The relationship of species distribution to soil moisture in Compartment I, Tom Swamp Block, Harvard Forest.

by

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Outline of contents

I. Introduction

A. Historical background

In the years between 1840 and 1870 farming was given up on much of the land in central New England. These "abandoned" fields reverted to forest. Characteristically, white pine* dominated in most of the old fields to the exclusion of other species. The conditions that made the old field stands possible are still functioning but are not well known. This sequence of events resulted in enormous tracts of nearly pure white pine which began to mature late in the 19th century. In the early years of the 20th century this resource had become the base of a valuable wood using industry. In these surroundings, the Harvard Forest was established in 1908.

In the usual course of events, transition hardwoods** followed the removal of the old field pines. One of the original precepts of the staff at the Harvard Forest was that with proper silvicultural treatments, pine could be made to regenerate itself inexpensively on these cutover lands (Fisher, 1921). Dense stands of seedlings were easily established following cuttings made in good seed years. This desired reproduction was accompanied and (or) followed by a vigorous growth of hardwood seedlings and sprouts that had to be held back if the pines were to survive. This was true even on areas that had produced large volumes of pine, but despite continued discrimination against them, hardwoods dominated most of the new stands. (Lutz and Cline, 1947)

*See page 1a for scientific names of all trees referred to by common names in this study.

**Synonymous to type 8, northern forests, Journal of Forestry 30 : 461.

This successional trend is the rule on the finer textured, more compact, upland till soils of the transition hardwood region. Such soils, neither extremely wet nor dry, occur on 80% of the Harvard Forest. Intensive efforts to reestablish white pine on them met with failure so nearly universal that they came to be known as "hardwood sites". The comparitive ease with which the succession could be halted on the sand and gravel outwash plains caused them to be known as "pine sites". These, with the permanently wet lands, made up the remaining 20% of the Harvard Forest. Hardwood sites similarly outnumber pine sites over most portions of the transition hardwood region.

Attempts to reestablish white pine on hardwood sites were abandoned upon recognition of the difficulty and consequent expense of doing so with the methods then in use. The staff of the Harvard Forest had to choose among alternative methods when restocking cutover old field pine stands.

1. Intensive pasturing to restore conditions favorable to the reinvasion of white pine. This has obvious economic limitations.
2. Restock the area by planting, a method proven nearly as laborious and uncertain of outcome as natural regeneration of white pine. (Lutz and Cline, 1947)
3. Work with nature, favoring the best trees in the new stand of transition hardwoods.
4. Establishment of mixed stands, retaining all softwoods that gave evidence of ability to compete successfully with the hardwood majority. (Cline and Lockard, 1925)

Skillful use of the last two methods demanded a more precise site evaluation than pine, hardwood, swale, or marsh. While it was not difficult to establish a satisfactory growth of species adapted to extremely wet or dry sites, varying degrees of success had been achieved on the hardwood sites. Mixed stands did well in some places, not in others. Tracts devoted to pure hardwoods showed composition differences unexplainable in terms of site evaluation methods then in use. To inexpensively produce large amounts of quality wood on hardwood sites it was essential to learn the effects of factors influencing composition and growth on these areas.

B. Studies of site factors influencing stand composition on the Harvard Forest.

Methods of site evaluation in past use at the Harvard Forest have ranged from general observations of topography to precise measurements of sunlight. Comparisons of topsoil; good or poor, loamy or sandy, heavy or light, have been in general use. Such factors as slope, aspect, humus layers, fertility, acidity, and indicator plants have been used with varying success. The complexity of the interrelationships between these and the other factors of site make it unlikely that any of the above will be generally useful as measures of site quality.

Theoretically, the soil profile is an accurate guage of site quality. Each site is assumed to develop its characteristic profile in response to the influences of parent material, climate, physiography, and plant and animal life. However, the endless variety of these influences develops such a profusion of profiles that it is safe to assume no two alike. Furthermore, disturbances such as fire, wind, erosion, and floods can cause vast and immediate changes in soil profiles. The Soil Survey of the U. S. Department of Agriculture has, to make classification possible, grouped certain ranges of recurring profiles into soil types.

During the years 1939 to 1941 the Soil Survey prepared soil type maps of the Harvard Forest. Modern maps of this sort can be of considerable assistance in site evaluation, although users lacking detailed knowledge of their preparation and interpretation and sensing their strong agricultural bias, may consider them of limited use in forestry. The soil maps did lead to abandonment, at Harvard Forest, of organic horizons as indicators of site quality, substituting consideration of the entire depth from the land surface to ten or fifteen feet below as the potential root growing zone. The introduction of depth into studies of soils on the Harvard Forest gave recognition to parent material, impervious layers, and fluctuating water levels as important factors of site. Attempts to relate the units of the soil maps to associated forest cover became a common and, on the hardwood sites, an unsuccessful student exercise. There was little difficulty on soils of extreme wetness or dryness where the relationships between trees and soils had been established previously by use of older methods. This inability to relate tree growth to soil map units on the hardwood sites has two explanations; (1) use of small scale reconnaisance symbols on large scale maps and (2), probable failure to locate and record accurately soil boundaries that, as defined, are not easily mapped.

The following excerpts from Spurr (1950) indicate some of the limitations of the present soil maps as a technique of site evaluation on the Harvard Forest.

"In working with the soils maps of the forest over a period of years, in accompanying the soil surveyor on his work, and in trying to correlate forest composition with the established soil types, it became evident to the author that hard-and-fast distinctions between soil types were hard to make." (Page 129)

"That the parent materials of the local soils are relatively uniform, or at least so mixed up as to form a local zonal complex of Charlton - Brookfield - Gloucester soils has been demonstrated. (Page 161)

"Every indication points to soil moisture being a controlling factor in forest vegetation in the Petersham area, with other soilcharacteristics being, locally at least, of relatively little importance." (Page 148)

There is substantial agreement with the last comment in the work of Hicock (1931), Westveld (1933), Diebold (1935), Lunt (1948), and Westveld (1952). Other investigators, apparently working with factors other than soil type, found soil moisture to be the only factor that could be correlated consistently with tree growth (Tillotson, 1913; Pearson, 1920; Corson, 1929; Auten, 1930 and 1945; and McDermott, 1954). This finding is so nearly unanimous that the one discovered exception to it is quoted. "On the soils studied, the influence on forest tree growth of wide differences of height and duration of water table was not striking." (Spaeth and Diebold, 1938)

Stout (1952), working on hardwood sites of the Harvard Forest, was able to relate the presence of red oak in a dominant position to a rooting zone of more than twenty inches to a compact layer and a locally convex topography. White ash was commonly dominant where the compact layer was less than twenty inches below the surface of the ground and the local topography concave. The compaction was assumed to temporarily perch the water table in the rooting zone. No attempt was made to apply these findings over areas larger than relatively small plots.

Three more excerpts from Spurr (1950) indicate a method of site classification stemming from use of the present soil maps.

"The safest and most useful classification of the soils of the Harvard Forest might well be a generalized one based solely upon mode of deposition of parent material and upon moisture relations." (Page 130)

"Other than a difference in fertility between upland and outwash soils, moisture appears to be the major soil characteristic which markedly effects forest composition." (Page 161)

"The associations of the Harvard Forest, far from being made up of a hodge-podge of species scattered indeterminately over the area, constitute a regular series of types, composed predominately of a surprisingly few species, and closely correlated to successional stage and site as expressed in terms of soil moisture." (Page 102)

C. The problem.

A majority of the references cited show soil moisture to be an important determinant of forest composition. The working hypothesis of this study was that soil moisture regime controls the local distribution of tree species on the Harvard Forest. The soil profile has been used as an indirect measure of soil moisture regime, a condition not well adapted to direct measurement, (Robinson, 1936; Lutz and Chandler, 1947; Soil Survey Manual, 1951; and Hills, 1954). At any point in the forest, soil profile development is assumed to be a relatively unchanging condition in the absence of severe disturbance; e.g. fire, wind, erosion, or tillage. Mapping units of soil profile development and of forest cover were identified on the ground and recorded on seperate maps. The validity of the hypothesis was tested by superimposing maps of the two conditions and noting coincidence of the mapping units.

D. The study area.

These provisions governed the selection of a study area.

1. An upland hardwood site with a minmum of topographic irregularity.
2. Soils developed on lithologically similar tills.
3. A uniform history of land use.
4. A well stocked, even aged stand of transition hardwoods.
5. A minimum history of recent silvicultural treatment.

No tract of the Harvard Forest was found to qualify on all counts. Physically, the eastern end of compartment I, Tom Swamp

Block was entirely acceptable and was chosen for the study area. Its outstanding disadvantage was a long history of silvicultural treatment that would cast doubt on any assumed relationship between species distribution and the factors of site. It was felt that such doubt could be minimized by study of the records, observation of the evidences of cutting, and a constant awareness that man has been a factor in the development of the stand. An interesting possibility is to rate the effectiveness of past treatments favoring white pine in altering composition on this part of the forest.

The study area lies on a drumloidal hill and has an average slope of 12% to the north-north-west (see figure 2). The village of Petersham lies one half mile to the east. Elevation is from 980 to 1100 feet above sea level. The bedrock is uniformly of Hardwick Granite (Emerson, 1912). Soils are of the Charlton catena (Simmons, 1939). Prior to 1908 the area had an essentially uniform history of land use (Raup and Carlson, 1941). For stand descriptions and histories since the removal of the old field pine see Lutz and Cline (1947), particularly pages 39 through 50.

II. Soils

A. Mapping

Preliminary examination of the soils of the study area with an auger showed a well defined range of moisture conditions closely related to local topography. Situations of maximum moisture, found on concave surfaces, had dark, shallow horizons tending to grayness. A compact layer occurred 16 to 20 inches below the surface and carried a vigorous flow of seepage water. Situations of minimum moisture, found on convex surfaces, had

Horizon	Typical dry profile	Depth in inches	Typical intermediate profile	Depth in inches	Typical wet profile
A_1	Texture, loam or coarser Least organic content Surface convex Many fine roots, no large Worm middens scattered, over 10" apart Least numbers of worms	1 2 3 4 5 6 7 8	Texture loam or finer Higher organic content Surface usually concave Some large roots Worm middens very frequent less than 6" apart Greatest numbers ofworms.	1 2 3 4 5 6 7 8	Texture loam or finer Highest organic content Surface concave Large roots common Worm middens frequent, 6" to 10" apart Worms common
B_{21}	Color dark brown (7.5 YR 4/4) No mottles Uncompacted Little mixing by worms	9 10 11 12 13 14 15 16 17 18 19	Characteristic color, olive brown (2.5 Y 4/4) Not usually mottled Uncompacted Well mixed by earthworms	9 10 11 12 13	Characteristic color, very dark brown (10 YR 2/2) Usually some mottles Uncompacted Some mixing by worms
B_{22}	Uncompacted Strong brown to dark yellowish brown No mottles Zone of maximum water movement	20 21 22 23 24 25 26 27 28 29 30	Uncompacted Dark brown to olive brown (10 YR 3/3 to 2.5 Y 4/4) Few, fine, faint mottles Zone of maximum water movement	14 15 16 17 18 19 20 21	Compact Very dark gray brown (10 YR 3/2) Mottles coarse, distinct Zone of max. water movement
C_{gm}	Weakly cemented Mottled Appears to be dry even when saturated Few fine roots	31 32 33 34 35 36 37 38 39 40	Weakly cemented Mottled Appears to be dry even when saturated No roots encountered	22 23 24 25 26 27 28 29 30	Weakly cemented Mottled Appears to be dry even when saturated No roots encountered

Figure 1. Summary of soil characteristics, detectable with a soil augur, used as mapping criteria in T. S. 1.

