1935). Concurrently, plantations were established and treated on a large scale. Research on these included a study of exotics such as European larch (Hunt, 1931) and Norway spruce (Hosley, 1936), and experimental reclamation of badly weeviled white pine plantations by pruning and girdling (Cline and Fletcher, 1928; Cline and MacAloney, 1931, 1933, 1935; and Curtis, 1936). Continuing interest in the mensurational approach to silviculture was evidenced by the study of Gevorkiantz and Hosley of the effect of growing space on the form and development of white pine (1939).

The silvicultural approach to forest protection received great impetus during this period. Many acres of hardwood stands were thinned in an effort to develop a stand composition unfavorable to the gypsy moth (Baker and Cline, 1936; Behre, Cline and Baker, 1936). Also, the interrelationships between wildlife and forest management were considered (Hosley, 1937), especially as regards wildlife damage to plantations (Hosley, 1928, 1931). Insect pests studied included the white pine weevil (MacAloney and Johnston, 1933) and moundbuilding ants (MacAloney and Hosley, 1934).

The hurricane of 1938, by virtually removing the merchantable timber, brought about a deemphasis on the management aspects of the forest. For the first time, the habit of planting extensive areas every year was abandoned, and management activities were concentrated in natural stands. Weedings in hardwood stands were largely discontinued, while improvement cuttings were applied on a larger scale than before.

Research followed the old lines, but tended to be more detailed and technical, and possibly more basic. Past silvicultural experience was reexamined and reconsidered in detail (Lutz and Cline, 1947; Spurr, 1944). The studies of Holsoe (1947, 1948) on the relation of red oak and white ash development to growing space followed the trail blazed by earlier studies of white pine. Bess, Spurr and Littlefield (1947) reexamined in detail the problem of silvicultural control of the gypsy moth. More precise methods of following radial growth were adopted (Brown, Rose, and Spurr, 1947) and were applied to studying the immediate effects of selective thinning (Stephens and Spurr, 1947) and to the evolution of more practical thinning methods (Spurr, 1947).

In short, the stands of the forest today show the results not of a single consistent silvicultural policy, but a series of policies reflecting the thoughts and interests of such men as Richard T. Fisher, E. E. Carter, Albert H. Upham (Superintendant from 1910 to 1944), J. Nelson Spaeth, A. C. Cline, Neil W. Hosley, and the author. Sometimes the same area has been weeded in early years to favor white pine; weeded to favor red oak and white ash in the twenties; thinned to reduce the amount of red oak, a favorite food of the gypsy moth, in the thirties; and perhaps thinned to favor the red oak during the next decade. On the surface, the situation is confusing and hopelessly confounded. Nevertheless, if the present stands are studied in the light of their recorded history, much can be learned concerning the effects of the various silvicultural treatments. By bringing together all the case histories of the Forest, we should be in a position to ascertain at least some of the major effects of forest management on stand composition.

<u>Softwood plantations</u>

A greater area has been affected by softwood planting than by silvicultural treatments of natural stands. Also, plantations provide simple cases of the effects of silviculture on forest management as the desired composition is indicated by the species planted, and the success of the planted species can easily be ascertained. All the plantations in the Forest were visited by either the author or C. T. Brown, Jr. in 1944-45, at which time detailed notes on present condition were taken. Subsequently, many of the more important plantings were treated and measured. Case histories of many of these were prepared in 1944 and are included in the appendix. The present discussion is based largely upon these sources of information as well as upon the Harvard Forest stand records.

The 125 softwood plantings on the study area range in size from slightly less than one-half acre to forty-four acres. They may be subdivided according to whether the planting was done; (A) in open land; (B) in semi-open land; (C) after the cutting of pioneer hardwoods on old fields; (D) after the cutting of white pine or pine-hardwood mixtures; and (E) after the cutting of transition hardwoods. The number of acres planted under each of the above conditions in each of the decades covered is given in Table 25. The early plantations were very largely on open and semi-open land. During the second decade, planting was distributed fairly uniformly between the different conditions. From 1928 to 1937, emphasis was placed on planting following the clearcutting of pine and pine-hardwood types. Approximately one-half the acreage of plantations was set out during this period. Since the hurricane, however, no planting has been done except for one small experimental seed source trial (Norway spruce), not included in the present summary.

Table 25

AREA OF SOFTWOODS PLANTED BY DECADES

UNDER VARIOUS CONDITIONS

Condition class	1907-1917	1918-1927	1928-1937	1938-1947	Total
A. Open land	32	17	3	0	52
B. Semi-open land	18	26	6	0	50
C. After pioneer hard-woods on old fields	1	32	0	0	33
D. After white pine or white pine-hardwoods	6	34	169	0	209
E. After transition hardwoods	1	34	17	0	52
Total	58	143	195	0	396

The case histories of 19 of the more important plantations are included in the appendix.

Pertinent facts concerning the softwood plantations are summarized in coded form in Tables 26 to 30. Species are indicated by the initials of their common names. Thus WP, RP, SP, and PP refer to white, red, Scotch, and ponderosa pine respectively; NS, WS, and RS refer to Norway, white, and red spruce; EL, and JL refer to European and Japanese larch (when only L is indicated, several species of larch are included in a single plantation, frequently including Dunkeld larch and L. dahurica as well as the above), and Hem refers to hemlock.

In the vast majority of cases, 2-1 or 2-2 transplant stock has been used. Species set out with seedling stock (2-0 or 3-0) are designated with asterisks in the tables. It will be noted that plantings of seedling stock in general have shown much poorer competitive ability against hardwoods and have been less successful than those set out with transplants.

Silvicultural information in these tables is confined to the number of weedings and the total number of man-hours required by them. Improvement cuttings and thinnings which had no major effect on forest composition but rather dealt with stimulating growth of crop trees and improving stand quality are ignored. Those few improvement cuttings which had a major effect on composition are tallied with the weedings in these tables.

Plantation success is indicated by letters, A referring to stands where the planted species have taken over 80 to 100 percent of the area of the plantation; B covering 60 to 80 percent; C, 40-60 percent; D, 20-40 percent; and E, 0-20 percent.

Finally, under "Present status", Bd indicates hurricane blowdown, Co followed by a number gives the year in which the planting was cut-over, and the letters G, M, and P refer to good, medium, and poor vigor as of 1944-45.

By all counts, the most successful plantations have been those established on open land (Table 26). Without exception, the planted species have come through to make up the entire new stand. Very little weeding or cleaning has been needed. Only 17 of the 30 plantations on open land have been weeded at all, and these have required on the average only 3½ hours of work per acre, largely to prevent the encroachment of hardwoods along the old fence rows. Most of the stands are on well drained till (Gloucester soil) in the Prospect Hill Block, but plantation 120 in Slab City V, planted on a sandy esker, has done equally well. Of the various species planted, red pine, Norway spruce and white spruce have done the best (case histories 22B and 25L in the appendix). White pine has shown less growth than red pine or the spruces and in addition has been seriously deformed by the white pine weevil under practically all conditions (15F2, 15G, 24G in appendix). Spruce-white pine mixtures have proven unsatisfactory because of the weeviling of the pine which has a faster early height growth than the spruce (24A, 24C in appendix), even though the spruce eventually becomes taller. Spruce-red pine mixtures, on the contrary, have proven among the best, as much of the spruce gradually drops out giving the red pine a much needed thinning at a time when felling operations are uneconomical (25K, 26N in appendix). Plantations of ponderosa pine (15B in appendix) and Scotch pine tend to go to pieces in their middle years.

Where old fields and pastures with a scattered advance growth of gray birch, pin cherry, aspen, sumac, white pine, and other pioneer species have

Table 26

SOFTWOOD PLANTATIONS ON OPEN LAND
(30 stands)

Plantation number	Comp.	Acres	Species	Weedings No.	Weedings Manhours	Success	Present status
9C	PH3	1.8	WP*	0	0	A	Bd
11A	PH1	1.5	WP	1	3	A	Bd
11D	PH2	1.0	WP	0	0	A	Co&G
12B	PH3	0.7	SP-JL*	0	0	A	Bd
12C	BO6	6	WP	1	-	A	G
14C	PH7	1.2	SP	2	3	A	M
15B	PH3	0.3	PP	0	0	B	P
15F1	PH6	7	WP	0	0	A	M,Bd
15F2	PH6	3	WP	1	3	A	M,Bd
15F3	PH6	3	RP	1	1	A	Bd
15G	PH6	0.5	RP-WP	1	1	A	G,Bd
16B	PH3	0.7	WP	1	4	A	Bd
16C	PH3	1.0	WP	1	1	A	Bd
16E	PH5	3	WS	1	1	A	G
16H	PH6	0.4	WS	0	0	A	G
17B	PH4	0.6	WP-SP	0	0	B	G,Bd
19A	PH5	0.3	WP	0	0	A	G
19C	PH5	2.4	WS	1	1	A	G
20A	PH5	0.3	RP	0	0	A	M,Bd
20B	PH5	1.8	RP	0	0	A	M,Bd
22B	PH9	1.7	RP	1	2	A	G
24A	PH2	1.4	WS-WP	2	3	A	G
24C	PH2	1.7	WS-WP	2	5	A	G
24D	PH1	0.5	WP*	0	0	A	G
25K	PH1	5	RP-WS	3	1	A	G
25L	PH3	0.5	RP	0	0	A	G
26H	PH1	1.5	RP-WS	1	1	A	G
27C	PH1	0.6	RP-WS	2	9	A	G
27D	PH1	0.4	RP-WS	0	0	A	G
28H	PH5	2.6	WS	1	8	A	G

been planted, the results also have been highly successful (Table 27). The only outright failures have been attempts to establish white spruce on an excessively drained sandy kame in the middle of Tom Swamp (23C, 24K). In these cases, failure was due to inability of the species to survive under the adverse site conditions and not to hardwood competition. Scotch and red pine on the same site, however, have survived and grown adequately. More than 25 man-hours of weeding were needed in only one plantation. This was a white pine plantation (23B) on a sandy glacial outwash plain west of the kame mentioned above. Here, the gray birch was left as an overstory, part of it being removed 3½ years after the planting in 1926 and the rest of it being cut when the plantation was 12 years old in 1935. Omitting these five plantations on excessively drained soils, the remaining 19 plantings on semi-open land required on an average of 2½ weedings each, taking a total of 11 man-hours per acre. With the exception of occasional areas of imperfectly drained land within the plantations (case history 24B), the planted species came through well. Red pine-spruce mixtures such as 26J are today growing better than comparable pure red pine (26I) or pure spruce (26K). White pine on semi-open sites comes through fairly well (23A). White spruce also does well, both in pure stands (24H), and when freed from overtopping Scotch pine (24F).

The third group of softwood plantings consist of cases where the gray birch and other pioneer hardwoods on old fields had become thoroughly established and had to be clearcut before the planting (Table 28). These thirteen plantations were put in between 1917 and 1925. In all but two instances, the planted species were brought through successfully with an average of 4.4 weedings totalling 27 man-hours per acre. Failures were

Table 27

SOFTWOOD PLANTATIONS ON SEMI-OPEN LAND
(Abandoned farmland with scattered gray birch, cherry, pine, etc.)

(24 stands)

Plant. number	Comp.	Acres	Species	Weedings No.	Weedings Manhrs.	Success	Present status
9A	PH2	1.5	WP*	1	10	A	Bd
9B	PH3	1.5	WP*	1	16	A	Bd
9D	PH2	0.8	WP	0	0	A	Bd
10A	PH4	13	WP*	1	2	A	M,Bd
13G	PH8	0.3	NS	3	18	A	M
13H	PH8	0.3	RP-WP	1	6	A	Go30
15E	PH5	1.1	EL	2	10	A	Bd
21E1	TS8	0.9	RP	3	5	A	G
21E2	TS8	1.1	RP*	2	3	A	M
23A	PH3	0.9	WP	3	23	A	G
23B	TS8	0.5	WP*	2	52	A	M
23C	TS8	0.2	WS*	2	3	B	P
24B	PH2	1.3	WS*-WP	6	25	B	M
24F	PH1	1.0	WS*-RP*	3	25	A	M
24H	PH1	2.6	WS*-Pic. abr.	3	8	A	G
24K	TS8	0.8	WS*	2	3	B	P
26I	PH4	6	RP	5	7	A	G
26J	PH4	4	RP-NS	5	7	A	G
26K	PH4	5	NS	5	10	A	G
27B	PH2	1.2	RP-L.dah.	3	12	B	G
29G	PH5	0.6	EL-WS(34)	1	7	A	G
34E-35E	PH5	2.3	WS	1	6	A	G
35H	PH5	1.3	WS	2	13	B	M
37A	PH1	1.8	NS	1	9	B	M

Table 28

SOFTWOOD PLANTATIONS FOLLOWING CUTTING OF PIONEER HARDWOODS ON OLD FIELDS

(13 stands)

Plant. number	Comp.	Acres	Species	Weedings No.	Weedings Mnhrs/A.	Success	Present status
17A	PH1	0.6	RP	6	57	A	Bd
19B	PH2	1.7	RP	3	9	A	G
21A	PH1	1.4	EL*-SP-Hem*	3	22	A	M
22A	PH1	1.0	RP	3	12	A	Bd
22C	TS5	1.0	RP	3	15	A	G, Bd
24D	PH2	2.8	WS*-WP-Hem	8	40	A	M
24E	PH2	1.2	SP*-WS*-NS(16)	4	32	A	M
24J	TS8	1.7	WS*	0	0	B	P(GB uncut)
25D	PH1	0.6	EL*-WP	4	27	A	M
25E	PH1	1.8	SP-Hem-WS	5	31	A	M
25H	PH1	13	RP-WS	5	24	A	G
25I	PH3	2.3	NS-SP-WP*	4	31	A	M
25J	TS5	4	WS	6	26	D	M

experienced when white spruce was planted on excessively drained sand (24J), the gray birch overstory not being cut before planting; and when white spruce was planted on imperfectly drained soil (25J). Many of the successful plantations were of an experimental nature, involving species such as European larch, Scotch pine, and hemlock which have proven unsatisfactory under any condition. Where red pine was planted, however, the cost of weeding was only 15 man-hours per acre (19B, 22A, 22C, 25H). Plantation 19B (see case history and Figure 28) is one of the better stands in the forest. White pine proved more difficult to bring through, requiring an average of more than 40 man-hours of weeding per acre.

The largest acreage of plantations have been put out on cut-over white pine and pine-hardwood land (Table 29). Some were established as early as 1914, but most were put out between 1928 and 1937. Weeding has not been generally intensive in these stands, with the result that many of the plantings have failed.

Outstanding failures have been the supplementary plantings in the Tom Swamp Block where scattered trees were planted in an effort to supplement natural reproduction. The important cases have been detailed in Bulletin 23 (cases 4, 5, 6, and 11). Supplementary planting has proved completely unsatisfactory and has been abandoned.