*Moisture at or above field capacity.

brighter colored, unmottled, thicker horizons tending to reddish or yellowish. The compact layer occurred 30 to 36 inches below the surface and carried a less vigorous flow of water. At the time of mapping the moisture content of the soil was at or above its field capacity. Borings taken midway between areas of maximum and minimum moisture conditions clearly indicated the transitional position of these soils.

The terms wet, intermediate, and dry* were selected to identify the three recognized conditions of soil moisture on the study area. Nine circular plots of fifty feet in radius, three each of wet, intermediate, and dry soils were chosen for further study. Closely spaced borings in each plot had revealed nearly uniform profile development characteristic of one of the three drainage conditions. Pits dug near the center of the plots furnished information for detailed profile descriptions. (See pages 2a - 4a.) Features found to be common to profiles of each drainage condition were selected as suitable mapping criteria. (Figure 1) Profile features not identifiable with a soil auger, such as structure and consistence, were later discarded as unsuited for use with this method of mapping soils.

As experience was gained in mapping, color at fifteen inches below the surface was found to be an easy and reliable test of profile development. On dry soils a dark brown color was characteristic; on intermediate soils it was olive brown, and on wet soils a very dark gray brown. These colors apply only to the

*It must be kept in mind that these are relative terms, applicable only to that part of the range of soil moisture conditions found on the "hardwood sites". Extremes of droughty or saturated soils were not a part of this study.

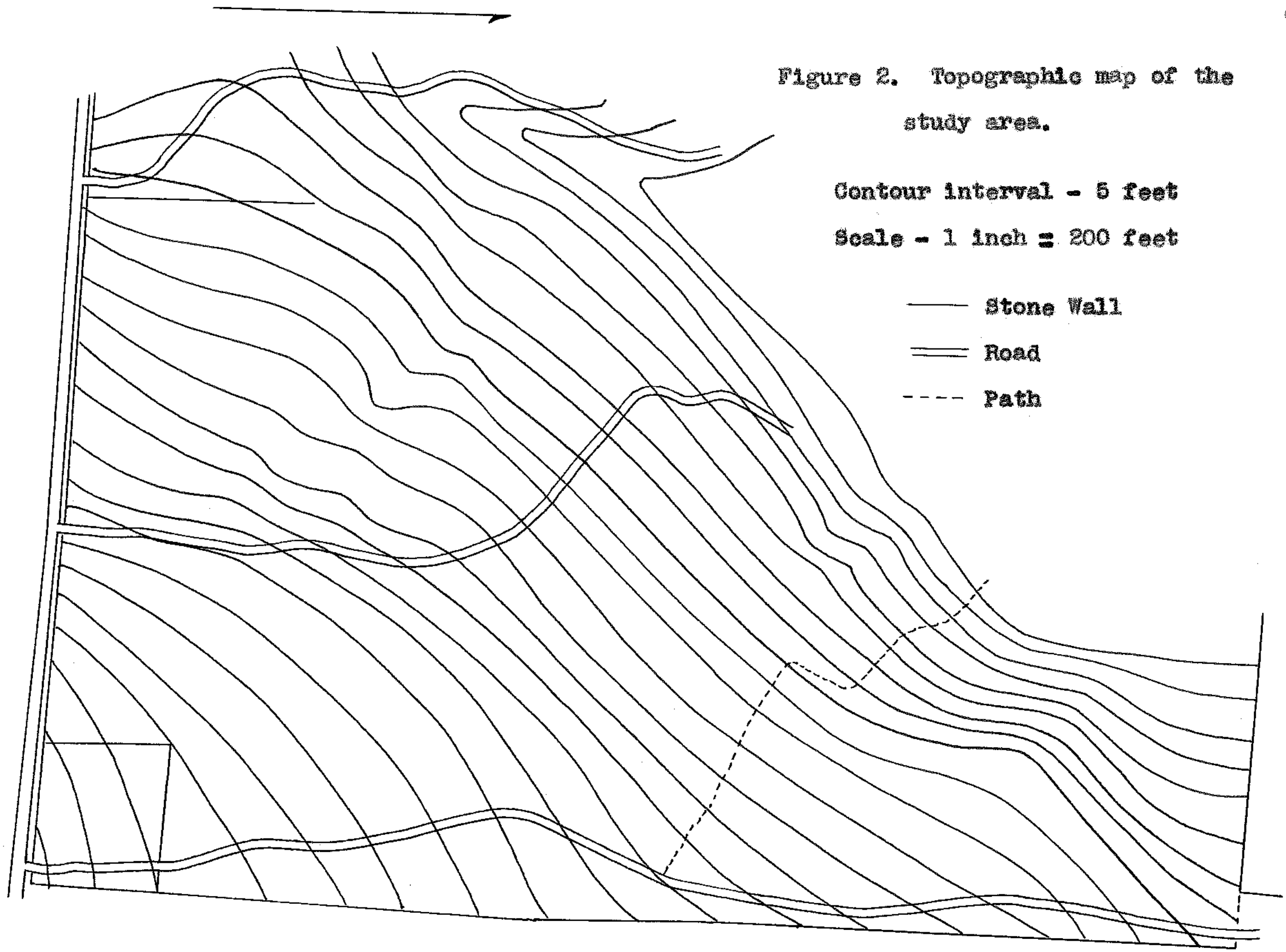

Figure 2. Topographic map of the study area.

study area and, even there, are not found universally. When positive identification could not be made by color, depth to mottling and depth to the compact layer were found to be good means of identification. Small glass vials containing samples of the three soils were carried for purposes of comparison to insure unchanging interpretation of color while mapping. Color names used in describing these soils are those accompanying the Munsell Color Charts.

Wet soils were identified by making borings away from the centers of depressions at ten to twenty foot intervals until an intermediate profile was encountered. The point judged to seperate wet from intermediate soil was marked with a small flag. This process was repeated at 50 foot intervals until the line of flags was closed, thereby identifying the wet soil boundary as closely as the mapping criteria permitted. Dry soils were identified by making a similar series of borings away from the crests of knolls, ridges, and other minor elevations until an intermediate profile was encountered. A boundary was again formed by closing a line of small flags. Soils between those identified as wet or dry were then checked with the auger and, if found to be of sufficient uniformity, mapped as intermediate soils. The location of each boundary, as identified by the flag lines, was recorded with a surveyors transit and a stadia rod.

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These methods, admittedly unusable for most soil survey purposes, were felt to be justified as a research measure. Inaccurate boundaries have been found to be the commonest fault of most soil maps. (Soil survey manual, 1951) It is felt that

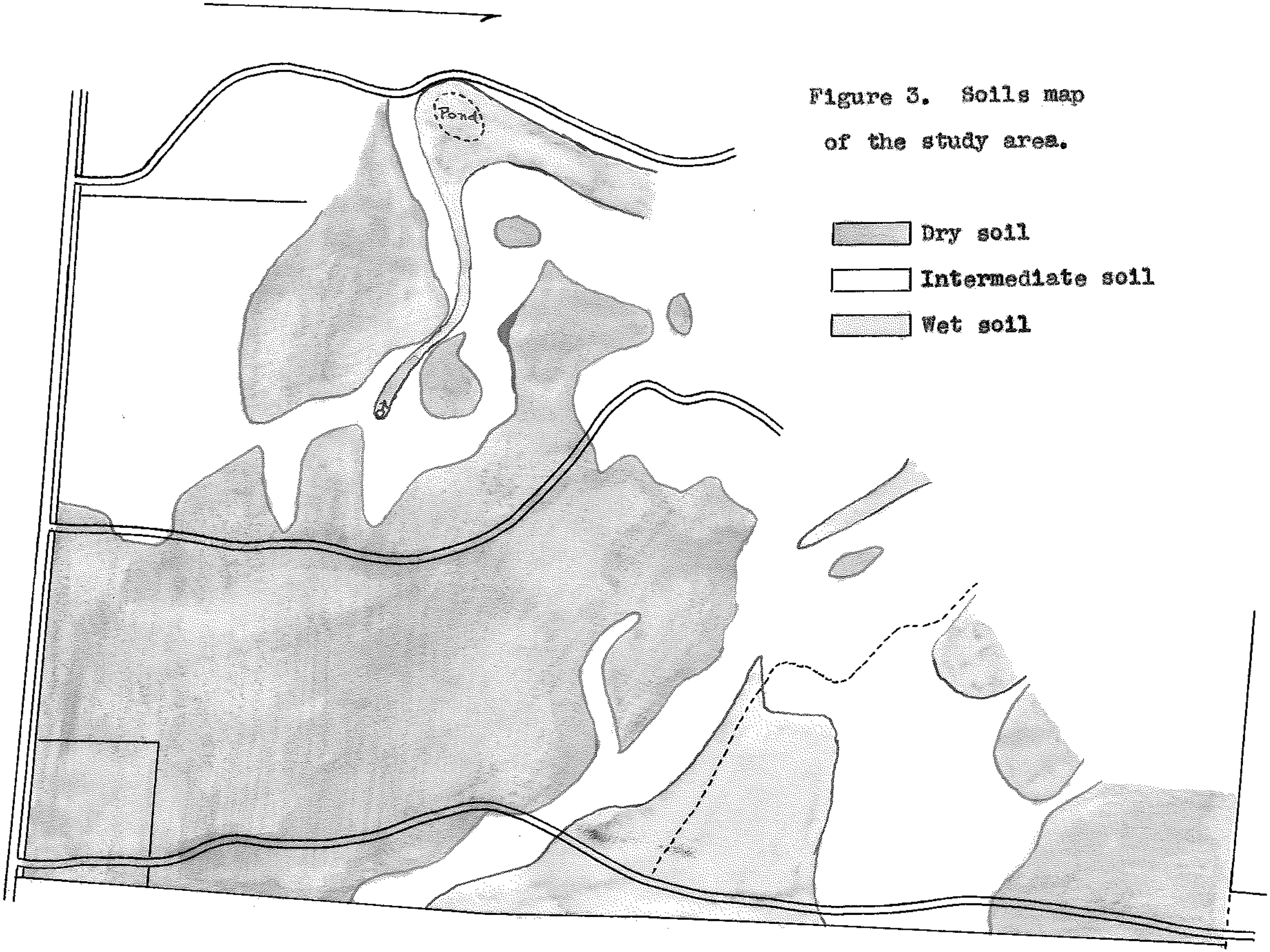


Figure 3. Soils map of the study area.

the finished map represents soil moisture conditions with considerable accuracy.