Where blocks of planted trees have been set out, success is apparently conditioned largely by the species planted, the site, and the amount of weeding. Red pine has been by far the most successful species. In nine plantations set out prior to 1936, red pine has come through in all instances, requiring only an average of 16 man-hours per acre of weeding. White pine

Figure 28. RED PINE PLANTATION 193[illegible]

Table 29 - Part 1

SOFTWOOD PLANTATIONS AFTER CUTTING OF PINE AND PINE-HARDWOODS
(41 stands)

Plant. number	Comp.	Acres	Species	Weedings No.	Weedings Mnhrs/A	Success	Present status
14E1	SC5	1.8	NS	4	11	A	G
14E2	SC5	0.5	WP	4	11	A	G
14F1	SC10	2.1	WP	5	14	A	G
14F2	SC10	1.5	NS	5	26	E	F
19D	TS1	4	RP-WP	4	10	E	F
19E	TS4	5	RP	4	13	E	F
21D	SC3	2.9	WP	3	19	C	G
21E	SC3	3.3	RP	4	23	A	G
25C1	TS1	1.5	WP*-SP*-NS*	3	10	E	G
25C2	TS1	2.0	RP	5	16	A	G
26A1	TS3	1.3	NS	4	18	E	F
26A2	TS3	0.9	WP	3	33	C	G
26A3	TS3	3.9	RP	4	15	B	G
26E	TS4	1.1	RP	5	35	E	F
26F	TS4	3	WP	4	17	D	M
26G	TS4	0.9	RP	4	30	B	G
26H	TS5	0.6	RP	3	13	A	G
26M	SC7	3.3	NS	3	27	E	M
28B1	SC4	1.5	WP	3	9	A	M
28B2	SC4	1.2	RP	3	10	B	G
28B3	SC4	1.0	WS	3	9	C	G
28B4	SC4	0.5	WP-WS	3	9	E	F
28C	PHB	2.8	WP	4	26	B	M
28D	SC3	0.8	WP	2	7	D	M
28E	SC3	0.5	WP	2	14	E	D
28F1	SC2	1.9	WP	3	15	E	M
28F2	SC2	1.0	WS	3	15	E	M

For continuation, see part 2

Table 29 - Part 2

Plant. number	Comp	Acres	Species	Weedings No.	Weedings Mnhrs/A	Success	Present status
30A	T87	44	RP	4	7	B	G
			WP	4	7	B	P
			L	4	7	B	G
31A	PH3	29	RP	3	10	A	G
			WP	3	10	C	M
			WS	3	10	C	G
			L	3	10	A	G
32A	T83	1.6	WP	2	11	B	M
32B	T85	1.8	WP	2	12	C	M
33H	PH8	21	RP	2	14	A	G
			WP	2	14	B	G
			SP	2	14	B	G
			EL	2	14	A	G
			WS	2	14	C	M
34C	S02	6	WP	2	11	E	P
			WS	1	5	E	M
			DF	1	5	E	P
			L*	1	5	A	G
34D1	S02	0.5	WP	2	13	D	M
34D2	S02	1.0	WS	1	4	E	P
35J-36A,F	S02	7	WP	0	0	E	M
36A	S02	2.5	WS	0	0	E	M
36H	S07	9	WP	0	0	D	M
			RP	0	0	A	G
			NS*	0	0	E	P
37H	PH3	19	WP	1	10	B	M
			RP	1	10	A	G
			NS*	1	10	C	M
			L*	1	10	A	G
38A	PH4	12	RS	1	9	C	G
			WS	1	9	C	G
			RP	1	9	A	G
			WP	1	9	D	G
			WC	1	9	D	M
38C	T87	4	WP	0	0	E	G
			RP	0	0	B	G

has been much less successful. Two early plantings on very well drained soil (14M2, 14F1) have prospered with only 11 and 14 man-hours of weeding respectively. In six cases on well drained land, from 40 to 90 percent of the white pine has come through with 18 man-hours per acre, but hardwoods still occupy up to half the stand. In another nine cases up to 1936, white pine has largely failed despite weedings involving up to 15 man-hours per acre. If one desires to bring planted white pine through following the clearcutting of old field white pine or pine-hardwood stands, he must apparently be prepared to weed the plantation 3 to 5 times, and expend a total of 15 to 40 man-hours per acre in order to succeed.

Of the older Norway spruce plantations on cutover pine land, two (14E1 and 26M) have come through well with 11 and 27 man-hours of weeding per acre respectively; while one (14F2) has failed despite 26 man-hours of weeding. The older white spruce plantations on cutover land have been largely unsuccessful. Relatively little weeding has been done in these, only 7-8 hours per acre on the average, so little can be drawn in the way of conclusion.

Particularly in the 1930's, large areas of cutover pine land were planted to blocks of various species, red pine and larch generally being planted on the driest and most open sites, white pine in the intermediate locations, and Norway and white spruce in the lower locations. The larches have been of several species including Larix europea (European larch), L. leptolepis (Japanese larch), and L. dahurica (Siberian larch). Other species planted have included Scotch pine, Douglas fir, red spruce, and northern white cedar. In general, little weeding has been done in these plantations, the amount ranging from o to 14 man-hours per acre. The fact also that species are confounded with site makes the drawing of conclusions dangerous. Nevertheless, there can be no question but that red pine and the exotic larches are coming through in a great many instances despite the small amount of weeding. White pine is largely suppressed, but is free where weeded heavily. The spruces are mostly still in their juvenile period of slow growth, and are often suppressed. Where growing on well drained sites, however, and where weeded heavily, they will apparently make up a major portion of the new stand. Case history 37E in the appendix details the record of a typical plantation.

The final group of plantations consists of 17 stands planted following the clearcutting of transition hardwoods (Table 30). In these cases, hardwood competition, largely in the form of stump and seedling sprouts, has been excessive. A fine example of the failure of supplementary planting of even such vigorous species as red pine under these conditions is provided by plantation 22E, described in case history 22-2 in the appendix. In this instance, even 41 man-hours of weeding per acre failed to bring through an appreciable amount of the planted species. Nevertheless, the regular red pine plantations have been very largely successful when weeded repeatedly. The six best red pine plantations have required 4 or 5 weedings, totalling an average of 25 man-hours per acre. One red pine plantation given only 6 man-hours per acre of weeding has failed.

White pine has been largely unsuccessful on cutover hardwood lands. In the most successful plantation, only one-half of the present stand is now white pine despite 31 man-hours of weeding per acre. The other cases are failures, with weedings ranging up to 22 man-hours per acre. The above

Table 30

SOFTWOOD PLANTATIONS AFTER CUTTING OF TRANSITION HARDWOODS

(17 stands)

Plant. number	Comp	Acres	Species	Weedings No.	Weedings Mnhrs/A	Success	Present status
19D	PH3	0.5	NS	0	0	E	P(Hd uncut)
21G	TS4	1.1	RP	4	32	C	M
22B	TS2	0.7	RP	4	42	E	P
25G1	PH9	5	RP-NS	4	30	A	G
25G2	PH8	3	WP*-NS	5	31	C	M
25D	PH7	2.0	NL*-Hem-NS*	4	29	C	M
25G	PH2	2.6	RP-NS*	4	15	B	M
26L	PH7	11	WP-NS	6	27	D	M
26P	PH1	1.4	RP	4	19	A	G
26R	PH2	2.1	RP-NS	4	30	A	G
26S	PH8	1.8	RP	5	25	A	G
27A	PH7	3.6	NS-WP	5	22	D	M
28C	TS5	12	RP	1	3	A	G
			NL	1	3	A	G
			WP	1	3	E	P
			NS	1	3	E	M
28J	PH8	0.9	WP	2	3	E	G
29A	PH2	0.7	WP	3	13	E	G
29C	PH7	1.8	WP	2	11	E	P
30B	PH7	1.8	RP	1	6	D	M

plantations are all on well drained glacial till. One plantation (280) is on very well drained stratified drift. Here, the red pine and the European larch have done well, while the white pine and Norway spruce have failed.

From the above analysis of all softwood plantations in the study area, a fairly clear picture emerges of the extent to which planting has changed forest composition. All plantations on open and semi-open land have been successful. Red pine, Norway spruce and white spruce have been the most satisfactory species on these sites.

On cutover land, site is important. Few if any plantations on imperfectly drained land have survived hardwood competition. On excessively drained sands, only red pine, and possibly Scotch pine and European larch have proved capable of consistently taking over the area, with white pine and Norway spruce proving successful only under conditions of less extreme drought and infertility. Most of the plantations on cutover land have been put out on well drained uplands (Gloucester, Brookfield, and Charlton soils). Weeding is necessary in all instances. Red pine is the most successful species, requiring 15-16 man-hours of weeding per acre on cutover pioneer hardwood, white pine, and pine-hardwood lands, and around 25 man-hours per acre on cutover transition hardwood lands. Also successful are the exotic larches. Because European larch is almost invariably killed by porcupine girdling, however, only the Japanese larch, Siberian larch, and possibly Dunkeld larch can be brought through to maturity. White pine can be brought through only by intensive weeding. On cutover lands of all types on glacial till, probably 40 man-hours per acre distributed among 3 to 5 operations at intervals of several years are necessary to bring this species through. Less definitive information is available concerning Norway spruce and white spruce. Neither is successful on imperfectly drained soils or on very well drained soils. On well drained glacial till, both form good plantations. Their slowness in height growth during early years, however, make many weedings necessary when they are planted on cutover land. Apparently these species will require more weeding than red pine but less than white pine.

None of the other species tried can be recommended for planting in the light of present-day knowledge. These include Scotch pine, ponderosa pine, and northern white cedar. Other species such as Douglas fir, red spruce, and Asiatic spruce (*Picea shrenkiana*) have not been sufficiently tried to permit an evaluation, although the one plantation of the latter is quite promising (24H).

The most successful species in the Harvard Forest plantations have been red pine, Norway spruce, and white spruce. The first occurs naturally in Petersham in very limited numbers, being at the extreme southern end of its endemic range. The two spruces are exotics, Norway spruce being of course a European species, and white spruce extending only as far south as central Vermont and New Hampshire. Among the other exotics planted in the Forest, certain of the larches are also promising. Little can be said at this time concerning the ability of these exotics and near-exotics to reproduce naturally and to establish themselves in competition with the native species. Some red pine and apparently some white spruce have come in naturally in blowdown plantations of these species, however, and these species at least may well become naturally more abundant in the area.

Hardwood plantings

From time to time, series of small hardwood plantings have been set out in the forest. These include 45 units, of which 25 have been white ash; 5, black walnut; 4, yellow poplar; and the remainder small scale trials of Asiatic chestnuts, basswood, sugar maple, butternut, red oak, European beech, and paper birch. Practically the only successes have been a tenth-acre stand of red oak planted in 1926 in Slab City II, and a 1931 broadcast seeding of paper birch on a patch of scarified burned-over land in Prospect Hill VII. Chief causes for failure have apparently been frost damage, and deer and rabbit browsing.

Cases involving natural stands

The 66 cases involving natural stands with little or no planting of softwoods can be subdivided into (1) those in which the stand at the time of first treatment was made up of white pine or white pine and hardwoods, and (2) those in which the stand was predominantly made up of hardwoods at the beginning of treatment. Each group may further be divided into cases (A) involving intermediate cuttings only, (B) cases involving clearcutting only, (C) cases involving silvicultural treatment before but not after clearcutting, and (D) cases involving partial reproduction cuts or silvicultural treatment subsequent to clearcutting. Only the last group of stands can be said to have been intensively managed.

Cases beginning with white pine and pine-hardwood stands

Because of the extensive clearcutting of the white pine type and the destruction of much additional acreage by the hurricane, only a few stands which have received intermediate cuttings are still standing. Four of the five (26-1, 35-1, 37-2, and 40-1) represent 13 acres in which the white pine was freed from overtopping gray birch and other pioneer hardwoods on old fields. This operation involved relatively little labor, yielded low quality cordwood, and was successful in practically all instances in turning a pine-pioneer hardwood stand into a more or less pure stand of white pine. The best examples still in pine include the stands in the north end of SC V (35-1) and in the center of SC X (40-1).

In addition to stands still in white pine, at least 10 other cases represent stands in which the pine was freed from pioneer hardwoods but was later clearcut or blown down. In all, around 30 acres of pine have been successfully released.

One case history of a pine-hardwood stand that has not been completely cut is 8-2, a five-acre stand along the Pierce Road in the south-central part of PH VIII. Up to the time of the hurricane, the area was mapped as a pine-pioneer hardwood mixture. The first cutting, in 1911, was a reproduction cut. No record has been left, but the character of the subsequent stand suggests that it was the first cut of a shelterwood operation in which the hardwoods were cut and the pine left; the fact that there are no records of cordwood or sawlogs taken from the area indicates that it may well have been a student exercise in a fairly young stand. In 1927, the area supported 490 cubic feet of pine per acre and 610 cubic feet of hardwood. Ten years later, the white pine volume was 1400 cubic feet and that of hardwood 1210 cubic feet. Of the latter volume, only 45 cubic feet of red oak and 75 cubic feet of other hardwoods were considered to be of sawlog quality. The 1938 hurricane blew down the pine, and some of the hardwood. Somewhat less than 3,000 board feet of pine per acre was salvaged in 1939 and around 10 cords of hardwood was taken out in 1941. The residual stand in 1946 was 60 years old, and consisted of red oak, white pine, red maple, and white oak in an open overstory. The understory ranged up to 35 feet high, was of medium density, and consisted primarily of red maple, red oak, and white pine in that order. The case is of interest in that the 1911 cut and the 1938 blowdown may be considered as heavy partial cuts which have converted a poor quality even-aged stand of white pine and hardwoods to a two-storied stand of medium quality consisting of hardwoods and white pine.

The second group of cases involve clearcutting of pine and pine-hardwood types without either previous or subsequent treatments. The eleven cases (2-1, 6-2, 7-1, 8-9, 8-10, 8-11, 23-4, 27-2, 28-2, 35-2, and 37-1) cover 45 acres. In no case was white pine reproduced. The ensuing young growth consists largely of seedlings and seedling sprouts of red maple, red oak, gray birch, pin cherry, black cherry, aspen, paper birch, white ash, and other hardwoods. The composition of such stands has been studied in detail by McKinnon, Hyde and Cline (1935), and is similar to that found following the blowdown of white pine (Chapter 7). Undoubtedly, the clearcutting of white pine on well drained upland soils and all wetter soils leads to a transition hardwood stand which is characterized in middle age by red oak and red maple, with hemlock coming in with the passage of years.

The next group consists of white pine and pine-hardwood stands that received silvicultural treatment, and that subsequently were clearcut or blown down by the 1938 hurricane. The new stand, however, has not received any silvicultural treatment. Thirteen cases covering 42 acres fall in this group. The early treatment may have consisted in removing gray birch and other overtopping hardwoods from the pine (cases 1-1, 4-1, 8-4, 8-8, 21-8, 22-3, 22-4, 26-2, and 27-1), of thinning operations in the pine (cases 23-7, 25-5, and 26-2), or of reproduction cuttings of the shelterwood type (cases 8-3 and 34-1). In general, the new stands are similar to those that follow clearcutting only, with the exception that in several cases (including 8-8, 23-7 and 34-1) white pine will apparently make up a portion of the stand. The presence of white pine in these unweeded stands, together with the presence of volunteer white pine in several of the plantations on cutover white pine land (for instance, case 37B in appendix), leads to speculation whether white pine cannot be reproduced to a greater extent on the well drained soils than it has in the past.

The fourth and final group of white pine cases include those which have received intensive silvicultural treatment, either in the old stand having been removed by some method other than clearcutting, or the new stand having been weeded. The 12 cases, covering 48 acres, are largely confined to the southeast portion of the Tom Swamp Block and include six of the cases detailed in Bulletin 23 (Lutz and Cline, 1947). The present discussion can therefore be confined to providing information on the cases not previously published, and to making minor additions and corrections to the published cases.

All but one of these cases falls on imperfectly drained or well drained upland soil derived from glacial till. The one case on a sandy soil (3-4) is detailed in the appendix and represents an interesting confirmation of the similar cases in Tom Swamp IX to be published in Part II of the 30-year study by Lutz and Cline. Here, on a sandy knoll, ample white pine reproduction was established by what amounts to a seed tree cutting, and appears to have an excellent chance to survive with relatively little further weeding.