Reference to Simmons and the Soil Survey Manual will more closely identify wet, intermediate, and dry soils in pedological terminology. For convenience, these passages are quoted in the appendix, pages 5a through 7a. Dry soil is comparable to the well drained classification and closely resembles Simmons' Charlton. Wet soil is comparable to the poorly drained classification and is similar to Simmons' Whitman but probably insufficiently water retentive to fit the present day description of that soil. Intermediate soils combine the moderately well drained and somewhat poorly drained classifications. They are the transitional areas from wet to dry soils most closely resembling the Sutton of Simmons' map.

B. Water fluctuations within soil types.

Records were maintained from November 18, 1955 until July 21, 1956 on variations in the fluctuations of free water in the nine pits used for profile descriptions. The only major break in the records is the time from December 18 until April 16 when the soil was frozen. Sixty five readings were made over a period of 128 days. No readings were taken from the time a hole went dry until the next rain. Readings were taken on alternate days before the foliage was fully emerged as fluctuations were much slower at that time. Figure 3A is the record of the levels of the water in each hole over the 128 day period.

A number of relationships become apparent upon examination of figure 3A. The most striking is the very much faster rate at which water of saturation is withdrawn from the soil after the full emergence of the foliage. There is a direct relationship

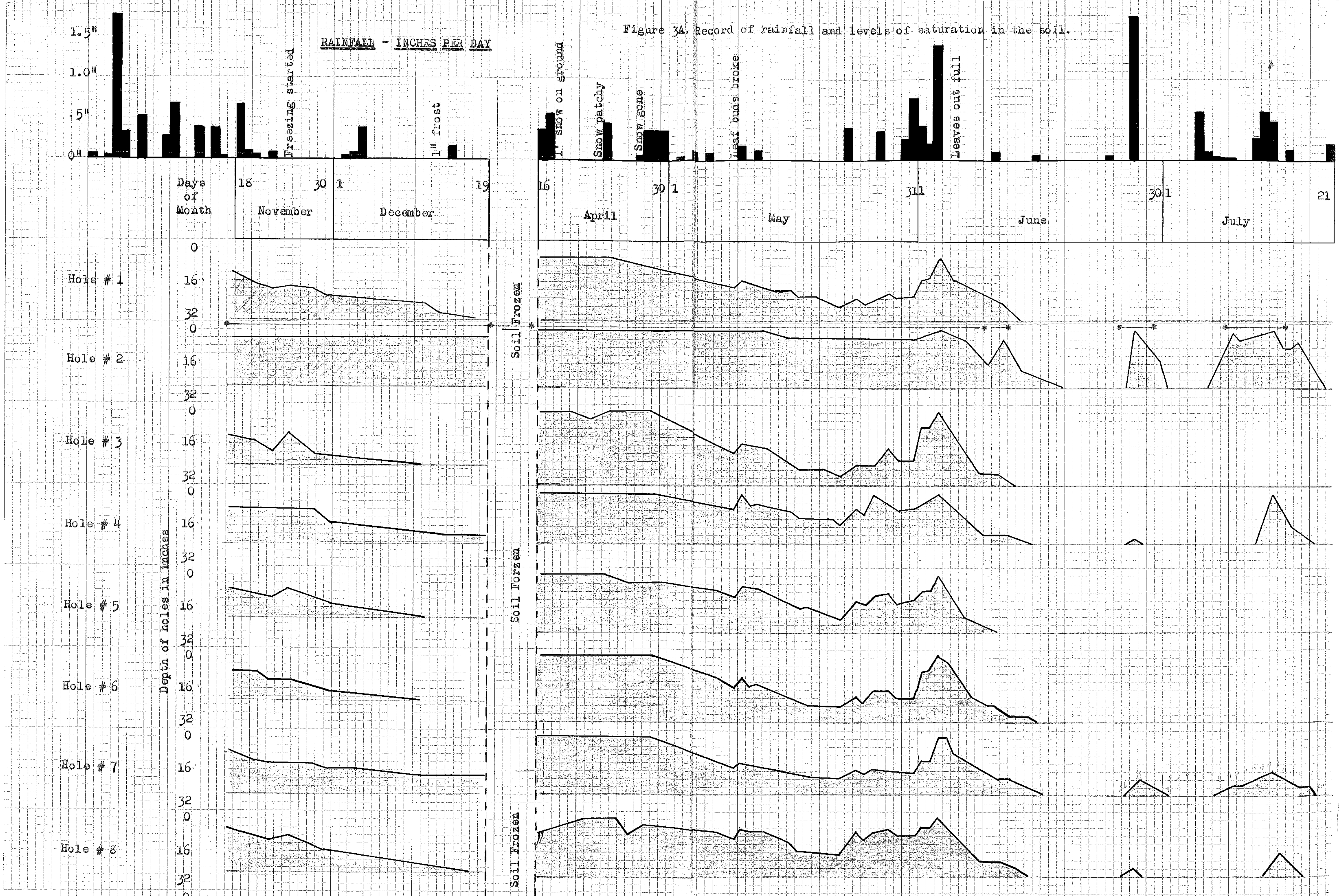


Figure 3A. Record of rainfall and levels of saturation in the soil.

between the level of saturation in the large area of wet soil and the small intermittent stream entering the study area from the swale to the east. Figure 3B shows that hole 2 lies closest to the stream and to its source. This hole was never found filled unless the stream had commenced flow, and the water level never fell below 6 inches until it had ceased to flow. Holes 9, 4, 8, and 5 are next nearest the stream and respond in about that order to variations in the volume and duration of its flow. The storm of June 28 caused hole 2 to fill to the surface, but resulted in only partial filling of holes 4, 8, and 9. The flow of surface water was visible until June 30 for several feet past hole 2 where it was absorbed into the soil. Presumably, the volume and duration of surface runoff was insufficient to saturate the entire area of wet soil. During the more protracted rainfall of July 12 to 14, saturation was reached on holes 2, 4, and 9 but hole 8 only partially filled as stream flow past it was of only a few hours duration.

It seems signifigant that white ash, predominant over the entire area of wet soil, appears to be most vigorous between hole 2 and the stone wall to the east, the wettest site on the study area.

Hole 7 responded to rains of December 4 and July 16 that had no effects on other holes in intermediate soils. It showed a more protracted response than any other hole to the storms of June 27, July 5, and July 12 to 14. It was the only hole to remain full for two days after the rains of June 3 and the only one on intermediate soil to contain water throughout the month of December. These variations from the behavior of the water levels in the other pits are assumed to be due to the additions of seepage or flows of underground water. Hole 7 is at the lowest

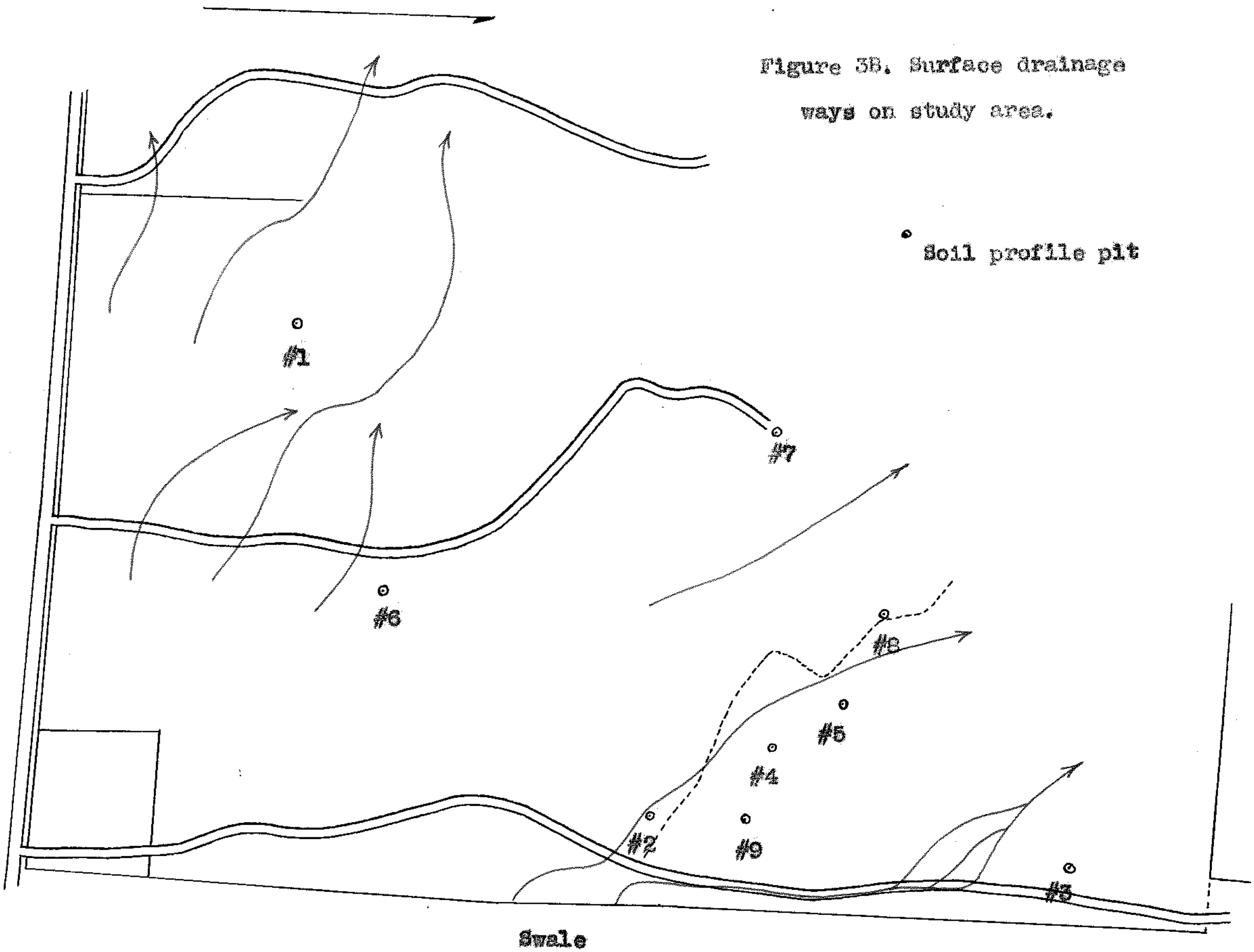


Figure 3B. Surface drainage ways on study area.

elevation of any soil pit and has a long slope of dry soil underlain by compact till lying directly above it and to the east. It is surprising that seepage flow has not been indicated in holes 5 and 8 as they are in positions where it is often encountered.

Holes 1, 3, 5, and 6 dried out most rapidly after snow melt and after the rain of June 3. They showed no response to rainfall after the emergence of the foliage. Hole 1 was not observed to fill over the six inch level. It is of interest to note that this, the dryest soil, supports the largest red oaks. (See page 17a.) It also carries the only stand containing appreciable quantities of white pine, 9.3%. However, the presence of a stand of relatively successful pine on this soil becomes less remarkable when white pine of equal age is encountered in somewhat lesser quantities on the intermediate soils to the south and east.

Total percipitation for the period November, 1955 to July, 1956 was 29.72 inches on the recorder at the forest headquarters. This is 1.48 inches below the average for that period. There were some responses of saturation water levels to rainfall when none was indicated on the recorder, three miles from the study area. (See Nov. 24, figure 3A.) There is no response in any hole to the six-tenths inch storm of July 5 and a marked response to the .04 inch rainfall of July 9. These inconsistencies must be due to differences in the local patterns of rainfall and could have been overcome by use of a rain guage on the study area.

Table 8 summarizes the water level data contained in figure 3A. It shows plainly the greater depth of rooting space above the C horizon available to trees growing on dry soil. No attempt was made to record the fluctuations of the free water in the C horizon.

Table 1. Numbers of days during which free water occurred at given levels in the soil profile pits.

Hole No.	Depth in feet from the surface to free water in soil pits. 0'	½'	1'	1½'	2'	2½'	3'	Total
1	0	9	11	18	23	23	44D	128
2	30	63	9	5	5	16D	-	128
3	9	11	5	18	15	22	48D	128
4	17	14	32	16	22	27D	-	128
5	7	12	28	19	13	49D	-	128
6	14	6	16	15	28	5	44D	128
7	15	14	12	40	38	19D	-	128
8	5	20	31	13	20	39D	-	128
9	12	28	42	11	13	22D	-	128

D indicates numbers of days when holes were dry.

The numbers of days during which free water occurred at each level was multiplied by the value in feet for that level. The product was "day-feet", an expression of the relative quantities of unsaturated soil in the rooting zone at each soil pit. Dividing total day-feet for each soil pit by 128, the number of days of record, gave a weighted mean depth in terms of feet of unsaturated soil for the three examples of each of the three soil types.

Table 2 (next page) shows a definite relationship between soil type, as defined in this study, and ~~in~~ the weighted mean level of free soil water, over the period of the record. Comparison of the values in the column "Weighted mean depth of saturated soil" with "Depth to mottling" shows a distinct similarity on holes 4, 5, 7, and 8. There is no relationship between these values on holes 1, 2, 3, 6, and 9. It is suggested that an entire years record of soil water fluctuations might show greater coincidence of these figures. The present record begins and ends during the season of maximum soil moisture conditions.

Table 2. The relationship of day-feet of unsaturated root growing space to soil type.

Increasing order of wetness.	Hole number	Day-feet	Weighted mean depth of unsaturated soil	Depth to mottling*
Dry soils				
1	1	278.0	2.17' - 25"	Below 35"
2	3	266.5	2.08' - 25"	Below 31"
3	6	242.0	1.89' - 23"	Below 28"
Intermediate soils				
4	5	211.0	1.65' - 20"	16" - 22"
5	8	198.0	1.55' - 19"	13" - 21"
6	7	197.5	1.54' - 19"	13" - 20"
Wet soils				
7	4	174.5	1.36' - 16"	13" - 17"
8	9	153.5	1.20' - 14"	15" - 20"
9	2	98.0	.77' - 9"	18" - 25"

*Information taken from profile descriptions, examples pg. 2a - 4a.

Root development is almost entirely confined to that portion of the soil profile above the compact till (Soil Survey Manual, Stout, pages 2a - 4a). The rooting zones of dry, intermediate, and wet soils have been shown to have measurable differences in drainage. Variations in drainage have been found to be of considerable signifigance (Lutz and Chandler, 1947) through direct effects on soil aeration and the resultant indirect effects on the chemical, physical, and biological activities within the soil. The effect of soil type on species distribution will be considered in the remainder of this paper.

III. Species distribution

A. Mapping method

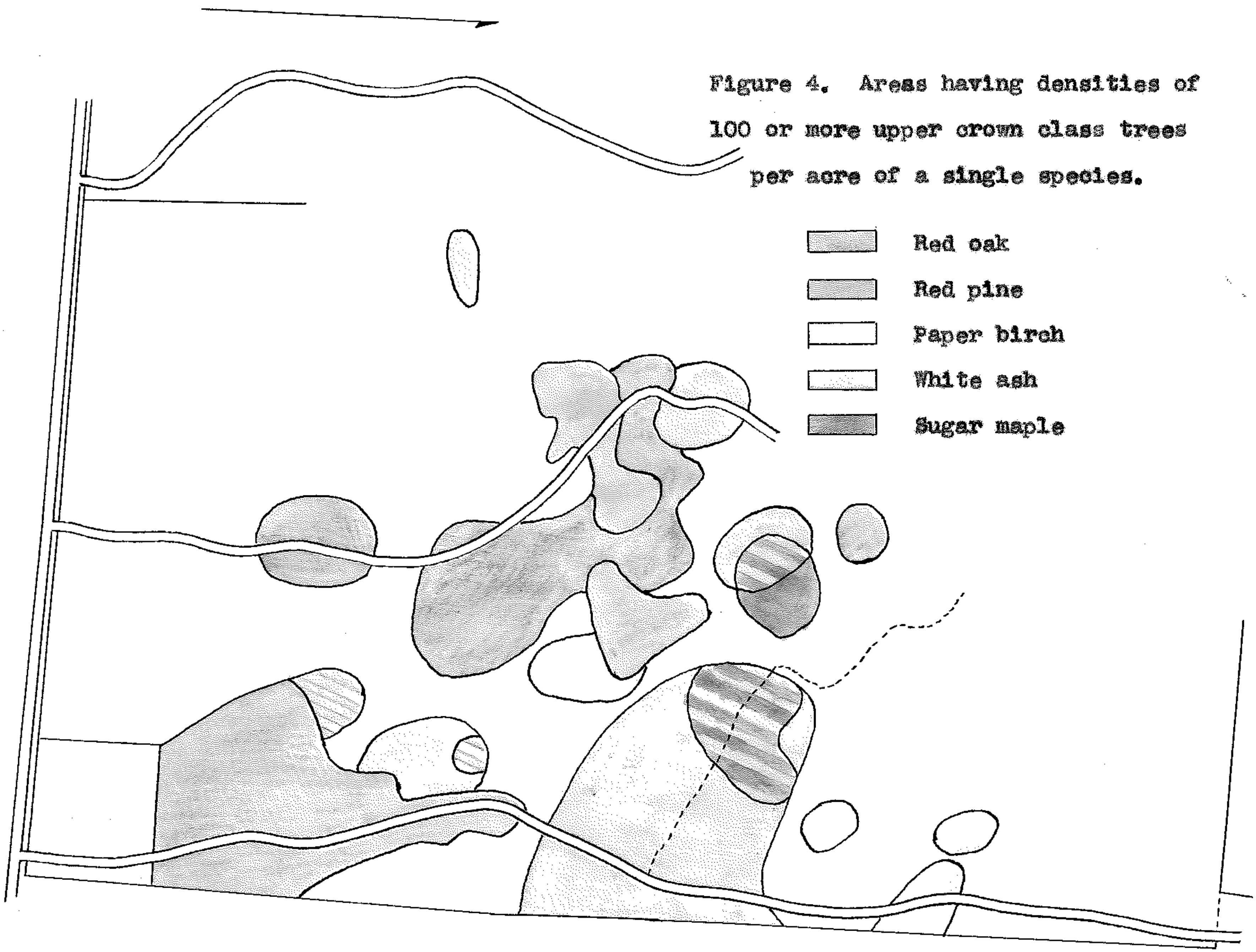
The north-south wall that forms the eastern boundary of the compartment was used as a base line for cruising the study area. Parallel cruise lines were laid out at 60 foot intervals at right angles to the base line. A hand compass was used to extend the cruise lines along a magnetic bearing of N 75 W to the western edge of the study area. All upper crown class* trees growing not more than 6.6 feet from either side of the cruise line were tallied. This spacing achieved a 22% cruise of the area. All trees were numbered when tallied to simplify relocation. Tally information included the species and assigned number of each tree, its distance west from the base line, and its distance north or south from the cruise line.

All tallied trees were plotted on a base map of the study area. Colored dots represented the location of each tree. From this base map, species distribution maps were prepared for each kind of tree encountered. Several facts became apparent immediately from observation of the tally figures and the species maps.

(1) Four species compose 84% of the upper crown class trees on the study area. White ash was the most numerous (30%), followed by red oak (22%), paper birch (20%), and sugar maple (12%). See cruise summary, page 8a.

*For these purposes, an upper crown class tree may be defined as one having (1) the top of its crown over the midpoints of the live crowns of the adjoining overstory trees and (2) over half its crown with overhead space unoccupied by other crowns, and into which space it can expand. (E. Gould, Experiment 56 -2)

Figure 4. Areas having densities of 100 or more upper crown class trees per acre of a single species.



(2) There are surprisingly few places where the population per acre of any species exceeds 100 upper crown class trees per acre. With an average density of 450 upper crown class trees per acre, a fairly uniform forest composition is indicated. (See figure 4.)

(3) Red maple, a tree of universal occurrence in the Harvard Forest, constitutes only 5.4% of the upper crown class trees on the study area.

(4) Yellow birch, usually considered a wet land species, is present in greatest numbers on dry soil while virtually absent on the wet soils.

(5) Red maple, black and yellow birch, and white pine compose 14% of the upper crown class trees on the study area.

(6) Basswood, hickory, hop hornbeam, elm, gray birch, white oak, and beech compose the remaining 2% of the stand. (See page 9a for the results of a 100% cruise of these minor components of the stand.) It was felt that small numbers and spotty distribution invalidated any conclusions that might have been drawn as to the presence or absence of these species on the various soil types.