On the till soils, however, successful white pine reproduction has been very sparse and sporadic. In five cases totalling 20 acres and in three additional areas that had been planted, practically no white pine has come through. Case 21-1 (case 2, Bull. 23) represents the clearcutting of old field pine following a seed year (1914) on a springy slope. The pine had previously been given a low thinning in 1908-09, but the cut was not sufficiently heavy to qualify as a shelterwood cutting. Related cases involving supplemental planting are 21-2 (case 4, Bull. 23) and 21-3 (case 6, Bull. 23). Cases 21-4 (case 7, Bull. 23) and 21-7 represent a similar set of conditions, except that hardwoods in the new stand were favored from the start rather than pine. Case 22-1 (case1, Bull. 23) is on a low-lying site where pine occupied the small elevations and hardwoods the imperfectly drained swales. This forty-year old stand is the oldest stand in the Forest that has been intensively managed from its inception, even though early weedings favored pine rather than the present cover of hardwoods. Case 23-6 is listed as a plantation (26A), but the several small unplanted areas included constitute an example of the replacement of pine-hardwoods by hardwoods following clearcutting. Finally, case 23-5 records an effort to reproduce white pine by spot clearcutting that resulted in pure hardwood second growth. All but the last case represent efforts to reproduce old field white pine by clearcutting, and the failure of all is probably related to the nature of the sites which are somewhat less well drained than the average old field pine site.

In six pine and pine-hardwood cases covering 25 acres, some white pine has come in, and has been brought through by repeated weeding. All but one of these cases is in the eastern part of the Tom Swamp Block. The unplanted portion of case 24-2 (case 8, Bull. 23), and of case 24-3 (case 11, Bull. 23), case 25-1, case 25-4, and case 25-6 are all clearcuttings of white pine in which isolated clumps of white pine were brought through on the well drained upland portions, although most of the present stands consist of hardwoods. From 5 to 31 man-hours per acre were expended in weeding these stands. Two cases, 25-2 (case 9, Bull. 23), and 31-2 (case 10, Bull. 23), represent shelterwood cuttings of pine on well drained upland till. Fifteen and fourteen man-hours per acre of weeding respectively were required to bring through pure white pine clumps which today make up about one-third of the stands.

In these managed hardwood and hardwood-pine stands, considerable attention has been given to the control of the relative abundance of the various hardwood species through weedings and thinnings. This is a special and complex problem outside of the scope of the present work.

In summary, the cutting of old field white pine and pine-hardwood mixtures on imperfectly drained soils has resulted in the creation of transition hardwood stands in every case. The composition of the new stands is primarily red maple and red oak with other hardwoods, especially white ash and birches (Chapter 3). On the well drained sites, clearcutting the pine has also resulted in transition hardwood types, although small clumps of pine have been brought through by intensive weeding. Relatively little has been done with cuttings of the shelterwood type, but the isolated instances where partial cutting has been done, together with the appearance of considerable volunteer pine in several of the upland plantations on cutover pine land, leads to the feeling that the possibilities of reproducing at least some pine on the best drained upland sites have by no means been exhausted.

Cases beginning with hardwoods and hemlock-hardwoods.

As with the cases beginning with pine and pine-hardwoods, the hardwood cases may be subdivided according to the character of silvicultural treatment. The largest number of these cases are in the Prospect Hill Block. In many cases, the treatment is too recent and insufficiently controlled to permit any accurate judgement of the effects of silviculture on composition.

Of particular interest are the ten stands covering 75 acres which have received intermediate cuttings only. Case histories of three (2-2, 3-3, and 21-5) are included in the appendix. In one case (28-1), only a light thinning was made, but in the others heavy improvement cuttings were the rule. Whereas the stands at the beginning of treatment were mostly characterized by gray birch and other pioneer species, now red oak and red maple are predominant, with a hemlock understory becoming increasingly prominent in several instances.

The present average composition is well indicated by Table 7, which is in part based upon 7 sample plots in these stands. In cases 1-2, 1-5, and 8-5, grouped together along the Prospect Hill I-VIII road, scattered spots were clearcut in early years, but the largest portion of the area was given a heavy improvement cutting in 1936 to reduce the amount of red maple and to eliminate diseased and poorly formed hardwoods. Apparently the aim was achieved as only 23 percent of the basal area on the two permanent sample plots (44-8, plots 2 and 25) is today red maple. Sixty-seven percent is red oak, the two making up 90 percent of the stand. These cases and the ones in the appendix are typical of the others (7-2, 3-5, and 26-3) in which intermediate cuttings have hastened the elimination of pioneer hardwoods, increased the predominance of red oak and red maple, and hastened the introduction of hemlock. Stand 7-2, along the Pierce Road, is illustrated in Figure 29.

Figure 29. CASE 7-2 ALONG PIERCE ROAD, PROSPECT HILL VII

The clearcutting of hardwood types (cases 1-4, 2-3, 4-2, 6-1, 8-7, 21-6, and 25-3) has produced 43 acres of even-aged sprout hardwood stands of poor quality with red maple and red oak the predominant species. Most of the new stands are still young, but sample plots in two of the older stands provide an idea of composition on the wetter sites. Plot 19 in experiment 44-8 (case 6-1) represents a measurement at 31 years of a stand on imperfectly drained soil following the clearcutting of pure red maple coppice in 1913. In 1944, 50 percent of the basal area was again red maple, but 17 percent was yellow birch, 15 percent was paper birch, 11 percent was red oak, and 15 percent was black birch. Plot 27 in the same series (case 8-7) represents another measurement of a young stand following the clearcutting of red maple on imperfectly drained soil. After 22 years, red maple made up only 42 percent of the basal area, with black cherry accounting for 30 percent, red oak accounting for 19 percent, and paper birch accounting for 6 percent. In both these cases, red maple is relatively less important in the present stand than in the previous one.

Seven cases, covering 17 acres, involve at least some extensive silviculture. Most of these stands received at least some treatment before the harvest cutting or blowdown, but none thereafter (cases 1-3, 3-1, 23-3, 24-4, 40-2). The present stands, dating from the hurricane, are typical of the sprout hardwood growth on blowdown hardwood land (Chapter 7) with the exception of case 40-2. Here, chestnut was salvaged in 1919, leaving occasional large hardwoods, the young growth was weeded in 1927 to free white pine from seedling birch and sprouts, and most of the residuals blew down in 1938. The present stand consists of a scattered overstory of red oak over a released understory in which hemlock predominates. The effect of the partial cuttings and blowdown has been to increase the hemlock in the young stand at the expense of the hardwoods.

In addition to the above 5 cases, two instances of extensive silviculture involve heavy reproduction cuts. Case 32-1 records a coppice with standards cutting in 1911 on a poorly drained site, red maple, white pine, black cherry, and red oak stems being left. The cherry and pine have since dropped out of the stand, leaving a moderately stocked stand of red maple, red oak and yellow birch 50 feet high. Case 38-1 records the results of a heavy chestnut salvage cutting on a well drained site in 1921, leaving five cords per acre of hardwoods other than chestnut, ranging in diameter from 5 to 8 inches. In the present stand, red oak, red maple, and black birch are predominant with lesser quantities of yellow birch, white oak, hemlock, black cherry, and white pine being present.

Of the five cases covering 13 acres and involving intensive silvicultural treatment of hardwood stands originating after the cutting of hardwood, two are detailed in Bulletin 23 and one is included in the appendix. Case 8-1 (see appendix and Figure 30) started out as a pine-hardwood stand. At 45 years of age, the entire stand was cut except for scattered red oak and white oak seed trees. Abundant chestnut reproduction was killed by the blight, and the seed trees were cut in 1930. The present stand is predominantly red oak with beech; white pine, and white oak being the principal minor species. The understory of hemlock, red oak, and tolerant hardwoods, however, presages the development of a hemlock-hardwood association in the absence of clearcutting.

Case 23-1 (Bull. 23, case 14) provides the only example of shelterwood cutting in hardwoods. About 50 percent of the dominant stand was cut in 1912, taking the largest hardwoods. At that time, red maple was the predominant

Figure 30. CASE S-1 ALONG LOCUST OPENING ROAD

species on the imperfectly drained portion with red oak, chestnut, white ash, and white oak also being common on the better drained portions. The final cutting in the 60-70 year old stand was made in 1916-17, and the young growth has subsequently been treated three times, producing a high quality mixed hardwood stand in which red maple is but a minor species. Case 22-2 is listed also as a plantation (22M) because of the extensive supplemental planting of red pine, but it can also be included in this group (see case history in appendix). Case 24-1 (Bull. 23, case 13) provides another example of the excellent composition and quality of hardwoods obtained by weeding the young stand after the cutting of the prior stand of hardwoods. The remaining cases (8-6 and 23-2) provide similar evidence but on a less intensive scale. In these, the proportion of red maple has been reduced somewhat by weeding, while the proportion of red oak, paper birch, yellow birch and other more desirable species has been increased.

The general effect of silviculture in hardwood stands has been to decrease the proportion of pioneer species and red maple in the stand, to increase the proportion of red oak, and to encourage a vigorous hemlock understory. These changes, it should be noted, are precisely the same as are to be expected through natural successional development (Chapter 3). Silviculture in most cases has merely hastened natural trends.

Chapter 7

NATURAL RESTOCKING FOLLOWING THE 1938 HURRICANE

Of all the factors, natural and anthropeic, affecting the present-day composition of the Harvard Forest, wind has had the most obvious effect. Stand composition changes between 1938 and 1947 as detailed in chapter 2 are largely attributable to the effects of the hurricane of September 21, 1938, although silvicultural operations during this period also had their impact. The hurricane created conditions which greatly changed silvicultural policy, actual cutting operations, and the type and amount of forest products harvested (chapter 6). In the present chapter, attention is directed not to the residual stands, but rather to the natural restocking on blowdown areas. A detailed consideration is justified practically by the large acreage involved, not only in the Harvard Forest, but throughout New England as a whole; and scientifically by the opportunity to learn on these areas something of the effects of blowdown on the composition of the subsequent forest stands.

Damage and salvage

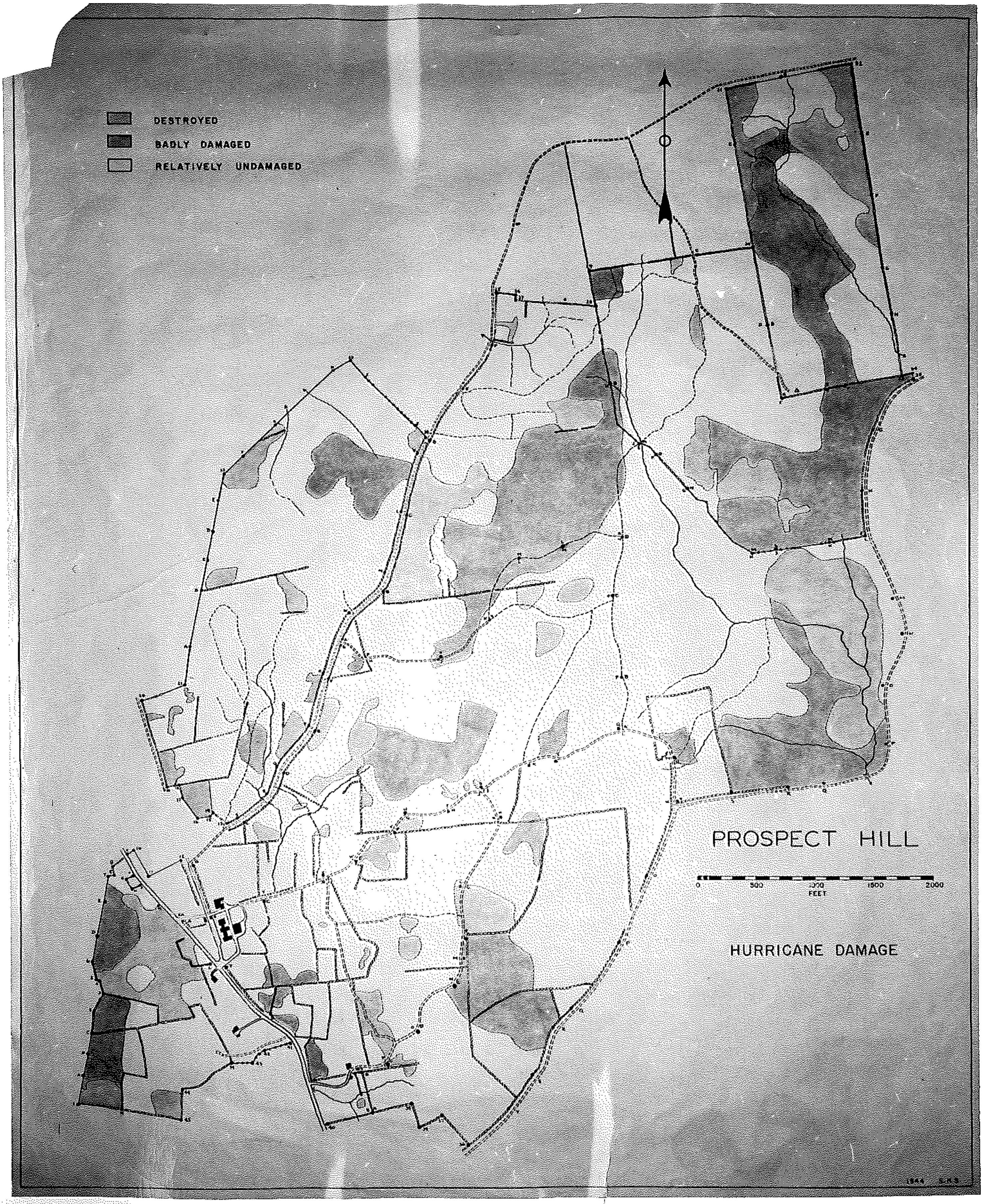
The New England hurricane of September 21, 1938 was one of the most destructive storms in the history of the United States. Considering the damage to the forests alone, nearly three billion feet of timber was blown down on more than six hundred thousand acres of forest land. Damage was severe throughout New England except in Maine and a narrow strip along the New York state line. In the white pine - hardwood region alone, nearly one-half by volume of the total softwood timber stand was destroyed (Baldwin, 1942).

In the Harvard Forest, at least two-thirds of the merchantable saw-timber was uprooted or left as broken snags. According to Rowlands (1939), more than half the timber was blown down on 43 percent of the area of the Harvard Forest. Of the stands more than 40 years old, 93 percent of the softwoods were blown down, together with 57 percent of the mixed wood stands and 38 percent of the hardwood stands. On the other hand, few of the younger stands of timber were seriously damaged (Figure 31).

Throughout the region, salvage operations were started immediately following the storm. The New England Timber Salvage Administration was established by the Federal Government to promote logging operations and purchase logs. By the end of 1942, this agency had handled about 700 million board feet. During the same period, some 90 million feet were salvaged on the White Mountain National Forest and nearly 600 million feet were cut by private agencies throughout the region (Baldwin, 1942). The war accelerated salvage operations somewhat, but also caused many mill operators to seek stands more profitable to operate, thus resulting in ever greater forest depletion.

In addition to the salvage operations, considerable clean-up work was done, principally to reduce the fire hazard. The New England Forest Emergency Project supervised slash disposal, fire lane construction and other hazard

Figure 31. HURRICANE DAMAGE, PROSPECT HILL BLOCK



reduction work on over 200,000 acres, while private owners cleaned up more than 100,000 additional acres.

Relatively little research has been carried out on the effects of the hurricane on the forests. Curtis (1943) published some observations on susceptibility to wind damage. Bess (1944) investigated insect damage following the storm and concluded that practically no standing trees were killed by bark beetles. Cline (1939) and the Committee on Silviculture of the New England Section, Society of American Foresters (1941) recommended that reliance be placed on natural reproduction for the restocking of blowdown areas, but the recommendation was made in advance of the appearance of the results of natural restocking surveys.

Previous restocking surveys

A small number of surveys have been carried out to obtain information on the rehabilitation of hurricane-damaged forest areas by natural restocking.

Cheston (1940) studied natural regeneration on the Keene (New Hampshire) and Union (Connecticut) forests of the Yale School of Forestry one year after the hurricane. He found that from 24 to 32 percent of the heavily damaged areas studied were covered by slash, a smaller percent of the area being unstocked, and the remainder restocked about equally with desirable and inferior species.

Natural regeneration on white pine lands in the Fox Research Forest at Hillsboro, New Hampshire was studied by Baldwin (1940), two years after the hurricane. Although he found an average of 16,000 stems per acre on blowdown areas, only one-half consisted of valuable species; and these were highly irregular in their distribution, areas up to one-half acre in size being virtually devoid of valuable stems. Baldwin's 61 milacre plots were divided between three soil types, and differences in composition between these soil types were apparent. White pine was found to be much more abundant on the sandy Danby soil than on the heavier Hermon and Canaan soils. Red oak, sugar maple, and gray birch, all important on the heavier till soils, were completely lacking on the Danby soil. Paper birch was apparently more abundant on the shallow Canaan soil than on the deep, but otherwise similar Hermon type.

In 1941, after two growing seasons had passed since the hurricane, Brake and Post studied the restocking on 137 former old field white pine areas in north-central Massachusetts. They concluded that, on the better sites, sufficient volunteer reproduction of the better elements was present in most cases to make possible the development of well-stocked timber stands of good quality. On the poorer sites, reproduction was much less adequate. They found that 98 percent of the better sites had more than 500 desirable stems per acre while 88 percent had more than 1000 stems. On the average sites, 93 percent had more than 500 stems, and 77 percent more than 1000 stems. On the poorest sites, however, 84 percent had more than 500 stems, while only 42 percent had more than 1000 stems per acre.

An intensive study of the natural restocking on one compartment (Tom Swamp III) of the Harvard Forest was undertaken by Larson, Yoder, Gill, and Praher in 1942 under the direction of H. J. Lutz and the writer. Twenty-three stands were included in this study, representing four principal soil types and several former cover types. Adequate restocking was found on all but the wettest areas.

Information on the composition of the young post-hurricane stands derived from the original data of Brake and Fost (1941) and Larson et al. (1942) has been included in chapter 4. The present discussion is largely based upon original plot data collected by the writer since 1942 in the Harvard Forest. Included are data from fourteen permanent sample plots established in the Forest in 1940 by J. W. Johnston, Jr., and subsequently remeasured at intervals by the author and others of the Harvard Forest staff.

Survey methods

In the series of restocking surveys carried on in the Harvard Forest, survey methods were modified from time to time. The resultant variations in methods involve primarily different sampling techniques, measurement of stocking, and site classifications. It was also necessary to lay down certain arbitrary rules; for instance, to distinguish between valuable and inferior stems, and between adequately restocking and non-restocking areas.

Variations in sampling techniques adopted were in the size and spacing of the plots.

To follow volunteer stands over a period of years, sample plots one-tenth or one-fortieth acre in size were established, one to each stand. Although these give a clearly inadequate measure of the restocking over the entire stand, they do provide a good picture of the changes from year to year.

In the measurement of current restocking, reliance was placed on mil-acre plots or quadrats, 6.6 feet square. In the earlier surveys, these plots were located systematically, 20 to 50 on each area depending upon its size. Later, a continuous strip of 50 mil-acre plots was run, starting at a point chosen at random, and running at right angles to main topographic features. While this single strip technique did not cover the area as well as mechanically-spaced plots, and consequently gave a less accurate picture of the particular area, it did save a great deal of time, and permitted the studying of many more tracts.

Measurement of stocking

The amount and adequacy of natural reproduction can be measured either in terms of abundance (stems per acre), or frequency (percent of quadrats stocked). In the earlier studies, the numbers of stems per acre was determined for each species and for each type of origin (seedlings, stump sprouts, seedling sprouts, or root suckers). These abundance values give a good record of stand condition, but have two drawbacks. First, every stem on the mil-acre plots must be counted and tallied, often an extremely arduous task. Then, despite the great amount of work involved, no measure is obtained of the distribution of the reproduction over the area. Abundance values may be quite accurate, but yet give no information as to whether the stems are distributed throughout the stand, or densely concentrated in a small area.

To overcome these difficulties, frequency rather than abundance has been increasingly used in restocking surveys (Lowdermilk, 1927; Haig, 1929, 1931). The term frequency (also frequency percent or frequency index) refers to the number of quadrats that are stocked with a given species or group of species. The unit of restocking, then, is the quadrat rather then tree, and frequency value will be affected by the size of the quadrat adopted. The mil-acre quadrat was used in the present studies because it is convenient to use in the field, and to handle in the computations. Furthermore, a spacing of 6.6 feet approximates that of the normal forest plantation. A stand restocked with a frequency of 100 will have at least 1000 well-spaced stems per acre and would be considered fully-stocked by most standards.

In order to compare the results obtained by the two measures of stocking, 540 mil-acre plots were tallied in a total of 20 stands in one compartment (Tom Swamp III) in such a way that data could be worked up in terms of both frequency and abundance. Table 31 shows the average frequency and abundance of the seedlings of each species in all twenty stands. The two measures yielded similar results, but certain differences are apparent. For instance, there are more than twice as many yellow birch seedlings as white ash on the area (abundance), but the ash are more widely distributed (frequency). An examination of the data reveals that the yellow birch are concentrated in the lower, moister sites.

Similar comparisons are afforded by the tables in Chapter 4 dealing with post-hurricane regeneration on various soil types and aspects. The same basic material has been worked up on both a frequency and abundance basis, the two measures yielding results comparable in general but differing in detail.

Both frequency and abundance, then, are valuable measures of stocking. Frequency values, however, are easier to obtain and give a measure of the distribution of trees over an area that is not obtainable from abundance values alone.

Table 31

FREQUENCY AND ABUNDANCE OF SEEDLINGS
BY SPECIES IN TOM SWAMP III, 1942

Species	Frequency	Abundance Stems/Acre
Red maple	43.2	1392
Black cherry	30.4	647
Red oak	29.2	489
White pine	27.1	679
White ash	19.4	346
Yellow birch	17.6	753
Pin cherry	15.4	420
Black birch	14.4	303
Gray birch	13.0	390
Paper birch	6.8	118
Sugar maple	4.8	51
Aspen	1.6	19
Others	6.8	74
All species	85.9	5675

Valuable and inferior stems

In order to determine whether or not an area is satisfactorily restocking, stems that will produce merchantable trees must be distinguished from those that will not. This distinction between valuable and inferior stand elements is arbitrary at best, but has proved reasonably satisfactory in practice.

The most important basis of distinction is species. Valuable species include all that are more or less long-lived and will ordinarily produce sawlogs, regardless of the present relative market value of the sawlogs. The short-lived species are generally considered inferior. These include aspen, gray birch, pin cherry, chestnut (killed early by the blight), striped maple, and shadbush. The latter three species were ordinarily not tallied. The short-lived species are largely pioneer in character and of seedling origin (Table 32).

For the material presented in the present chapter, the distinction between long-lived and short-lived species is primarily employed. Valuable and inferior elements may, however, also be separated on the basis of origin. Seedlings and single-stemmed seedling sprouts will ordinarily produce merchantable trees if of a long-lived species. A seedling sprout is defined as one originating from a low stump less than two inches in diameter. Under these conditions, the chances are good that the sprout will take over all or most of the existing root system, and that rot will not soon develop in the new sprout. Undesirable growth forms include multiple-stemmed seedling sprouts, stump sprouts, and root suckers.

Furthermore, a valuable element must be well-formed. Broken or deformed stems, diseased stems, or stems heavily attacked by insects are obviously inferior.

Table 32

RELATIVE ABUNDANCE OF GROWTH FORMS
OF SHORT-LIVED SPECIES, 1941

Growth form	Gray birch	Pin cherry	Aspen
	Number per acre		
Seedlings	2160	902	73
Seedling sprouts	18	43	36
Stump sprouts	6	2	—
Epicormic sprouts (Stem suckers)	4	9	3
Total	2188	956	112

A valuable stem or element may therefore be defined as a well-formed seedling or single-stemmed seedling sprout of a long-lived species. Conversely, inferior stems or elements include all poorly formed stems, and stems of undesirable origin, as well as all stems of short-lived species irrespective of form or origin.

Adequacy of restocking

Finally, an arbitrary decision is needed as to what constitutes adequate restocking. Such a standard is hardly necessary in a purely scientific discussion of the effect of the hurricane upon stand composition, but is highly desirable on silvicultural grounds. From a practical standpoint, the concept of adequacy of stocking provides a basis for determining whether or not planting sould be undertaken, and an insight into the future character and value of the stand.

On a frequency basis, 100 percent indicates full stocking, but this value is seldom attained. If 90 percent of the mil-acre plots are occupied, the stand may be considered well-stocked, and if 80 percent are filled, the stand may be considered adequately stocked.

As regards abundance, 1000 tree stems would certainly constitute adequate stocking if evenly distributed over the area. From Table 31, however, it can be seen that the 1392 red maple stems had a frequency of only 43.2 percent and that the total stocking of 5675 stems represented a frequency of only 85.9. To insure adequate stocking, therefore at least 5,000 stems per acre should be present in stands in the restocking stage.

The standards suggested are arbitrary and cannot be completely satisfactory. In the last analysis, adequate stocking can be determined only when both the frequency and abundance of the valuable stand elements are known. Furthermore, reasonable assurance must be had that the amount and distribution of new growth is sufficient that a fully stocked sapling stand will develop despite the normal losses from insects, diseases, and competition. In the absence of more complete information, however, the standards given above, being based on extensive field experience in the central New England transition hardwood and white pine forests, should at least provide a tentative basis for evaluation and action.

<u>The problem of significant variables</u>

So many variables affect natural regeneration that no one study can hope to encompass all of even the most significant variables. Yet at the same time, an arbitrary choice of a single "limiting factor" is exceedingly dangerous and apt to lead to inaccurate conclusions. The only course is in a limited study such as this is to narrow down the field to a few of what appear to be the most significant variables, recognizing at the same time that the variables chosen are not the sole ones of importance, that they cannot account for all the observed variation, and that the effects of the several variables are not clearly separable (Allen, 1929).

The relation between soil and natural restocking after the hurricane has already been discussed in Chapter 4, and will be amplified somewhat below. Another factor of obvious importance is the nature of the previous stand, and this will be the basis for sorting the data in the present chapter. Finally, the character of the blowdown area itself cannot be ignored, particularly the presence of residual trees and advance growth, whether the area was logged or not, and the size of the blowdown.

Effect of previous stand on post-hurricane regeneration

Of the various forest types, white pine growing on old farmland proved among the most susceptible to windthrow, and consequently a high percentage of the blowdown types have old field white pine as their predecessor. The information on post-hurricane regeneration in Chapter 4 refers to young stands following old field pine. So also do six permanent sample plots in the Harvard Forest (Exp. 40-1, plots A, F, G, H, I, J) which have been measured in 1940, 1941, 1942, 1944, and 1948 (Table 33). These plots are all located on well drained glacial till, four being in the Tom Swamp Block and one in each of the other blocks. Although short-lived species such as black cherry (largely eradicated in early years by tent caterpillar defoliation and suppression), pin cherry, gray birch, and aspen make up one-third of the present stand, considerable numbers of long-lived species also occur. Perhaps the most notable feature is that, except for the seedling white pine, paper birch, and gray birch which largely became established in 1941, there has been little change in the restocking since the plots were established. In other words, the restocking ten years after the hurricane is very largely made up of the plants present in the understory at the time of the hurricane plus pioneer species that became established shortly after the hurricane.

Of the long-lived species present today, there is every reason to believe that red maple and red oak will continue to make up the dominant stand. The white pine is largely suppressed by the hardwood growth and may be expected

Table 33

NATURAL RESTOCKING ON PERMANENT SAMPLE PLOTS

1. FOLLOWING OLD FIELD WHITE PINE ON GLACIAL TILL

6 Plots

Species	Abundance (stems per acre) 1940	1941	1942	1944	1948
Long-lived trees					
Red maple	1470	2000	1590	2160	1280
White ash	790	890	770	980	890
White pine	—	260	240	470	390
Red & black oak	320	520	400	370	320
Paper birch	—	290	260	220	200
Black & yellow birch	130	40	120	160	200
White oak	70	60	110	80	90
Sugar maple	30	10	10	10	20
Others (Hem, Hick, Basswd)	—	—	10	10	10
TOTAL	2810	4070	3510	4460	3400
Short-lived trees					
Cherry	3300	2500	1100	1800	980
Gray birch	100	590	400	320	490
Aspen	250	290	190	270	240
TOTAL	3650	3380	1690	2390	1710
TOTAL	6460	7450	5200	6850	5110

Plots A (PRIV), F (TSV), G (TSVI), H (TSI), I(TSI), J(SCII) to largely disappear. The white ash, paper birch, black birch, and yellow birch cannot compete overly well with the aggressive oak and maple and should become less important as the years go by. In other words, the post-hurricane stands following old field pine will evolve into a red oak and red maple association with lesser quantities of white ash and the birches, -- this being the same association that is known to follow the clearcutting of old field pine and that is described as the transitional type on well-drained soils in Chapter 3.

Confirmatory information on a frequency basis is provided by data from six small blowdown areas in the southeast corner of the Tom Swamp Block, considered by some as representing the best sites in the Forest (Table 34). Again it may be seen that a red oak - red maple association is the result of the blowdown of old field white pine on well drained glacial till. In this case, white ash and black birch will apparently be the chief secondary species as the gray birch is short-lived and the black cherry and white pine cannot be expected to survive in any number.

In contrast to the above cases where the hardwood advance growth under the previous pine stand accounts in large measure for the present stand are cases where immature pine stands were blown down at a time when their density was still great enough to prevent the establishment of an understory. The example in Table 35, a 28-year-old dense white pine plantation, is typical. Here, little has become established since the hurricane except pioneer species such as pin cherry and white pine, the latter having come in after the former. With no advance growth from the previous stand, the restocking is inadequate even after ten years. This is true not only for

Table 34

FREQUENCY OF RESTOCKING UNDER FAVORABLE CONDITIONS
TOM SWAMP I AND II, 1942

Species	Seedlings	Seedling sprouts	Stump sprouts	All elements
Red oak	31	11	—	41
Red maple	27	13	5	38
White ash	11	13	1	24
Gray birch	21	—	x	21
Black cherry	18	2	—	19
Black birch	12	1	1	14
White pine	12	—	—	12
White oak	6	3	x	8
Yellow birch	5	3	—	7
Sugar maple	3	2	x	6
Paper birch	5	—	—	5
Aspen	3	—	—	3
Basswood	1	1	—	2

Based upon 300 mil-acre plots in 6 small blowdown areas.

x indicates species present but at frequency less than 0.5 percent.

Species not listed but occurring at low frequency include beech, hickory, black oak, hemlock, red spruce, and large-toothed aspen.

Table 35

NATURAL RESTOCKING OF PERMANENT SAMPLE PLOTS
2. FOLLOWING IMMATURE WHITE PINE PLANTATION
ON OLD FIELDS ON GLACIAL TILL

1 Plot

Species	Abundance (stems per acre) 1940	1941	1942	1944	1948
Long-lived species					
White pine	—	80	—	—	520
Red maple	80	40	120	120	240
Red oak	40	80	40	40	40
Paper birch	—	—	160	40	—
Black birch	—	—	—	—	40
Total	120	200	320	200	840
Short-lived species					
Pin cherry	9840	5560	16800	11760	8880
Gray birch	—	120	200	200	280
Black cherry	—	—	40	80	—
Total	9840	5680	17040	12040	9160
Total	9960	5880	17360	12240	10000

Plot B (PHI)

the case cited (Plot 10), but for all similar instances of the blowdown of dense pine plantations and other stands where no advance growth was present.