B. Stand descriptions

To simplify handling the mass of unsorted data on the base map, the study area was divided into stands based on relative numbers of species of upper crown class trees. Eight of these stands were identified and outlined on the base map. The outlines were later adjusted to greater accuracy by on-the-ground examination of the various stands. A brief description of each stand is presented on the following pages. (See also pages 10a-17a)

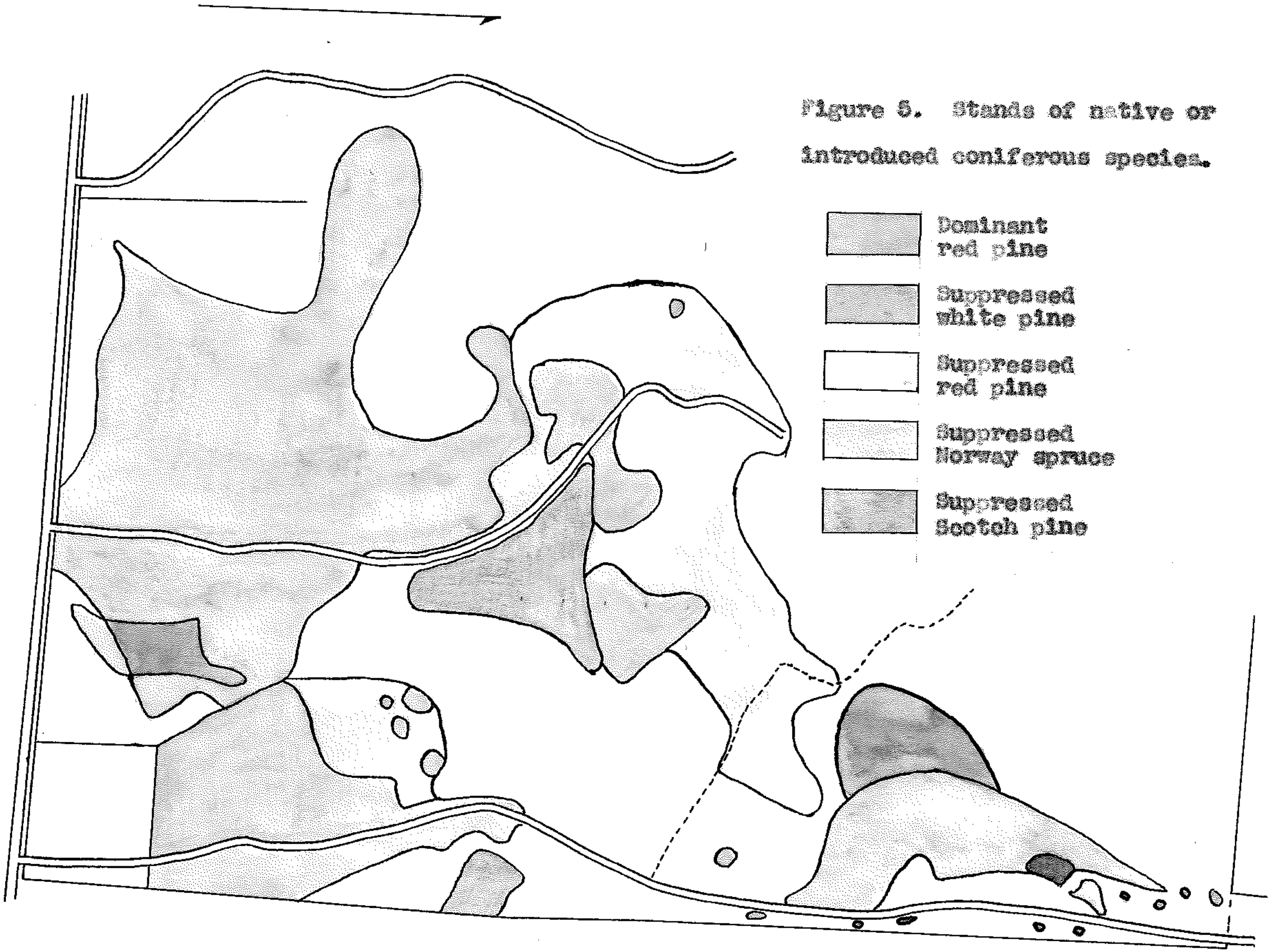


Figure 5. Stands of native or introduced coniferous species.

Stand 1.

The cruise figures indicate a much higher percentage of red maple in this stand than actually exists. This is taken to be the result of chance, inherent in the sampling method when so few trees compose the sample. On the ground, the stand appears to be a nearly equal mixture of red maple, white ash, and the birches. No discernable differences were found in the dry soils under this and those under the surrounding stand 2. Stand 1 is considered the chance result of seed dissemination.

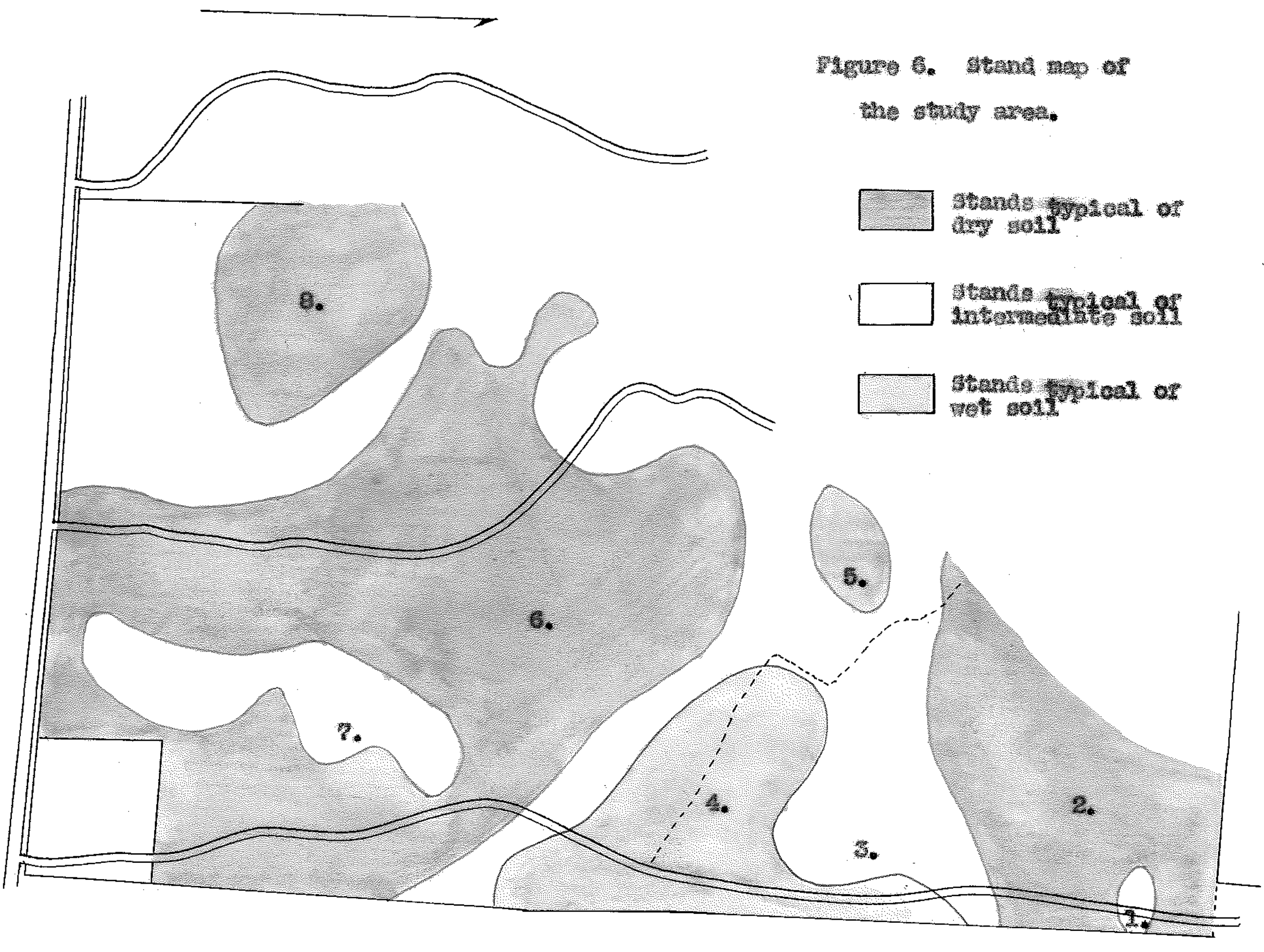
Stand 2.

It is apparent, both on the ground and from the cruise summary, that the birches predominate in this stand. Examination of the map of plantation species (figure 5) shows that Norway spruce, white and Scotch pines were planted extensively in this area following the removal of the old field pine. The records (TS 1, thinnings of 1910 and 1911) note a poor type of advance growth dominated by red maple, a species heavily cut in subsequent weedings. The light seeded birches probably took over these "improved" areas. Personnel at the Harvard Forest have long regarded the birches as "crown sensitive" species and have favored their growth in proximity to coniferous plantings. The soils are predominately dry, sloping, sometimes sharply, to the northwest. There are pockets of intermediate and wet soils in the drainageways.

Stand 3.

White ash is the commonest tree in this stand, but red oak and paper birch occupy a larger proportion of the canopy. The stand may be characterized by saying that no species is clearly predominant. In general, it lies on intermediate soils.

Figure 6. Stand map of the study area.



Stand 4.

White ash clearly dominates this stand. Where red oak and paper birch have come in they are larger, faster growing trees but there are not many of them. Sugar maples are numerous in the canopy and form, with ash, a dense understory. This stand is on the wettest soils in the study area. An intermittent stream through the center of the stand carries considerable runoff and drains the swale to the east.

Stand 5.

In numbers and position red oak is the dominant tree, closely followed by the birches. White ash and the maples form a considerable understory. The stand occupies a small, very rocky ridge having dry soil on its uppermost portions.

Stand 6.

Similar to stand 5 but with less black and yellow birch and more white ash and sugar maple in the canopy. Redoak is clearly the predominant tree with paper birch its closest competitor. The stand occupies dry soils with local overlaps into intermediate soils. It is the third largest stand on the study area.

Stand 7.

This is, in several ways, the most interesting stand on the study area. The soils underlying it are practically indistinguishable from those carrying pure red pine to the east and the red oak - paper birch stand to the north and west. Many of the remaining red oaks show cutting injuries. There is a higher percentage of suppressed white pine in this stand than in any other and there is some red pine. Paper birch is the largest and best tree in the stand. A considerable decrease in height and diameter of the trees is apparent as the observer goes from the adjacent stand 6 into this one. The proportions of species composing this stand are very similar to those in stand 3, an effect of management to further considered.

Stand 8.