Hardwood stands were generally more resistant to hurricane damage than softwood or mixed wood stands, and only one permanent plot was established following the blowdown of hardwoods (Table 36). Red maple, white pine, and the birches are the most abundant species. Again, however, the pine is largely suppressed even at the present stage of development. Red oak and hemlock, though not as abundant, are represented by large vigorous stems and should prove to be more important than indicated by abundance values.

A better sample is available for hurricane blowdown areas following old growth white pine and hemlock stands on glacio-fluvial sand (Table 37). Of the five plots, one is at the Boulder Site in Tom Swamp IV (Plot E), two are located in the old Barre Woods along the Swift River in the Slab City Block (Plots K and L), and one is located in Tom Swamp IX (Plot C). On the latter plot, which represents the driest site, little restocking of any kind has become established, but the average of the five shows good restocking of white pine, with a scattering of various hardwoods. Obviously the restocking on the excessively-drained sands is much less adequate than on glacial till. Equally important, however, is the apparent fact that white pine is successfully restablishing itself on these "natural white pine soils", while the hardwoods are few in number and not particularly vigorous.

A final case deals with natural reproduction in a selectively cut white pine on sandy soil after the residual stand was blown down by the

Table 36

NATURAL RESTOCKING ON PERMANENT SAMPLE PLOTS
3. FOLLOWING HARDWOODS ON GLACIAL TILL

1 Plot

Species	Abundance (Stems per acre) 1940	1941	1942	1944	1948
Long-lived species					
Paper, black, & yellow birch	320	3160*	1450	480	1340
White pine	240	1360	950	1000	760
Red maple	1200	1320	925	500	580
Hickory	80	—	75	—	360
White ash	120	40	50	100	110
Red and black oak	320	80	250	260	100
Hemlock	80	80	175	100	90
White oak	40	—	25	180	80
Sugar maple	40	40	275	180	80
Total	2440	6080	4175	2800	3500
Short-lived species					
Gray birch	—	—	2375	960	600
Pin cherry	560	520	100	260	200
Black cherry	—	40	200	40	160
Aspen	—	—	—	20	—
Total	560	560	2675	1280	960
Total	3000	6640	6850	4080	4460

*Undoubtedly includes gray birch

Plot D (TSIV)

Table 37

NATURAL RESTOCKING ON PERMANENT SAMPLE PLOTS
4. FOLLOWING OLD GROWTH WHITE PINE AND HEMLOCK
ON GLACIAL STRATIFIED DRIFT

5 Plots

Species	Abundance (stems per acre)				
	1940	1941	1942	1944	1948
Long-lived species					
White pine	580	670	650	860	570
Red maple	260	290	160	200	170
Paper birch	—	20	150	20	100
Red oak	70	80	140	170	90
White ash	30	110	60	50	50
Hickory	—	20	40	20	40
White oak	10	20	30	40	30
Hemlock	20	20	—	10	10
Basswood	20	20	10	20	10
Sugar maple	20	10	—	—	10
Black birch	30	—	10	—	X
Yellow birch	—	X	10	10	X
Beech	30	20	10	10	X
Elm	—	X	10	—	X
Total	1090	1280	1280	1410	1080
Short-lived species					
Pin cherry	610	840	860	900	420
Gray birch	40	310	300	340	310
Black cherry	50	130	100	210	90
Aspen	10	90	80	70	40
Total	710	1360	1340	1520	860
Total	1800	2640	2620	2930	1940

X indicates species is present with frequency less than 5 percent

Plots G(TSIX), N (TSIV), K (SCIV), L (SC IV), H (TS IX) hurricane (Table 38, Plot N). Here the composition is similar to that in the above cases, except that the white pine and other species are more abundant. The year by year tally, however, indicates strongly that the present stand was established under the overstory prior to the hurricane, and that it has changed little since 1938.

In general, it would appear that the young stands following the hurricane are generally comparable with the pioneer stands on cutover land described in Chapter 3, and that they will in time grade into close equivalents of the described transitional associations. On glacial till, a red oak - red maple association is arising with such minor components as are characteristic to the soil drainage and the locality; on stratified sands a white pine - red oak - red maple stand seems to be the rule.

Character of the blowdown area

The above data, sorted though it is by the character of the previous stand, serves to point out the great importance of residual trees and advance growth in forming the new stand. Much of the present stand on blowdown areas is derived from advance growth under the old stand. Where there was no advance growth, present restocking is completely inadequate and the areas could well have been planted. In other words, it appears that the blowdown areas did not provide sites favorable to the establishment of new growth. Only pioneer species such as pin cherry and gray birch were able to invade these areas in any number. Even white pine could not establish itself in any great number in blowdown sites on sandy soils, and has come in on the glacial till soils only after hardwoods have developed.

Table 38

NATURAL RESTOCKING ON PERMANENT SAMPLE PLOTS
5. FOLLOWING SELECTIVELY CUT WHITE PINE
ON GLACIAL UNSTRATIFIED DRIFT

1 Plot

Species	Abundance (Stems per acre) 1940	1941	1942	1944	1948
Long-lived species					
White pine	1320	2720	1520	1380	1650
Red maple	1040	1560	1900	1580	1130
Red oak	560	320	400	500	500
White oak	—	80	—	120	140
Hemlock	80	40	140	60	70
Paper birch	—	40	—	20	20
Black birch	280	—	—	—	10
Beech	—	—	—	20	—
Total	3280	4760	3960	3680	3520
Short-lived species					
Gray birch	80	320	260	160	230
Black and pin cherry	40	280	120	280	170
Aspen	40	—	20	40	60
Total	160	600	400	480	460
Total	3440	5360	4360	4160	3980

Plot H (Ts IX)

Since the new stand is largely evolved from advance growth and residuals, the size of the blowdown and the propinquity of seed supply does not appear to be particularly important in determining the character of the restocking. Actually, most of the blowdown areas are confined to a few acres in size as the pre-existing stands were comparably small and as the hurricane frequently tended to blow down patches of trees rather than everything. Even where large timber occupied large areas, however, and was completely blown down, the character of the new growth does not appear to be different from that in the typical small opening.

All the tracts considered in the above survey were logged after the hurricane. They may therefore be considered as cutover areas as well as blowdown areas, and it is not therefore surprising that the restocking on them is similar to that found on areas of standing timber cutover before and since the hurricane. A restocking survey of the Pisgah tract is thus of considerable interest in that it throws light upon post-hurricane regeneration in the absence of log salvage.

The Pisgah tract is a twenty-acre stand of primeval forest in Winchester, New Hampshire owned by the University. It is one of a number of stands in that locality which have been studied intensively (Cline and Spurr, 1942), and was completely blown down in 1938. No logging was done, however, on the argument that the windthrow was a natural disturbance and that the prostrate stand was in every sense as much of a virgin forest as the pre-existing old growth white pine and hemlock.

In the summer of 1942, four growing seasons after the hurricane, a transect was run from the top of the ridge dominating the east portion of the tract southwest across the topography to the end of the blowdown timber. Seventy mil-acre plots were tallied by the stocked-quadrat method.

Conditions following blowdown on this virgin timber tract differed very greatly from those on second growth areas. The tangled blowdown of heavy timber (largely hemlock and white pine) was four to ten feet thick over most of the area. Under this criss-cross of logs, the soil was moist and relatively undisturbed except around the uprooted stumps. The boles of the fallen trees covered over 30 percent of the area, and inasmuch as most of these were suspended several feet from the ground, they affected practically all of the surface. Mineral soil was exposed in stump pits on about 8 percent of the area. Rock outcrops, either naked or covered by a thin organic layer, were prominent on another 15 percent of the transect. Wet Whitman soil covered somewhat less than 5 percent of the area, the remainder being a shallow phase of Hermon (the podzol equivalent of Gloucester).

The tree reproduction differed as between high slopes and low slopes (Table 39). On the high slopes (26 plots), seedlings of paper birch, red maple, black cherry and black birch predominated. Little advance growth of any kind had persisted. The stand on the low slopes (44 plots), however, was dominated by hemlock and beech advance growth. Seedlings of other species were present but most seemed likely to be soon overtopped. Yellow birch occurred instead of the black birch of the high slopes.

The beech recorded was all advance growth except for one seedling. About sixty percent of the hemlock consisted of advance growth, most of this occurring on low slopes. The advance growth ranged up to 10 and 15 feet in height and much of it had persisted for many years under the old

Table 39

FREQUENCY OF RESTOCKING ON THE PISGAH TRACT, 1942

Species	High slopes	Low slopes	Total
Species most frequent on high slopes			
Paper birch	69	48	56
Red maple	42	23	30
Black cherry	42	16	26
Black birch	46	7	21
Species most frequent on low slopes			
Hemlock	35	55	47
Beech	12	27	21
Yellow birch	4	16	11
Infrequent species			
Red oak			3
White pine			2
Red spruce			1
Grey birch			1
Total	94	94	94

stand. Hemlock seedlings were equally as common on high as on low slopes. The other trees present consisted almost entirely of seedlings which had germinated since the hurricane. Paper birch dominated areas of exposed mineral soil although black birch and black cherry also occurred there. Noticable was the absence of pin cherry, aspen, and gray birch.

In this case where no logging followed the blowdown of old growth pine and hemlock, the following stand represents essentially a later successional stage than the preceding one, being characterized by hemlock and beech. In other words, the blowdown accelerated rather than set back successional development by felling the overstory and releasing the tolerant understory.

Summary

Studies of natural regeneration in and around the Harvard Forest since the hurricane of September 21, 1938 have yielded much information about successional trends on hurricane blowdown areas. Many factors apparently affected the composition of the new stand on a given area, prominent among them being the composition of the former stand, growth present at the time of blowdown, soil type, and the occurrence of logging or fire after the blowdown. Where ample advance growth was present and no logging was carried out, the new stand is essentially a late-successional association. Where advance growth is present but logging has been carried out, the composition of the regeneration is transitional in successional relationship. Where little or no advance growth occurred, or where subsequent fire or logging destroyed growth, pioneer associations have resulted. In practically every case, the character of the new stand was apparent within only two growing seasons after the hurricane. The absence of later successful invasion of seedlings is attributable in part to the competition from growth already established, and in part to unfavorable environmental conditions in the blowdown areas. A silvicultural lesson may be drawn from these findings. The silviculturist should apparently depend largely upon advance growth rather than upon subsequent seeding, even in central New England where growing conditions are generally favorable.

Chapter 8
SUMMARY

Forty years of recorded stand history in the Harvard Forest, Petersham, Massachusetts, provide an opportunity to evaluate the influence of site and forest management on stand composition. Changes in composition are recorded by stand maps prepared at intervals through this period. Present-day information is obtainable from the detailed stand maps prepared in part from modern infrared aerial photographs. The Harvard Forest records together with original experimental work provide the needed information on site and forest management factors.

The important forest trees in central New England have grown here for at least five thousand years, despite major climatic fluctuations during that period. It is apparently safe, then, to deal with the major trends in forest composition in the Harvard Forest purely on a present-day basis. The major species have long been established and should be able to compete and adjust themselves under almost any foreseeable climate in the next few centuries. If the present trend toward warmer conditions continues, trees having the more southerly ranges may be expected to increase slightly in abundance. On the other hand, if the present trend is reversed, and the much longer trend toward increasing cold is reestablished, the opposite will occur. In any event, the present major species will be the major species for several centuries.

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The virgin forests of central New England were made up of the same species that are common today, and were highly variable due to variations in site and catastrophic history. We have good reason to believe that white pine was an abundant species only on sandy and gravelly soils and on exposed ridgetops, but that it occurred either singly or in groups throughout the rest of the forest. The upland forests of the Petersham area were largely oak, chestnut and hickory — indicating if anything a somewhat milder and drier climate than exists today as hickory is no longer a common genus and in fact is not distant from its northern limits in the Petersham area. Red maple was also undoubtedly abundant and widespread. The position of hemlock in the virgin forest is not clear. Although theoretically an important component in the climax forest, its distribution was possibly restricted to ravines and other protected sites by fire.

Since the settlement of the town in 1733, the land has been cloaked with four different vegetations, — the virgin forest, the flora of pasture and mowing land, old field white pine, and transition hardwoods. One of these vegetations was agricultural and three predominantly forest. Each has differed widely in composition, form, and structure. Not only has the forest cover changed, but the drainage relationships of the soil have also been changed by the damming of streams and the subsequent gradual filling up of ponds by vegetation.

The generalized record of stand composition changes since 1907 provided by the study of the old stand maps makes it apparent that the post-agricultural succession is a dominant factor determining forest composition today. Three of the naturally occurring types, — the white pine type, the white pine-hardwood type, and the pioneer hardwood type, — originated chiefly on abandoned farm land. In addition, some of the areas mapped as transition hardwoods undoubtedly originated on old fields. All in all, these old field types covered roughly 40 percent of the study area in 1907 and still include about 12 percent of the area.

In addition to the natural pioneer types, the coniferous plantations, covering 18 percent of the study area, constitute artificial pioneer associations, ecologically similar to the old field white pine types.

Transitional successional stages are chiefly represented by transition hardwood types, although some of the pine and hemlock stands undoubtedly fall into this category. Somewhat more than 50 percent of the forest is of this nature today. Finally, the hemlock and hemlock-hardwood types, together with a small portion of the hardwood and white pine types, represent a later stage in succession. These types made up not more than 5 percent of the area in 1907 and now account for nearly 20 percent.

The present-day associations in the Harvard Forest, far from being made up of a hodge-podge of species scattered indeterminately over the area, constitute a regular series of interrelated types, composed predominantly of surprisingly few species, and closely correlated to successional stage and site as expressed in terms of soil drainage.

Two species are practically omnipresent. Red oak and red maple are equally prominent in all successional stages and one or the other is prominent on all sites. Both exhibit a marked relationship to soil drainage, the red oak being the most frequent on the drier and the red maple being most common on the wetter sites.

White pine is the characteristic old field tree, and also the characteristic tree of very well drained sites. On all sites, however, scattered white pine persists into the transitional stages, and becomes increasingly important in the late successional stages as a few trees reach the overstory and become dominant over the rest of the stand. White pine thus appears to be a minor but important and characteristic component of late successional stages on all sites from the wettest to the driest.

Hemlock has increased markedly in abundance over the past forty years, and is now the third most frequent species in the Forest. It exhibits little preference for site, but is largely restricted to the late successional stages in that it is found on areas long removed from agricultural use or clearcutting.

Forest site influences may be divided into soil and local climate. In the Harvard Forest, the soils are almost entirely of one age, that of the last Wisconsin glaciation. About 92 percent of the area is overlain with glacial till and 8 percent with glacial stratified drift. The till probably averages less than 10 feet in thickness, and is very largely derived from the local bedrock which is near the surface almost everywhere. The bedrock itself is an intimate mixture of granitic intrusives together with schists and gneisses metamorphosed from Paleozoic sedimentary rocks. It is therefore difficult to segregate the Gloucester soils derived from the granites from the Charlton and Brookfield soils derived from the metamorphics.

Inasmuch as there are also no pronounced site differences attributable to these different soil series, it seems advisable to group all the glacial till soils and to recognize only drainage relationships and the difference between till soils and glacial stratified drift soils. Excessively drained soils — largely derived from glacio-fluvial sands — occupy 8 percent of the study area. The other drainage classes are largely developed on till: 59 percent of the study area being classified as well drained, 12 percent as imperfectly drained, 14 percent as poorly drained, and 7 percent as very poorly drained. This last class consists of muck and peat bogs.

Other than the difference in fertility between stratified drift soils (of glacio-fluvial origin) and till soils, soil moisture appears to be the major soil character which markedly affects forest composition. By segregating sites on the basis of soil drainage alone, an excellent stratification of forest types can be obtained. Sites thus recognized are highly correlated with stand composition.

Local climate information gathered over a period of two years indicates that the local climates differ significantly from place to place throughout the Harvard Forest. Considering stations in the open only, the maximum temperatures are higher, the minimum temperatures are lower, and the frost-free season is shorter in concave areas of poor air drainage than in convex areas characterized by good cold air drainage. Vegetation modified local climate even to a greater extent than does topography.

Although it is to be expected that forest composition is influenced by local climate to a major extent, actual proof of the relationship is not at all ample. Other variables exert an obvious masking effect, and an extremely detailed study would be needed to isolate the importance of the local climatic factor. That local climate is highly important in influencing plant distribution, however, cannot be doubted. For instance, the soils classification based upon water drainage carries with it a corollary implication of air drainage and therefore of variation in local climate. Thus, a well drained site is apt to have a moderated climate suitable to plants of a generally southern distribution, and a very poorly drained site is apt to be characterized by temperature extremes and a short growing season. It is on these latter sites that red spruce, black spruce, and tamarack are confined, all three species occurring close to their southern limit in the Harvard Forest.

From an analysis of all 125 cases of softwood plantings in the Harvard Forest, a fairly clear picture emerges of the extent to which planting has changed forest composition. All plantations on open and semi-open land have been successful. Red pine, Norway spruce, and white spruce have been the most satisfactory species.

On cut-over land, site is especially important. Few if any plantations on imperfectly drained land have survived hardwood competition. On excessively drained sands, only red pine and possibly Scotch pine and European larch have proved capable of consistently taking over the area, with white pine and Norway spruce proving successful only under conditions of less extreme drought and infertility.

Most of the plantings on cut-over land have been put out on well drained upland till. Weeding is necessary in all instances. Red pine is the most successful species, requiring 15-16 man-hours of weeding per acre on cut-over pioneer hardwood, white pine, and pine-hardwood lands; and around 25 man-hours per acre on cut-over transition hardwood lands. Also successful are the exotic larches. White pine can be brought through only with intensive weedings, requiring probably 40 man-hours per acre distributed among 3 to 5 operations at intervals of several years. Norway and white spruce require more weeding than red pine but less than white pine.

Seventy-one cases deal with natural stands. The cutting of old field white pine and pine-hardwood mixtures on imperfectly drained soils has resulted in the creation of transition hardwood stands in every case. The composition of the new stands is primarily red maple and red oak with other hardwoods, especially white ash and the birches. On the well drained sites, clearcutting of the pine has also resulted in transition hardwood types, although small clumps of pine have been brought through by intensive weeding. Relatively little has been done with cuttings of the shelterwood type, but the isolated instances where partial cutting has been followed, together with the appearance of considerable volunteer pine in several of the upland plantations on cut-over pine land, lead to the view that the possibilities of reproducing pine on the best drained upland sites have by no means been exhausted.

The general effect of silviculture in hardwood stands has been to decrease the proportion of pioneer species and red maple in the stand, to increase the proportion of red oak, and to encourage a vigorous hemlock understory. These changes are precisely the same as are to be expected through natural successional development. Silviculture in most cases has merely hastened the natural trends.

Studies of natural regeneration in and around the Harvard Forest since the hurricane of September 21, 1938 have yielded much information concerning successional trends on hurricane blowdown areas. Many factors apparently affect the composition of the new stand on a given area, prominent among them being the composition of the former stand, advance growth present at the time of blowdown, soil type, and the occurrence of logging or fire after the blowdown. Where ample advance growth was present and no logging was carried out, the new stand is essentially a late-successional association. Where advance growth is present but logging has been carried out, the composition of the regeneration is transitional in successional relationship. Where little or no advance growth occurred, or where subsequent fire or logging destroyed this growth, pioneer associations have resulted. In practically every case, the character of the new stand was apparent within only two growing seasons after the hurricane. The absence of later successful invasion of seedlings is attributable in part to competition from growth already established, and in part to unfavorable environmental conditions in the blowdown areas. A silvicultural lesson can be drawn from these findings. The silviculturist should apparently depend largely upon advance growth rather than upon subsequent seeding in, even in central New England where growing conditions are generally favorable.

. . . .

The present forest associations, then, are apparently complex, but turn out to be fairly simple in their broad aspects, being closely related to soil drainage and to successional stage. A well defined series of gradational stages relate the white pine sand plains to the spruce bogs. On well drained sites, short-lived species such as gray birch, pin cherry, and aspen characterize pioneer associations, with white pine as the principal old field species. The transitional association is basically a red oak-red maple type with other hardwoods making up a minor proportion of the stand. This in turn develops into late successional stages in which hemlock and an occasional white pine join with red oak to make up the basic association.

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APPENDIX

PONDEROSA PINE

29-year-old Plantation from Southern California Seed

PH III, 15-B
0.4 Acre

June 6, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Well drained knoll. Elevation 1200 feet.

Land-use History:

Old pasture. At time of planting, this area was a clearing in a pasture growing up to scrubby white pine. The sod was unusually tough.

Silvicultural History:

Planting, 1915. 530 ponderosa pine 1-2, grown in Petersham from Southern California seed. Spacing 6 x 6.

Inspection, 1918. 71% survival, the highest of any of the six ponderosa pine plantings of 1915.

Thinning, 1944. Trees in poor condition and heavily diseased (Cronartium Comptoniae, Arth.). 47% of trees removed. About 200 trees per acre left. Average dbh, 5.5". Average height, 26'. Stand also contains 20 volunteer white pine and 3 hardwoods in dominant position.

Discussion:

Although poor, this is the best ponderosa pine planting on the Forest. Because of the space-demanding character of the species, the stand was thinned heavily to try to save the planting.

WHITE PINE

29-year-old Plantation

PH VI, 15-F(2)
5.5 Acres

June 20, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

High slope, well drained. Elevation 1310 feet.

Land-use History:

Pasture from before 1830 to time of planting.

Silvicultural History:

Planting, 1915. 3500 white pine 1-2 from Harvard Forest nursery. Spacing 6 x 6. Side hole method.

Inspection, 1919. 70% of trees healthy, 24% weak, and 6% dead.

Inspection, 1932. 840 trees per acre. Average dbh, 3.8". Average height, 17'. Heavily weeviled.

Weeding, 1934. Occasional overtopping paper birch cut back.

Pruning, 1935. About 200 trees per acre pruned to height of about 12'. 6 man-hours per acre.

Thinning, 1944. 21% of trees removed (14% of free trees). 680 trees per acre left. Average dbh of free trees, 5.78". Average height, 30'. Control plot established. Much of stand destroyed by hurricane. About 2 acres left.

Discussion:

Despite heavy weeviling, enough good stems are left to make a satisfactory stand. Growth is adequate, but inferior to adjoining red pine (now mostly blown down). Little treatment was necessary.

RED AND WHITE PINE

29-year-old Alternate Row Plantation

PH VI, 15-G
0.5 Acre

June 16, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

High slope, well drained. Elevation 1310 feet.

Land-use History:

Pasture from before 1830 to time of planting.

Silvicultural History:

Planting, 1915. 302 red pine 1-2, 334 white pine 2-1, and 22 jack pine 1-2 from Harvard Forest nursery. Spacing 6 x 6. Red and jack pine in alternate rows with white pine. Four planting methods: A. Careful mattock center hole; B. Mattock side hole; C. Slit sod off; and D. Slit sod on.

Inspection, 1923.

	A	B	C	D
Height - white pine	7.1'	7.0'	6.6'	6.5'
- red pine	9.5'	9.2'	9.1'	8.6'
- jack pine	-	11.1'	-	-
Survival - white pine	91%	94%	89%	78%
- red pine	100%	85%	90%	90%

Weeding, 1934. Two overtopping hardwoods removed. 1 man-hour per acre.

Hurricane damage, 1938. East half of stand blown down. Salvage operation yielded logs.

Thinning, 1944. 30% of red pine, 1 white pine, and 2 jack pine removed. RED PINE: 488 trees per acre. Average dbh of free trees, 6.8". Average height, 36'. WHITE PINE: 300 trees per acre. Average dbh of free trees, 5.1". Average height, 28'.

Inspection, 1944.

	A	B	C	D
Dbh free trees - white pine	5.39"	5.75"	4.61"	4.42"
- red pine	6.54"	6.75"	6.24"	7.21"

Discussion:

Red pine has outdistanced white pine on this rather poor site, and now occupies about 35% of the canopy. The jack pine too has done well, but is of poor form. Hole planting definitely resulted in better growth and survival than did slit planting, at least for white pine, and quite possibly also for red pine.

RED PINE

25-year-old Plantation on Cut-over Gray Birch Land

PH II, 19-B
1.7 Acres

June 1, 1944

Soil:

Charlton loam.

Site:

Gradual slope southeast of spruce bog. Elevation 1200 feet. Soil rich with fair drainage.

Land-use History:

Under cultivation to about 1885, followed by pure gray birch.

Silvicultural History:

Clearcutting, 1918-19. 30-year-old gray birch yielded 14 cords per acre. Advance growth mowed. Brush piled and burned.

Planting, 1919. 2200 red pine, 2-3 stock. Seed from Champlain Valley. 6 x 6 spacing. Mattock hole method. 12 man-hours per acre.

Weeding, 1921. Gray birch, red maple, and paper birch removed. 2 man-hours per acre.

Weeding, 1923. 2 man-hours per acre.

Replanting, 1926. 58 red pine, 2-2 stock, from Harvard Forest nursery.

Weeding, 1930. Heavy. 5 man-hours per acre.

Inspection, 1932. 860 trees per acre. Average dbh, 3.3". Average height, 16'. Lowest branches beginning to die. No podzolization.

Pruning, 1936. 180 trees per acre pruned to average height of 10 feet. Pruning removed collar except in 17 controls. 19 man-hours per acre.

Thinning, 1938. Of 612 trees per acre, 116, or 19%, removed. Crown thinning. Pruned crop trees favored. 10 man-hours per acre.

Post-hurricane cleanup, 1939. Three small spots of blowdown and scattered leaners were felled. About 15% of stand affected. 28 man-hours per acre. 107 white ash, 3-0 stock, planted in clearings, 1941 (41-N).

Thinning, 1944. Of 660 trees per acre, 60, or 9%, removed. Yield, 90 board feet and 1.2 cords per acre. Average dbh, 6.9". Average height, 37'.

Discussion:

Gray birch competition was not sufficient to prevent the successful establishment of this red pine plantation. The cost, however, was about 100 man-hours per acre, including 28 hours of hurricane cleanup. Growth is good, and the last thinning yielded merchantable products.

Trees pruned through the branch collar are 75% to 100% healed over. Trees pruned outside the collar are less than 25% healed. (Exp. 36-5).

RED PINE

22-year-old Plantation on Peach Orchard

PH III, 22-B
1.7 Acres

June 27, 1944

Soil:

Gloucester stony fine sandy loam.

Site:

Well-drained mid-slope. Elevation 1180 feet.

Land-use History:

Successively a cultivated field, a mowing, and a peach orchard. At time of planting, an abandoned field with very light sod, a light grass cover, and a few pin cherries.

Silvicultural History:

Planting, 1922. 1644 red pine, 2-3 stock. 6 x 6 spacing, rows staggered. Slit method, sod removed. 13 man-hours per acre.

Inspection, 1932. 920 trees per acre. Average height, 12.0'. Average crown width, 2.5'. Very good plantation.

Weeding, 1934. Borders only. 3 man-hours per acre.

Hurricane salvage, 1940. About 25% of stand affected, mainly a strip along the south border. Trees felled and lopped.

Thinning and pruning, 1944. 14% of trees removed. Left were 530 trees per acre. Average dbh of free trees, 5.7". Average height, 36'. 200 crop trees per acre pruned to 17'.

Discussion:

This is a highly successful plantation. Time required has been about 25 man-hours per acre exclusive of hurricane salvage.

WHITE PINE

21-year-old Plantation on Peach Orchard

PH III, 23-A
0.9 Acre

June 27, 1944.

Soil:

Gloucester stony fine sandy loam.

Site:

Mid-slope. Practically level. Medium drainage.

Land-use History:

Successively a cultivated field, a mowing, and a peach orchard. At time of planting, the northern portion had seeded in very heavily to gray birch, and the southern portion had been cultivated in 1922 as a vegetable garden.

Silvicultural History:

Planting, 1923. 1120 white pine, 2-1 stock, and 322 white pine, 2-0 stock. Spacing 5 x 5. Slit method, sod removed. 24 man-hours per acre.

Weeding, 1923. Gray birch seedlings bent over about each planted pine. 7 man-hours per acre.

Replanting, 1925. 213 red pine, 2-2 stock, from Harvard Forest nursery. Mainly in the south portion of the stand. 5 man-hours per acre.

Weeding, 1927. Overtopping gray birch seedlings cut out. 5 man-hours per acre.

Weeding, 1930. Hole weeding to free pine from birch. 11 man-hours per acre.

Inspection, 1932. 1020 trees per acre. Average height, 6.3'. Average crown width, 3.7'.

Hurricane salvage, 1940. About 15% of trees, leaning or down, mostly in south portion, were felled and lopped.

Thinning, 1944. 19% of trees removed. Left were 880 trees per acre. Average dbh of free trees, 4.9". Average height, 25'.

Discussion:

Although this is one of the better white pine plantations on the Forest, both from the standpoint of growth and freedom from weeviling, it is inferior to the adjoining red pine plantations (22-A and 25-L). The red pine filled into the stand in 1925 are considerably larger than the older white pine.

WHITE SPRUCE AND WHITE PINE

20-year-old Plantation on Old Apple Orchard

PH II, 24-A
1.4 Acres

June 1, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Mid-slope. Well drained. Elevation 1150 feet.

Land-use History:

Under cultivation for at least 100 years. Was combined apple orchard and mowing at time of planting.

Silvicultural History:

Site preparation, 1924. Apple trees and fuelwood removed. Brush piled along field borders. Grass consumed by broadcast burning. 28 man-hours per acre.

Planting, 1924. 1800 white spruce and 900 white pine. Both 2-1 stock from Harvard Forest nursery. Spacing 5 x 5 feet. Mattock slit method. Sod removed. TWO ROWS OF SPRUCE ALTERNATED WITH ONE OF PINE. 54-man-hours per acre.

Replanting, 1927. 270 white spruce and 120 white pine, both 2-2 stock. Harvard tool. 8 man-hours per acre.

Weeding, 1929. Borders only. Machete. 1½ man-hours per acre.

Inspection, 1932. WHITE SPRUCE: 1240 trees per acre. Average height, 4.4'. WHITE PINE: 480 trees per acre. Average height, 4.4'. 60% weeviled. White pine crowns wider than white spruce (3.3' as against 2.5').

Weeding, 1935. Entire stand. Machete. 3 man-hours per acre.

Improvement cutting, 1944. All pines cut. No wood removed. These were poor quality scrubby trees, 95% weeviled. No spruce removed. Control plot established. WHITE SPRUCE: Average dbh free trees 4.0"; all trees 3.8". Average height 26'. WHITE PINE: Average dbh free trees 3.8"; all trees 3.4". Average height 21'.

Discussion:

White spruce and white pine are incompatible because of extensive weeviling to white pine during juvenile period when white pine is the taller tree. This stand should be a high quality one, nevertheless, as the white spruce has done exceptionally well.