This stand occurs in a portion of the forest where a limited success attended efforts to bring white pine into the canopy. Almost 10% of the upper crown class trees are white pine. Red oak is clearly the most successful tree although the sample taken does not bear this out in numbers of stems as well as volume per tree. The dry soil supporting the stand has developed on a small knoll surrounded by intermediate soils.

C. Volume studies.

All numbered trees on the cruise lines were revisited and measured for DBH and total height. Diameters were read to the nearest one-tenth inch with tree calipers. Heights were estimated by eye to the nearest foot with frequent checks, using the Forest Service hypsometer. The largest stands, assumed to be the best samples, reveal volume differences coincident with soil type.

Table 3 (next page) indicates a progressive lessening of volume per acre and of average volume per tree in the range from wet to dry soil. Had the excellent red pine growing on stand 6 been included in the tally, the volume figures for that stand would have been somewhat higher. The table assumes an equal

Table 3. Variations of volume with soil type.

Soil type	Stand number	Acres	Total vol. in stand	Volume* per ac.	No. h'w'd. trees	Ave. vol. per tree
Dry	6	1.896	2437.94'	1286'	816	2.98'
Inter.	3	1.904	2400.94'	1261'	981	2.45'
Wet	4	.672	782.05'	1164'	505	1.54'

*All volume figures expressed in terms of cubic feet.

age for all stands, an erroneous assumption as the areas on which these stands occur were clearcut between 1915 and 1923 (figure 8). To eliminate all known sources of error, table 4 was derived from portions of stands of transition hardwoods containing no conifers, each of two acres extent, of known age, and having as nearly similar histories as possible.

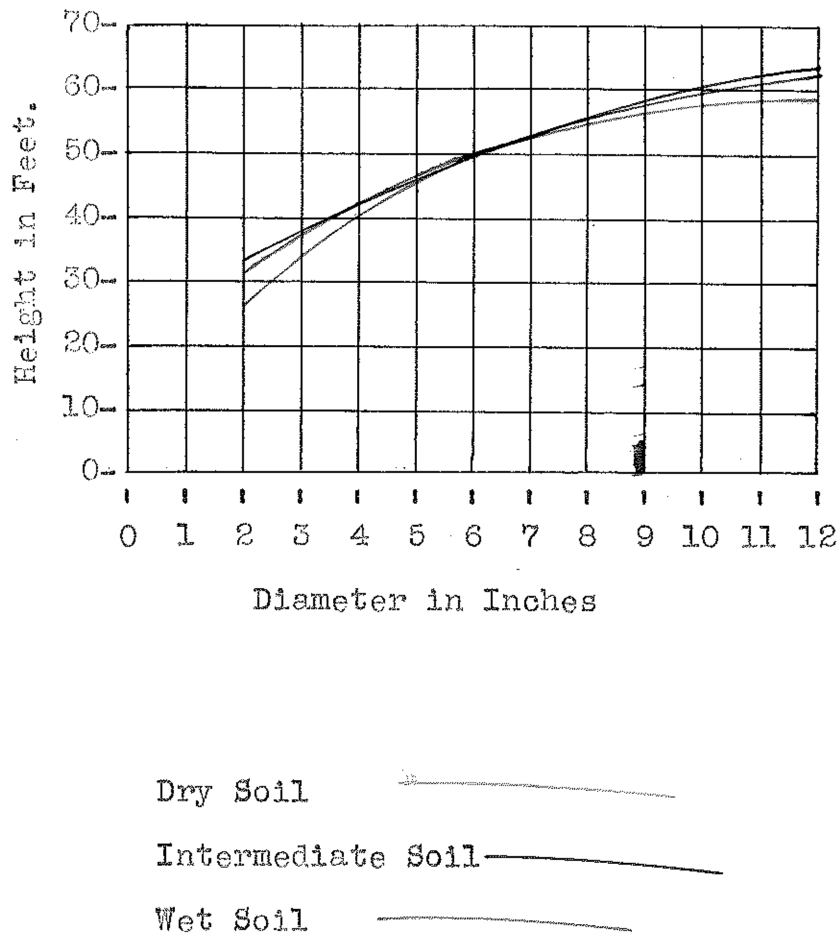
Table 4. The influence of soil type on average annual volume growth.

Soil type	Stand number	Volume per acre in cubic feet	Trees per acre	Volume per acre	Age of stand	Ave. vol. produced per acre per year
Dry	6	1445	470	3.07'	38	36.1'
Inter.	3	1272	640	2.00'	38	33.5'
Wet	4	1100	825	1.33'	35	31.6'

Table 4 shows volume figures per acre and per tree of the same magnitude as those in table 3. The average volume produced per acre per year indicates a relationship between the stands and the soils on which they grow. Table 4 shows more clearly the progressive decrease in annual wood production by stands on dry, intermediate, and wet soils.

Table 4 also shows that numbers of trees increase as the

Figure 7.



Growth Curves of Red Oak on All Soil Types.

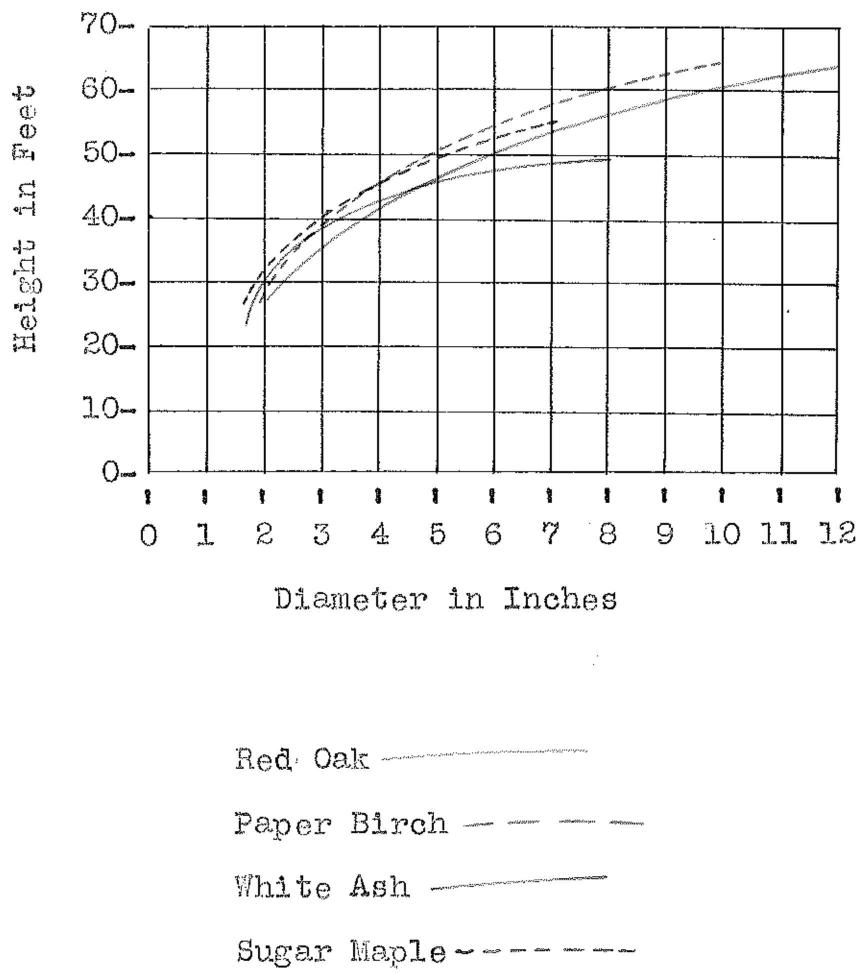
as soil conditions become wetter. To further investigate this situation, height over diameter curves were plotted for white ash, sugar maple, red oak, and paper birch on each soil type. Figure 7 shows the resultant curves for red oak. The most remarkable feature of these curves is that each of the four species shows no signifigant growth differences from one soil type to another. The great spread of dimensions on either side of the mean heights and diameters tends to further cancel out small differences between curves. (See pages 18a - 21a.)

The height over diameter curves show a consistent difference in the growth rates of each species, regardless of soil moisture conditions. Figure 7A illustrates the typical relationship of the curves of the four selected species on the same soil type. Red oak reaches the greatest diameter on all soils with paper birch its closest competitor. On dry and intermediate soils red oak has the greatest height growth, but is exceeded in this respect by paper birch on the wet soils. White ash and sugar maple are about equal in height and diameter growth on all soils and are invariably considerably smaller in both respects than red oak or paper birch.

Tables 3 and 4 clearly show a progressive decline from dry to wet soils in volume of stands and of single trees. Height over diameters curves indicate an essentially similar response by each ~~of each~~ of the predominant species to the various soil types. Therefore, the volume differences in these stands cannot be attributed to variations in the rates of growth of individual trees induced by soil moisture conditions.

The increase in density of trees per acre in response to

Figure 7A.



Growth Curves of Most Numerous Species on Wet Soils.

wetter soil types apparent in tables 3 and 4 is of considerable signifigance and may be further explored by tabulating excerpts from the stand tables on pages 12a, 13a, and 16a. Similar responses occur in each stand, but the largest stands are presumed to be the best samples.

Table 5. The influence of soil type on stand composition.

Species	Density - trees per acre			Percent composition		
	Dry soil stand 6	Inter. soil stand 3	Wet soil stand 4	Dry soil stand 6	Inter. soil stand 3	Wet soil stand 4
White ash	66	162	444	15.2	32.5	59.1
Sugar maple	37	72	124	8.6	13.9	16.4
Red maple	17	34	39	3.9	5.6	5.1
Red oak	155	98	72	35.4	19.1	9.5
Paper birch	120	98	60	27.4	19.1	7.9
Black birch	26	19	10	6.0	3.6	1.4
Others	14	33	5	6.0	6.3	.6
TOTALS	435	516	754	100.0	100.0	100.0

Table 5 indicates that the density of white ash and the maples increases with increasing wetness of the soil while that of red oak and the birches decreases as soil moisture becomes greater. The larger total volume and the greater growth rate per year of stands on dry soil is explained by the presence of higher percentages of faster growing species. The greater numbers of white ash and the maples per acre on wet soil are insufficient to compensate, volumewise, for their slower rate of growth.

Figure 10 shows the mean percentages of the commonest trees on each soil type. Standard deviation measures the reliability of relative numbers of a given species as indicators of soil type. Large numbers of white ash are shown to be a statistically reliable indication of wet soil. Large numbers of red oak and paper birch are good indicators of dry soil. High mean percentages of the remaining tree species are not good indicators of soil type.