WHITE SPRUCE AND WHITE PINE

20-year-old Plantation on Brushy Pasture

PH II, 24-B
1.3 Acres

June 1, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Low slope with moderate to poor drainage. Elevation 1120 feet.

Land-use History:

Cultivated at one time, then a pasture. At time of planting, abandoned pasture was rapidly growing up to white pine, scrub apple, and alder.

Silvicultural History:

Site preparation, 1924. Area cut over and broadcast burned to dispose of dead grass. 3 man-hours per acre.

Planting, 1924. 1200 white spruce 3-0 and 400 white pine 2-1 from Harvard Forest nursery. Spacing 5 x 5. Harvard tool. THREE ROWS OF SPRUCE ALTERNATED WITH ONE OF PINE. 29 man-hours per acre.

Weeding, 1926. Heavy growth of alder, gray birch, and apple cut to ground. 3 man-hours per acre.

Replanting, 1927. 787 white spruce 2-2 and 110 white pine 2-2. Portion near Locust Opening Road overgrown with alders. 17 man-hours per acre.

Weeding, 1929. Heavy sprout growth of alders in south part of stand cut back. 3 man-hours per acre.

Weeding, 1931. Same. 10-man-hours per acre.

Inspection, 1932. WHITE SPRUCE: 1220 trees per acre. Average height 2.7'. WHITE PINE: 420 trees per acre. Average height 4.8'. White pine crowns wider than spruce (3.3' as against 1.5').

Weeding, 1932. Alders in south portion of stand. 1 man-hour per acre.

Weeding, 1935. 6 man-hours per acre.

Weeding, 1943. South portion. 2 man-hours per acre.

Improvement cutting, 1944. North portion. 31% of free pine and 12% of free spruce removed. WHITE SPRUCE: 890 trees per acre. Average dbh free trees, 3.46"; all trees, 3.20". Trees in inside row average 0.42" larger than trees bordering pine. Average height 22'. WHITE PINE: 230 trees per acre. Average dbh free trees, 5.05"; all trees, 4.78". Average height 24'.

Discussion:

South part of plantation a failure despite six weedings because of poor drainage and alder competition. Spruce throughout smaller than in similar stands (24-A, 24-C) because of seedling stock rather than transplants. White pine and white spruce incompatible (See 24-A). This is the first plantation established with the Harvard tool.

WHITE SPRUCE AND WHITE PINE

20-year-old Plantation on Mowing

PH II, 24-C
1.7 Acres

June 1, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Mid-slope. Medium drainage. Elevation 1140 feet.

Land-use History:

Once under cultivation, then a mowing. Hay cut annually until time of planting.

Silvicultural History:

Site preparation, 1924. Broadcast burned to remove dead grass.

Planting, 1924. 1700 white pine 2-1; 1500 white spruce 3-0; and 200 white spruce 2-1, all from Harvard Forest nursery. Spacing 5 x 5. Harvard tool. CHECKERBOARD SQUARES, EACH COMPOSED OF 16 TREES OF ONE SPECIES. 53 man-hours per acre.

Replanting, 1927. 425 white spruce 2-2 and 155 white pine 2-2. 9 man-hours per acre.

Inspection, 1932. WHITE SPRUCE: 860 trees per acre. Average height, 3.6'. WHITE PINE: 800 trees per acre. Average height, 6.4'. White pine crowns wider than spruce (4.4' as against 2.0'). Pine 80% weeviled.

Weeding, 1934. Gray birch, pin cherry, and aspen removed. Cutting heavy in spruce groups, light in pines to minimize weevil injury. 5 man-hours per acre.

Weeding, 1935. 4 man-hours per acre.

Thinning, 1943. NORTH PORTION heavily thinned. 44% of pine and 21% of spruce removed. CENTRAL PORTION left as control. SOUTH PORTION lightly thinned, mainly by girdling scrubby pines. 29% of pine and 8% of spruce removed.

Inspection, 1944. WHITE SPRUCE: Average dbh of inside trees, 3.6"; of outside trees, 3.3". Average dbh of all trees, 3.5". Average height, 26'. WHITE PINE: Average dbh of inside trees, 4.0"; of outside trees, 4.7". Average dbh of all trees, 4.5". Average height, 24'.

Discussion:

White spruce and white pine incompatible because of extensive weeviling to white pine during period when white pine is the taller tree. Spruce is of excellent quality and is being favored.

WHITE SPRUCE AND SCOTCH PINE

20-year-old Plantation on Pasture

PH I, 24-F
1.0 Acre

June 6, 1944

Soil:

Brookfield stony fine sandy loam. Sutton stony fine sandy loam.

Site:

Low slope. Rather poor drainage. Elevation 1140 feet.

Land-use History:

Successively a cultivated field, an apple orchard, and a pasture. At time of planting, apple trees, red oak, and red maple were present on the area.

Silvicultural History:

Site preparation, 1924. Apple trees and hardwood advance growth cut out. Grass broadcast burned. 17 man-hours per acre.

Planting, 1924. 990 white spruce, 3-0 stock, and 400 Scotch pine, 2-0 stock (Riga strain). Spacing 5 x 5. Harvard tool. Three rows of spruce alternated with one of pine. 30 man-hours per acre.

Weeding, 1927. Mostly along borders. 10 man-hours per acre.

Replanting, 1927. 740 white spruce, 2-2 stock and 200 white pine, 2-2 stock. Earlier low survival due to small stock used. 18 man-hours per acre.

Weeding, 1930. Mostly along borders. Scotch pine heavily weeviled. Also budded by squirrels. 13 man-hours per acre.

Weeding, 1934. Borders. 2 man-hours per acre.

Inspection, 1932. WHITE SPRUCE: 1380 trees per acre. Average height, 2.3'. Average crown width, 1.4'. SCOTCH PINE: 600 trees per acre. Average height, 4.5'. Average crown width, 3.3'.

Improvement cutting, 1944. Scotch pine scrubby. All pines removed except in control plot. WHITE SPRUCE: 1280 trees per acre. Average dbh of free trees, 3.6"; all trees, 3.0". Average height, 22'. SCOTCH PINE: 200 trees per acre in control plot. Average dbh of free trees, 5.7"; all trees, 5.2". Average height, 22'.

Discussion:

The spruce is in excellent condition except in the wetter portions of the stand. Removal of the Scotch pine in 1944 was probably not necessary, but should result in better soil conditions. The only value of Scotch pine in this and similar plantations is that of a nurse tree. Its use may avoid early thinnings and may result in better form of other species with which it is planted.

WHITE PINE

20-year-old Seed Source Experiment

PH I, 24-G
0.5 Acre

June 27, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Mid-slope. Moderate drainage. Elevation 1140 feet.

Land-use History:

Formerly cultivated. At time of planting, a mowing with moderately heavy sod.

Silvicultural History:

Planting, 1924. 924 white pine, 3-0 stock, from Harvard Forest nursery. Seed of 6 lots, each collected from a single mother tree in Petersham. Spacing 5 x 5. Lots in east-west rows. Harvard tool.

Lot	Mother tree	Site	Dbh	Ht	Mean seed weight
1	Open grown	I	16"	35'	21 mg.
2	Dominant in old field stand	II	15"	75'	16 mg.
3	Open grown	II-	12"	30'	22 mg.
4	Co-dominant. Same as 2.	II	12"	70'	18 mg.
5	Old growth. Boulder site.	II	28"	100'	15 mg.
6	Stagnant old field stand	II-	10"	50'	14 mg.

Picking weevils, 1930. 425 weevils collected in 6 man-hours.

Inspection, 1932. 1260 trees per acre. Average height, 7.2'. Average crown width, 4.5'. Weeviling severe.

Thinning, 1944. 17% of trees removed. Left were 990 trees per acre. Average dbh of free trees, 5.2". Average height, 28'. 16 man-hours per acre.

Experimental measurements:

Lot	1929 Height	1939 Height	1944 Height	1939 Dbh	1944 Dbh
1	3.2'	18'	26.4'	3.7"	4.85"
2	4.4'	19'	27.5'	3.5"	4.95"
3	5.0'	20'	28.2'	4.3"	5.00"
4	4.3'	20'	26.4'	4.2"	4.89"
5	3.8'	19'	27.7'	3.7"	5.14"
6	4.1'	18'	25.6'	3.9"	5.05"
Basis	All trees	5 each	10 each	5 each	All trees

Discussion:

This experiment was poorly designed in that the lots were not randomized but were planted systematically from north to south. Weeviling disrupted height growth and reduced the value of the experiment. Although inconclusive, there are indications that growth differences between the lots do exist, lot 3 either being the fastest growing or being the largest because of the heavy seed from which it originated.

WHITE AND ASIATIC SPRUCE

20-year-old Plantation on Old Field

PH I, 24-H
2.6 Acres

June 28, 1944

Soil:

Brookfield stony fine sandy loam. Sutton stony fine sandy loam.

Site:

Low slope. Medium to poor drainage. Elevation 1120 feet.

Land-use History:

Cultivated field at one time. At time of planting, old mowing and pasture with scattering of white pine, gray birch, and pin cherry.

Silvicultural History:

Planting, 1924. 3826 white spruce, 3-0 stock, and 550 Asiatic spruce (_Picea shrenkiana_), 2-2 stock. Spacing 5 x 5. Harvard tool. Asiatic spruce planted pure west of white pine (24-G). 25 man-hours per acre.

Weeding, 1927. 3 man-hours per acre.

Replanting, 1927. 1410 white spruce, 2-2 stock. Original planting had failed to a large extent because of the small stock and heavy ground cover. 12 man-hours per acre.

Weeding, 1930. Scattered birch, aspen, and red maple sprouts removed. Spruce 1' - 2' high. 2 man-hours per acre.

Inspection, 1932. WHITE SPRUCE (South portion of stand): 1700 trees per acre. Average height, 2.8'. Average crown width, 1.8'. ASIATIC SPRUCE: Average height, 2.1'. Average crown width, 1.7'. Some white spruce mixed in with the Asiatic. These averaged 2.0' in height.

Weeding, 1933. Sprouts along north-south stone wall and in south portion of stand removed. 3 man-hours per acre.

Inspection, 1944. WHITE SPRUCE (South portion of stand): 1250 trees per acre. Average dbh of free trees, 3.5". Average height, 21'. ASIATIC SPRUCE: 1420 trees per acre. Average dbh of free trees, 2.8". Average height, 19'. In same area, 130 trees per acre of white spruce averaged 4.1" dbh and 21' in height.

Discussion:

Failure of the first planting points to the inadvisability of planting seedling stock on sites with a heavy sod cover. Both spruces have done well, but are inferior to the white and Norway spruce grown in mixture with red and white pine in nearby stands.

RED PINE AND WHITE SPRUCE

19-year-old Plantation on Mowing

PH I, 25-K
5.0 Acres

June 26, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Low slope with fair to poor drainage. Elevation 1150 feet.

Land-use History:

Alternately a cultivated field and a mowing for more than 100 years. At time of planting, a good mowing with heavy grass.

Silvicultural History:

Planting, 1925. 3225 red pine and 3300 white spruce, both 2-2 stock. Spacing 5 x 5. Harvard tool. Alternate rows of spruce planted 3 weeks after pine. Unusual care was taken to keep rows straight. 28 man-hours per acre.

Replanting, 1927. 34 red pine and 225 white spruce, both 2-2 stock. 2½ man-hours per acre.

Weeding, 1929-30. Hardwood weeds around edges removed. 1 man-hour per acre.

Weeding, 1932. Hardwood weeds around edges removed; also patch of older weeds near northeast corner. ½ man-hour per acre.

Inspection, 1932. RED PINE: 740 trees per acre. Average height, 5.3'. Average crown width, 3.9'. WHITE SPRUCE: 840 trees per acre. Average height, 4.1'. Average crown width, 2.3'.

Weeding, 1935. Gray birch and red oak cut around edges. ½ man-hour per acre.

Pruning, 1937. About 200 red pine crop trees per acre pruned to height of 8' - 10'. Area east of road only. 16 man-hours per acre.

Hurricane salvage, 1940. About 15% of trees leaning. These were removed wherever interfering with rest of stand.

Thinning and pruning, 1944. 18% of red pine and 40% of spruce removed. RED PINE: 550 trees per acre. Average dbh of free trees, 6.1". Average height, 31'. 200 crop trees per acre pruned to height of 17'. WHITE SPRUCE: 380 trees per acre, of which 270 are free to grow. Average dbh of free trees, 3.8"; all trees, 3.2". Average height, 27'.

Discussion:

A highly successful plantation. Both species are taller than those in pure plantations on similar sites. The mixture of red pine and white spruce results in the accelerated growth of the spruce, due to side pressure by the red pine. The pine, too, grows faster than in pure stands because of the greater amount of crown space which results from the slower growth of the spruce during the first 15 years.

RED PINE

19-year-old Plantation on Peach Orchard

PH III, 25-L
0.5 Acre

June 26, 1944

Soil:

Gloucester stony fine sandy loam.

Site:

Mid-slope. Well drained except along southern border. Elevation 1160 feet.

Land-use History:

Successively a cultivated field, a peach orchard, and a mowing. Heavy grass cover at time of planting.

Silvicultural History:

Planting, 1925. 737 red pine, 2-2 stock, from Harvard Forest nursery. Spacing 6 x 6. Harvard tool. 18 man-hours per acre.

Inspection, 1932. 1200 trees per acre. Average height, 5.7'. Average crown width, 4.7'.

Hurricane salvage, 1940. Stand badly damaged. Trees cut and lopped. About 35% of stand (near south border) in good condition.

Thinning, 1944. 12% of trees removed. Left were 900 trees per acre. Average dbh of free trees, 4.9". Average height, 27'.

Discussion:

Although this stand is 2 years younger than the adjoining white pine plantation, the trees are larger and in better condition. On less fertile soils, red pine outstrips white pine. Heavy snow in November 1943 caused considerable top breakage.

26I, 26J, 26K

RED PINE AND NORWAY SPRUCE

18-year-old Plantations on Little Prospect

PH IV, 26-I, 26-J, 26-K
14.5 Acres

Soil:

Brookfield stony fine sandy loam.

Site:

Well-drained hilltop. Elevation 1250 feet.

Land-use History:

High pasture and apple orchard. About 1900, began seeding in to scattered scrubby white pine, gray birch, pin cherry, and red maple.

Silvicultural History:

Site preparation, 1924-25. Scattered pine and hardwoods cut. Slash burned.

Planting, 1926. Three areas. 2-2 stock. Spacing 6 x 6. Harvard tool. 22 man-hours per acre.

	Area	Species	No.
26-I	6.1	Red pine	6,425
26-J	3.6	Red pine	1,825
		Norway spruce	1,842
26-K	4.8	Norway spruce	5,726

Replanting, 1927. Pure spruce area only (26-K). 300 white spruce, 2-2 stock. 2 man-hours per acre.

Weedings, 1927, 1928, 1930, 1932, and 1938. Persistent hardwood competition removed, particularly in spruce stand. Total of 8 man-hours per acre.

Inspection, 1932.

	Species	Trees/A	Ave.height	Average crown width
26-I	Red pine	1840	3.5'	2.6'
26-J	Red pine	580	3.5'	2.3'
	Norway spruce	600	2.9'	1.9'
26-K	Norway spruce	1100	3.1'	2.2'

Inspection, 1944.

	Species	Trees/A	Ave. dbh free trees	Ave.height
26-I	Red pine	1110	4.3"	21'
26-J	Red pine	510	5.2"	25'
	Norway spruce	530	3.3"	25'
26-K	Norway spruce	1130	3.3"	22'
	White spruce	133	3.1"	

Discussion:

Both species have done better in the mixed plantation than in pure stands. When grown with spruce in alternate rows, red pine does not stagnate readily but spreads out into crown space above the spruce, which is slower growing in early life. The spruce itself has greater height and less taper when grown in close competition with pine.