D. The effects of management on stand composition.

The description of the study area notes a history of intensive silvicultural experimentation on this portion of Harvard Forest. The records indicate a general pattern in these cuttings. Following the removal of the old field pine, silvicultural efforts seem to have been confined to attempts to bring the native and introduced softwoods into dominance by cutting back the more vigorous hardwoods. The effects on present composition of these early cuttings cannot be readily evaluated. It seems reasonable to believe that the most vigorous hardwoods as well as those of poor form were cut most heavily, probably resulting in a somewhat younger, smaller, slower growing stand at present.

The records of cuttings and stand inspections from the 1920's indicate a small proportion of the pioneer species such as gray birch, black cherry, aspen, and sumac. White ash invariably occurred in the greatest numbers. (See examples, next page) During this period, little distinction was made when liberating conifers; all interfering trees were cut back to the ground or lopped off at a convenient height. The records of 1929 and 1930 indicate that this policy had been abandoned. The entire area had been overgrown with a stand of

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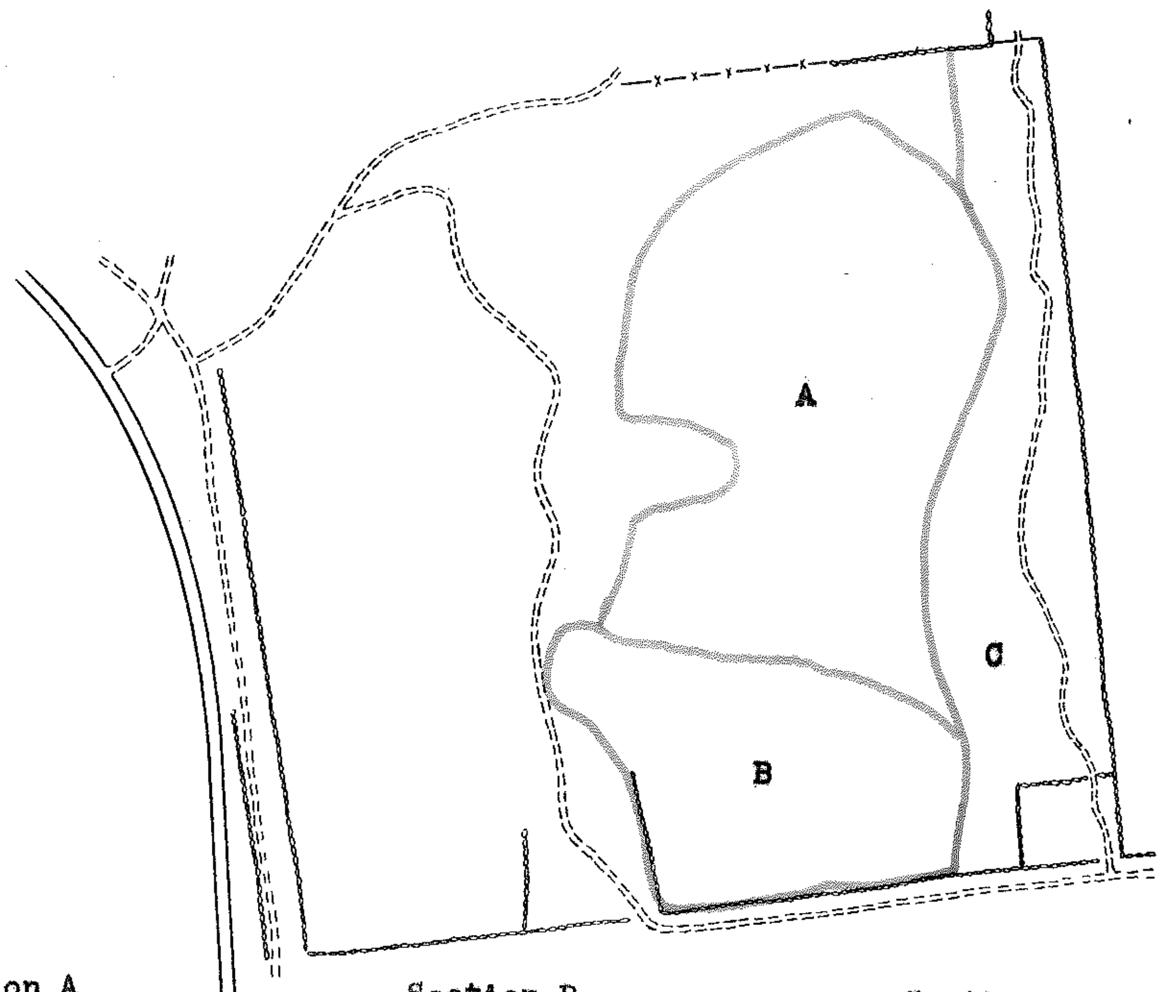
Figure 8. Summary of treatments in the study area.
(Harvard Forest records)



Section A	Section B	Section C
Clear cut - 1917	Clear out - 1915	Clear cut - 1923
Inspection - 1918	Inspection - 1918	Weeding - 1927
Weeding - 1921	Weeding - 1919	Weeding - 1929
Weeding - 1930	Partial weeding - 1927	Partial weeding - 1933
Imp. cut & thinning-1935	Weeding - 1930	Partial weeding - 1934
Weeding & thinning-1941	Weeding & thinning-1941	Imp. cut & thin - 1935
Thinning - 1948	Imp. out & thin - 1935	Weeding and thin- 1941
	Thinning - 1948	Thinning - 1948

transition hardwoods with the exception of the three stands then, as now, in pure red pine. (See figure 5, opp. page 16.)

The following lists are excerpts from two stand inspection reports of 1918. They list, in numerical order, the natural hardwood reproduction that succeeded the old field pine. Area A was clear cut in the winter of 1914 - 1915; area B in the winter of 1916 - 1917. (Harvard Forest records, TS-1, 1918-1927)

Area A, 3 yr. after clearcutting.		Area B, 1 yr. after clearcutting	
Species	Numbers of stems	Species	Numbers of stems
White ash	650	White ash	1,460
Red maple	440	Red oak	250
Red oak	345	Sugar maple	170
Black cherry	270	Chestnut	115
Birches	230	Poplar	85
Chestnut	80	Red maple	70
Poplar	40	Black cherry	60
White oak	20	Birches	55
Sugar maple	15	Basswood	25
Hickory	15	White oak	20
Basswood	15	Hickory	10
Totals	2,120		2,320
White pine	4,100	White pine	350

Reference to figure 5 shows a large body of understory white pine in the south central portion of the study area. Its location closely coincides to the clear cut Area A. (Compare figure 5 with figure 8.) This present pine understory is almost certainly a relic of the tremendous seedling population of 1918. It is signifigant that a much larger reproduction of red maple is recorded in the same area A. This distribution of red maple is still apparent on the ground but is not indicated in the stand figures. The high reproduction of white ash in Area B is clearly reflected in the present stand as is the somewhat higher proportion of sugar maple.

The proportions of trees recorded on Areas A and B do not differ greatly from the proportions of trees composing the present stands. The scarcity of birches in Area B is an exception to this generalization. Species present then as major or minor components of the stand are present in about the same relative quantities today. Chestnut, poplar, and black cherry are no longer of consequence. Most of the white pine has been suppressed.

The records indicate a general policy of favoring white ash and cutting back red maple in the years from 1930 to 1948. The cuttings of 1934 - 1935 discriminated somewhat against red oak as a favored food of the gypsy moth. The same records state a policy of allowing paper birch and white ash, "crown sensitive" trees, to remain on plantation margins, implying that red oak was removed from these situations.

A study of sprouts was undertaken to learn which species had been cut during thinnings and to check on the records as to the number of thinnings that each stand had received. Very few sprouts were discovered that could be dated to a cutting prior to that of 1934 - 1935. Stand tables made at that time indicate very few trees whose diameters were in excess of two inches, a fact that probably explains the lack of older stumps. Those that did not sprout have long since disappeared. The ones that did sprout have since covered the evidences of their origins. With but two exceptions, all examined trees of sprout origin dating to the thinning of 1934 - 1935 were red maple, an indication of the vigor of the campaign against this species. The few sprouts discovered to date to an earlier cutting were red maple or white ash. Evidences of the improvement cutting of 1941 are common on the eastern edge of the study area. The same stands contain many sprouts dating to the years 1944 or 1945, but no records exist of a cutting made at that time.

Table 6. Numbers of standing trees over two inches DBH and of stumps on fifty foot plots in typical stands.

Species	Stand 6, dry soil.		Stand 3, inter. soil,		Stand 4, wet soil.	
	Trees	Stumps	Trees	Stumps	Trees	Stumps
White ash	3	3	18	39	67	35
Sugar maple	0	0	4	3	6	1
Red Maple	4	5	2	4	1	0
Red oak	12	13	3	13	6	2
Paper birch	0	0	8	2	5	2
Black birch	9	1	5	1	0	0
Yellow birch	8	5	1	1	0	0
White pine	0	0	0	0	1	0
White oak	1	8	0	0	0	0
Black cherry	0	1	0	4	0	0

Table 6 indicates that the total number of white ash removed from these three plots exceeds the sum of all the other species removed. However, this is no indication that ash was not the favored species as large quantities remained. Some discrimination against red oak is evident in stand 3, probably because quantities of white ash were available as replacements.

A general thinning of the entire study area was carried out in 1948. An untreated strip 400 by 600 feet was left in the center of the cut over stand. (See figure 11 for location.) This "control" plot is practically indiscernable from the surrounding thinned stands, but close observation shows it to have a somewhat higher percentage of large red oaks. In general, studies of stumps and sprouts on several plots showed no evidence of favoritism for any of the "timber" species, but further indicated the long standing antipathy for red maple.

Experiment 33 - 1 was established in 1933 near the center of the study area. (Figure 11) Its purpose was "To follow the course of development of a series of cuttings in producing high quality sawlogs on a rotation of seventy years" (Harvard Forest records, Exp. 33 - 1). Plot A (½ acre, intermediate soil) and plot B (¼ acre, wet and intermediate soils) were to be operated by a series of crown thinnings. Elements of inferior form or those overtopping crop trees were to be removed. Plot C (¼ acre, wet and intermediate soils) was to remain untreated in contrast to plots A and B. Thinnings were carried out in the treated plots in 1933 and 1948. Pages 22a - 24a summarize present conditions in these stands. Comparison of these tables indicates only small differences in composition between the treated and untreated plots. Plots A and B show smaller percentages of upper crown class trees with a somewhat smaller percent of total basal area, a condition almost certainly caused by efforts to concentrate growth on fewer trees. That these efforts have been successful is indicated is indicated by the average basal area increase per acre per year on the upper crown class trees on these plots; A - .5 square feet, B - .54 square feet, C - .37 square feet.

The records of experiment 33 - 1 contain data showing the numbers, species, and sizes of trees on plots A, B, and C in 1933.