RED PINE, NORWAY AND WHITE SPRUCE

18-year-old Plantation on Mowing

PH I, 26-N
1.5 Acres

June 27, 1944

Soil:

Brookfield stony fine sandy loam.

Site:

Mid-slope. Well drained. Elevation 1140 feet.

Land-use History:

Formerly cultivated. At time of planting, the area was a mowing in good condition with a heavy grass cover.

Silvicultural History:

Planting, 1926. 950 red pine and 780 Norway spruce, both 2-2 stock. The spruce was poor stock, yellow in color, and was planted too deep. Spacing 4.5 x 5. Harvard tool. 23 man-hours per acre.

Replanting, 1927. 500 white spruce, 2-2 stock, to replace Norway spruce which appeared to be failing. 7 man-hours per acre.

Weeding, 1930. Borders only. 1 man-hour per acre.

Inspection, 1932.

	Trees/A	Ave.height	Average crown width
Red pine	960	5.1'	3.6'
Norway spruce	400	3.3'	2.2'
White spruce	290	2.4'	1.3'

Pruning, 1937. 200 selected crop trees per acre of all species were pruned to height of 5' - 8'. 14 man-hours per acre.

Thinning and pruning, 1944. 18% of the pine and 48% of the spruce removed. Red pine crop trees pruned to 17'. Control plot left.

Inspection, 1944.

	Trees /A	Ave. dbh free trees	Ave.height free trees
Red pine	690	5.8"	29'
Norway spruce	310	3.3"	26'
White spruce	20	2.7"	

Discussion:

The pine is in excellent condition because of the natural thinning resulting from the early slow growth of the spruce. The replanting with white spruce was not justified. Despite a poor start, the Norway spruce has come through much better than the white and will form a small part of the final stand.

October 1, 1946

MIXED CONIFERS

9-year old Plantation on Little Prospect

PH III, 37-E
19 acres

Soil:

Gloucester stony loam. Acton stony loam.

Site:

High north slope. Well to poorly drained. Elevation 1180 to 1260 feet.

Land-use History:

Upland pasture until abandonment about 1880. Between then and 1895, seeded in to open stand of old field white pine (density 0.5-0.8) with scattered red maple, red oak, white oak, gray birch, paper birch, black birch, and pitch pine. Red maple swale in center clearcut for fuel in 1905.

Silvicultural History:

Seed tree cutting, 1934-35. 12,500 board feet of pine, 185 board feet of paper birch, and 5.2 cords of hardwood cut per acre. Cost of logging: $11.05 per Mbf; $6.55 per cord, both yarded. Sale price: $16.00 per Mbf in yard; $6.00 to $7.50 per cord. White pine seed trees left approximately every 75 feet over most of area. Slash partially burned. Many seed trees blown down during January thaw in 1935.

Planting, 1937. Spacing 6 x 6. Harvard tool. 22 man-hours per acre. White pine in northern part including high slope; red pine in southern part; spruce in center near sawdust pit; larch in clumps throughout pine. Red and white pine mixed in 0.4-acre area along west central edge. Planting stock as follows:

(1) White pine	10.5A	2-1 stock	15,110	Rangeley Lakes, Me.
(2) Red pine	7.2A	2-1	5,750	Winchendon, Mass.
(5) Norway spruce	0.5A	3-0	1,700	Baden, Germany
European larch	0.4A	2-0	1,000	Scotland
Korean larch	0.2A	2-0	600	North Korea
Japanese larch	0.2A	2-0	500	Japan

Hurricane salvage, 1939. Strip of pine along Kitchen Road, too small to be cut in 1934, was blown down. Limbed and dropped to ground in 16 man-hours.

Weeding, 1945. Hardwoods weeded back heavily in red pine, spruce, and larch areas; somewhat less so in white pine areas to reduce weeviling. 10 man-hours per acre. Wet areas (Acton soil) were left to hardwoods, chiefly red maple. White and red pine averaged 5 to 6 feet in height; spruce, 3 to 6 feet; and larch, 6 to 20 feet. Considerable volunteer white pine, especially in spruce area.

Discussion: A second weeding will be necessary around 1950. This stand is typical of plantations on cut-over pine areas. On the higher, dry slopes, hardwood competition is not too severe. On the lower moist slopes, repeated weedings will be necessary to overcome severe competition. In moist areas, red maple and other hardwoods have completely taken over the stand. The seed tree cutting was inconclusive, but might have been successful on the upper slopes had it been postponed until a seed year, and had the site been prepared, perhaps by burning. The lower slopes should have been allowed to come in to transition hardwoods. S.H.S.

INTEGRATED SILVICULTURAL OPERATION IN TRANSITION HARDWOODS AND HEMLOCK

PH III, Stands 3, 4, and 5, 1946
16 Acres (Part of 30-acre cutting)

Soil:

Gloucester stony loam. Acton stony loam. Whitman very stony silt loam.

Site:

Northwest facing mid-slope. Medium to poor drainage. Elevation 1150 to 1250 feet.

Land-use History:

Upland pasture until abandonment, probably about 1840. Old field pine cut about 1902, followed by transition hardwoods over most of area. Older hemlock along northeast boundary.

Silvicultural History:

Stand 3. Hemlock. 60-90 year old stand. First treatment in 1945 was light thinning which removed about 10% of stand, leaving 3540 cubic feet per acre, of which 2830 were hemlock, 270 white pine, 370 red oak, 50 beech, and 20 paper birch.

Stand 4. Hardwoods. Plot A had, in 1944, 1450 cubic feet per acre, was 42 years old and 52-55 feet high. After 1945 improvement cutting, 1090 cubic feet, or 75%, of which 570 were red oak, 250 red maple, 200 paper birch, 50 beech, and 20 black birch. Plot B had, in 1944, 2320 cubic feet, of which 1420 were white pine. Removal of pine clump for sawlogs in 1945 (spot clearcutting) left 1180 cubic feet per acre, or 51%, of which 450 were white pine, 300 red oak, 210 red maple, 130 black birch, 80 hemlock, and 10 white oak.

Stand 5. Plantation 13-D. Planted in 1913 with 600 Norway spruce grown in Forest nursery, 2-1 stock. Sprout hardwoods 7 years old, 12-18 feet high. 57 man-hours of student labor per acre. Rocks and roots made planting difficult. In 1944, spruce was completely suppressed, 2-6 feet high, heavily infested with spruce gall aphid, 80% survival. Overstory comprised 432 trees per acre, 54 feet high, comprising 1300 cubic feet, of which 670 were red maple, 380 red oak, and 150 black birch. No treatment.

Entire area was cut over in 1944 and 1945, with treatment varied to local conditions. Stand 5 left as control. In 1944, 80 cords were removed, requiring 8.9 man-hours per cord, including yarding. In 1945,156 cords were removed to complete operation.

Discussion: This is an example of an integrated silvicultural operation made on a commercial basis over a moderately large area. In various places, the operation partook of the character of a hurricane salvage cutting, improvement cutting (Stand 4, Plot A), thinning (Stand 3), spot clearcutting (Stand 4, Plot B), and release cutting (Stand 2. See separate case history). Only sample marking was done. Supervision was light. Cost per cord was less than in nearby clearcutting made the same winter by the same crew, which required 11.1 man-hours per acre per cord cut and yarded, including slash disposal. The suppressed Norway spruce plantation is a fine example of the capacity of the species to endure shade, and the futility of planting it on cut-over areas with a heavy wet soil. S.H.S.

Case 3-4

WHITE PINE SEED TREE CUTTING ON SANDY SOIL

PH III, Stands 1 and 2, 1946
3 Acres

Soil:

Jaffrey stony fine sandy loam. Kame of poorly assorted loose sand and gravel.

Site:

Mid-slope. Medium drained. Elevation 1150 feet.

Land-use History:

Cultivated at one time. Abandoned about 1882. Came into medium box quality white pine and scattered hardwoods.

Silvicultural History:

Hurricane damage, 1938. Previously untreated stand largely blown down, except for strip along northwestern edge. Prior volume: white pine, 4,492 cubic feet per acre; red oak, 164; paper birch, 77; other hardwoods, 18.

Hurricane salvage, 1941. Down trees cut into logs and piled on skidway by Forest crew. Yield: 15,800 board feet. Time: 9.2 man-hours per Mbf. Logs sold on skidway for $12.00 per Mbf ($15 for sound logs and $10 for wormy logs). Slash piled and burned on snow.

Liberation cutting, 1945. At time of improvement cutting in surrounding area, dense white pine reproduction from 1940 seed crop was noted on this area. All hardwoods were cut, yielding perhaps 3 cords, and brush was piled, care being taken to free pine seedlings. Strip of pines along border was left to furnish seed in expected seed crop.

Discussion:

Though not a planned experiment, this area illustrates the possibility of reproducing white pine on a sandy soil. The hurricane and subsequent log salvage were an ideal seed tree treatment. The 1940 and 1943 seed crops thoroughly restocked the area, there now being 2600 white pine seedlings per acre. Hardwood reproduction includes 850 seedlings, 480 seedling sprouts, and 280 stump sprouts per acre; red maple, red oak, and black birch making up three-quarters of the total. The 1945 treatment removed residual hardwoods and left the site in condition for white pine seedlings to take over. After the next seed year, the remaining white pines in the strip will be removed, being easily accessible to the road. A low-cost, successful regeneration of white pine on a "white pine soil". S.H.S.

October 8, 1946

Case 8-1

SPROUT HARDWOODS

26-year-old Stand on Locust Opening Road

PH VIII, Stand 1, 1946
2.5 Acres

Soil:

Gloucester stony loam.

Site:

Small, low knoll. Well drained. Elevation 1210 feet.

Land-use History:

Part of the same tract described in the case of PH II, Stands 1 and 2, 1946. Deeds from 1820 to 1885 running through the agricultural period describe the tract as a woodlot. This part of the area has undoubtedly been pastured, however, and may have been open around 1850. Some pine and chestnut were apparently cut around 1865.

Silvicultural History:

Reproduction cutting, 1910. No records of this operation are available, but it is shown on the 1916 map of cutting operations. Judging from evidence on the ground, the treatment was a seed-tree cutting in which 45-year-old pines and hardwoods were cut, leaving 45-year-old red and white oak seed trees in a few groups scattered throughout the stand. The 1913 type map shows the stand to consist predominantly of chestnut reproduction.

Liberation cutting, 1930-31. The seed trees left in 1910 were removed, thus freeing the 20-year-old stand of hardwood sprouts and seedlings and white pine seedlings. 10 cords of wolf and broken-topped red oak, white oak, and red maple were cut from about 0.4 acre; the rest of the stand being without seed trees.

Hurricane salvage, 1940. About 20 trees per acre of the 1910 hardwood crop were blown down. Those nearest the road were salvaged at the same time as the windfall across the road in PH III.

Measurement, 1944. A permanent quarter-acre sample plot was established. The stand per acre contained 826 cubic feet (5 inches DBH and over), of which 492 were red oak, 67 beech, 49 white pine, 41 white oak, 31 black birch, 25 black oak, 20 hemlock, 14 yellow birch, and 12 paper birch. 412 trees per acre were free-to-grow, and averaged 45 feet in height.

Discussion:

Here is an upland stand that has apparently never gone through the white pine successional stage, because it has never been completely cleared. The present stand, which is composed largely of hardwood sprouts, owes its existence to the persistence of the oak stumps in sprouting, and to the fact that the forest canopy has been opened up four times in the last century. The understory of hemlock, red oak, and tolerant hardwoods presages the development of a hemlock-hardwood association in the absence of future disturbances. S.H.S.

October 17, 1946

Case 21-5

UNEVEN-AGED HARDWOODS AND PINE

West Portion of Compartment

TS I, stands 1 (part), 2, and 4, 1946
(Hd-3, 1937)
18 Acres

Soil:

Charlton stony loam.

Site:

Moderately steep, west-facing, mid-slope. Elevation 850-1000 feet.

Land-use History:

Part of House Lot 51 deeded to Joseph Whitcomb in 1733, the year of settlement. Probably used as pasture from early date until gradual abandonment around 1860. The extreme north-west corner of the area was apparently never completely cleared, it being recorded as woodland on the map of 1830 and in a deed written in 1888.

Silvicultural History:

Improvement cutting, 1908-9. Stand made up of small areas of fairly dense and even pole and sapling growth and other areas of scattered wolf trees over young growth. Trees 10 to 60 years old. Principal species were red maple, large-toothed aspen, gray birch, paper birch, chestnut, red oak, sugar maple, and white pine. Small groups of aspen, 1/2 acre or less in size, clearcut. Wolf hardwoods removed and pole hardwoods thinned. About 10 acres treated (records contradictory -- 6.5 to 15 acres) yielding about 3 cords of fuelwood and 3000 board feet of aspen box-boards per acre. Apparently more than half of stand volume was removed.

Salvage cutting, 1914-15. About 3000 feet of scattered chestnut was cut at foot of slope in northwest corner of the compartment to salvage it before it would be killed by the blight. Probably the cut covered about 3 acres.

Hurricane salvage. A clump of white pine blowdown, 1/2 acre in size, was salvaged in 1939, and 87 cords of fuelwood were cut in 1941-42, mostly in the eastern part of the area (now, stand 4). Leaning and down trees were removed.

Discussion:

This is a more or less uneven-aged stand because of its gradual development from a partly wooded pasture, the 1909 improvement cutting, and the scattered salvage cuttings of chestnut in 1915 and of hurricane blowdown in 1942. Consequently, the stand is a fairly good, if unpremeditated, example of a selection forest, and will be managed as such in the future. S.H.S.

October 18, 1946

Case 22-2

TRANSITION HARDWOODS

26-year-old Stand Unsuccessfully Planted

TS II, stand 2, 1946
(P-Hd-1, 1937)
1.8 Acres

Soil:

Charlton stony loam.

Site:

Low slope. Elevation 860 feet.

Land-use History:

Pasture until abandonment about 1850.

Silvicultural History:

Clearcutting, 1920. A mature stand of better hardwoods, 70 years old, mostly red oak and chestnut, with an increasing amount of pine on the east edge. Clearcutting yielded about 27,000 board feet per acre. 22 cords were cut per acre, mostly from the tops. Slash burned.

Planting, 1922. 750 red pine, 2-3 stock, planted throughout area to supplement natural reproduction. No tree was planted within 3 feet of useful advance growth. 11 man-hours per acre. Heavy natural stocking of white pine in east portion of stand, and of red oak seedlings throughout stand.

Weeding, 1923. Pines released from overtopping hardwoods. 10 man-hours per acre.

Weeding, 1926. To free pine so as to develop stemwise mixture of red pine and better hardwoods. Rank-growing stump sprouts cut. 11 man-hours per acre.

Weeding, 1931. Hardwoods occupy 80% of area. Best formed hardwoods and well-defined pine groups released from gray birch, pin cherry, black birch, and hornbeam. 10 man-hours per acre.

Inspection, 1938. Hardwoods occupy 90% of area. Red oak, white ash, and sugar maple being the dominant species.

Weeding, 1940-41. Large-crowned, coarse-limbed red oaks removed. Paper birch and white ash thinned. Pine groups released. 185 trees per acre, totaling 132 cubic feet, were cut -- about 25% of stand. 10 man-hours per acre.

Discussion: An excellent example of the futility of trying to grow softwoods on a moist low slope which has always come in to hardwoods, even after pasturing. The hardwoods today are of fine quality. S.H.S.