Stand tables similar to those of 1956 (appendix) were compiled, from these figures. Comparison of these two sets of figures should indicate the effectiveness of stand improvement work in altering composition on the treated plots. So that numerical values of trees and of basal area will be comparable, all gains and losses are recorded as percentages of the total for each stand. Therefore, the value of -13 in the upper left corner of table 7 indicates that white ash composes thirteen per cent less of the total stand on plot A in 1956 than it did in 1933.

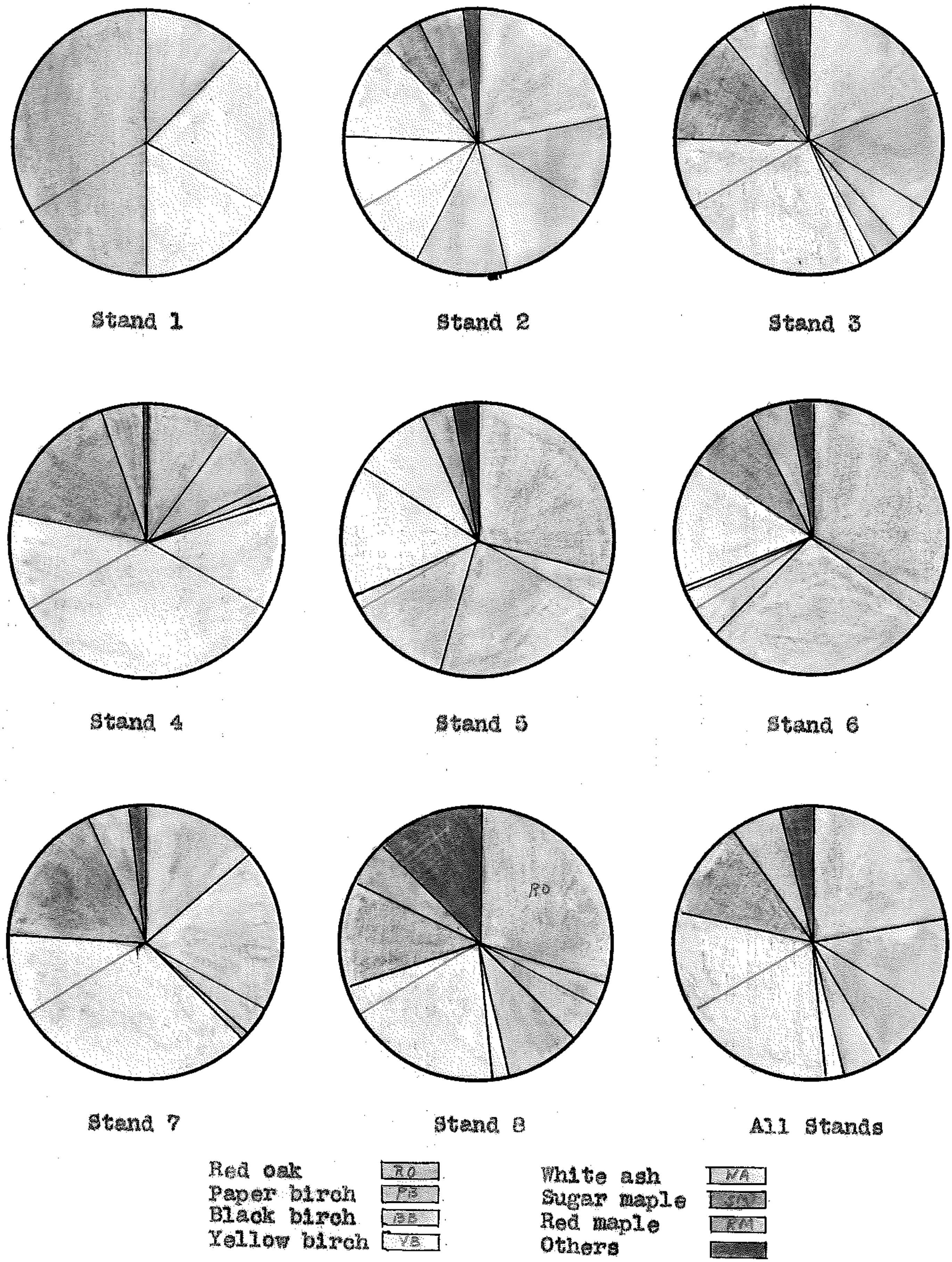
Table 7. Percent of gain or loss, by species, in numbers of trees and in basal area, between 1933 and 1956. Exp. 33 - 1.

Species	Plot A		Plot B		Plot C	
	% of nos.	% of BA.	% of nos.	% of BA	% of nos.	% of BA
White ash	-13	-24	-12	-27	-1	-14
Sugar maple	0	-2	+5	0	-4	-10
Red maple	0	-1	+6	+4	0	+3
Red oak	+7	+20	+2	+11	+7	+25
Paper birch	+2	+3	+4	+14	+1	-1
Black birch	-1	0	-1	0	-2	-3
Yellow birch	-2	-2	-3	-4	-1	0
White pine	0	-1	0	0	0	0
Basswood	+7	+7	0	+1	0	0

Study of table 7 shows that white ash has been cut most heavily in silvicultural work. The pronounced decrease in per cent of basal area of white ash is evidence of its slow rate of growth. Red oak shows some increase in per cent of numbers in all stands and sharp increases in per cent of basal area, evidence of its ability to take over growing space once occupied by white ash. Sugar maple shows less decrease on treated stands

Original is colored

Figure 9. Composition of stands in percent.



while paper birch shows greatest increase on plots A and B, evidence of favoritism toward these species. The sharp rise of basswood on plot A is probably not as spectacular as it appears to be. A relatively large proportion of these fast growing trees has grown on this plot since the beginning of the experiment, while virtually absent on the other plots.

The following generalizations are believed to summarize the policies governing cuttings made on the study area. Softwoods were favored wherever encountered if considered capable of satisfactory response upon release. White ash was favored over competing hardwoods. At the same time its slow rate of growth, thicket forming habit, sprouting ability, sensitivity to abrasion and sheer numbers have made it the principal object of silvicultural cuttings. Red oak was often cut back where it showed wolf tree tendencies or where well formed trees considered to be of greater value were available as replacements. Sugar maple and paper birch have, generally, been favored in thinning operations. Red maple has persisted in spite of strong discrimination. The remaining species do not occur in sufficient numbers over the study area to permit generalizations.

Comparisons of tallies made during several phases of the life history of the present forest cover has led to the conviction that silvicultural treatments have had minimum effects on the stands so far considered. No species has been eliminated from any stand. No considerable numbers of white pine have been brought into the canopy. The tendency for white ash to become less numerous and for red oak to occupy the vacated space has been apparent since the late 1920's. Other factors influencing species distribution since the removal of the old field pine have been more effective determinants of stand composition than have the efforts of man.

E. A stand altered in composition by management.

As indicated on pages 18 and 19, stand 7 is thought to show the effects of silvicultural work in several respects. The contrast between this stand and the adjacent one is readily discernable. Volume differences are pointed out in table 8.

Table 8. A comparison of upper crown class trees found growing on the soil types found on the study area.

Soil type	Stand number	Density per acre	Average DBH	Average height	Average volume cubic feet
Dry	6	435	5.1"	44'	1445
Dry	7	736	3.9"	38.5'	1061
Inter.	3	516	4.8"	42'	1272
Wet	4	754	3.7"	38'	1100

The above table shows stand 7, on dry soil, to comparable to stand 4, grown on wet soil. Careful examination of the profile development of the soils underlying stand 7 showed no signifigant differences between them and the typically dry soils under the surrounding stand 6.

Volume per acre has been previously shown to be a function of stand composition. Therefore, the volume figures shown in table 8, atypical of a stand on dry soil, should be explainable through composition differences. Table 9 compares the composition of stand 7 with the larger, previously considered stands assumed to be typical of each soil type. It shows the composition of stand 7 to be very similar to that of stand 3, developed on intermediate soils. This "off-site" development of stand 7 was caused by a factor other than soil moisture. Consideration will now be given management as the effective agency.

Table 9. A comparison of percentage composition of stands of upper crown class trees typical of each soil type on the study area.

Soil type	Stand number	White ash	Sugar maple	Red maple	Red oak	Paper birch	Black birch	Others
Dry	6	15.2	8.6	3.9	35.4	27.4	6.0	3.5
Dry	7	39.0	17.2	5.0	13.6	23.2	1.0	1.0
Inter.	3	32.5	13.9	5.5	19.1	19.1	6.3	6.3
Wet	4	59.1	16.4	5.1	9.5	7.9	.6	.6

Experiment 56 - 2 was established as a means of determining the effects of the understory on the development of the main canopy of trees. The southern half of the untreated portion of the general thinning of 1948 was the site of this work. All upper and lower crown class trees over two inches DBH were tallied on an area 300 by 400 feet. The eastern portion of the trees used in experiment 56 - 2 is adjacent to and closely resembles stand 7. Actually, the trees are somewhat larger and contain more red oak, probably because they are more distant from red pine plantation 25 - A. The western portion of the trees in experiment 56 - 2 is a typical part of stand 6.

Table 10 (next page) illustrates the differences between the two halves of experiment 56 - 2. It shows that the understory and overstory of stand 7 contains all of the species contained in stand 6. However, the numbers of red oaks are much less in stand 7 while all of the other species show an increase in total numbers. This relationship is equally evident in table 9. An important consideration not indicated so far is the very considerable numbers of red and white pine in the understory of stand and in the eastern portion of experiment 56 - 2. Considerably lesser amounts of these suppressed thirty year old softwoods occur in the remainder of experiment 56 - 2. Sprout studies showed no less than eight cuttings in stand 7. The Harvard Forest records mention seven weedings or improvement cuttings (figure 8) but do not indicate one for 1945.

Table 10. A comparison of two equal areas of trees of 2" DBH and over, tallied on experiment 56 - 2.

Species	Stand 6 understory	Stand 6 overstory	Stand 7 understory	Stand 7 overstory
White ash	132	58	153	116
Sugar maple	40	8	67	16
Red maple	125	33	147	87
Red oak	71	275	41	185
Paper birch	50	106	62	177
Black birch	34	30	52	32
Totals	452	510	522	613
	Ave. DBH per tree - 4.3".		Ave. DBH per tree - 3.8".	

A hypothesis explaining the presence, on dry soil, of a stand typical of intermediate soils is that the red oak was severely discriminated against in vain efforts to bring softwoods into the main canopy. The records indicate a policy of favoring a fringe of white ash and paper birch on the edges of plantations. Red oaks were removed from these situations because of wolfish tendencies. Stand 7 borders the best red pine plantation on the study area besides having its own pine understory. Investigation has established that eight "improvement cuttings were made in this stand. The few red oaks, the small size of the remaining trees, and the great density in

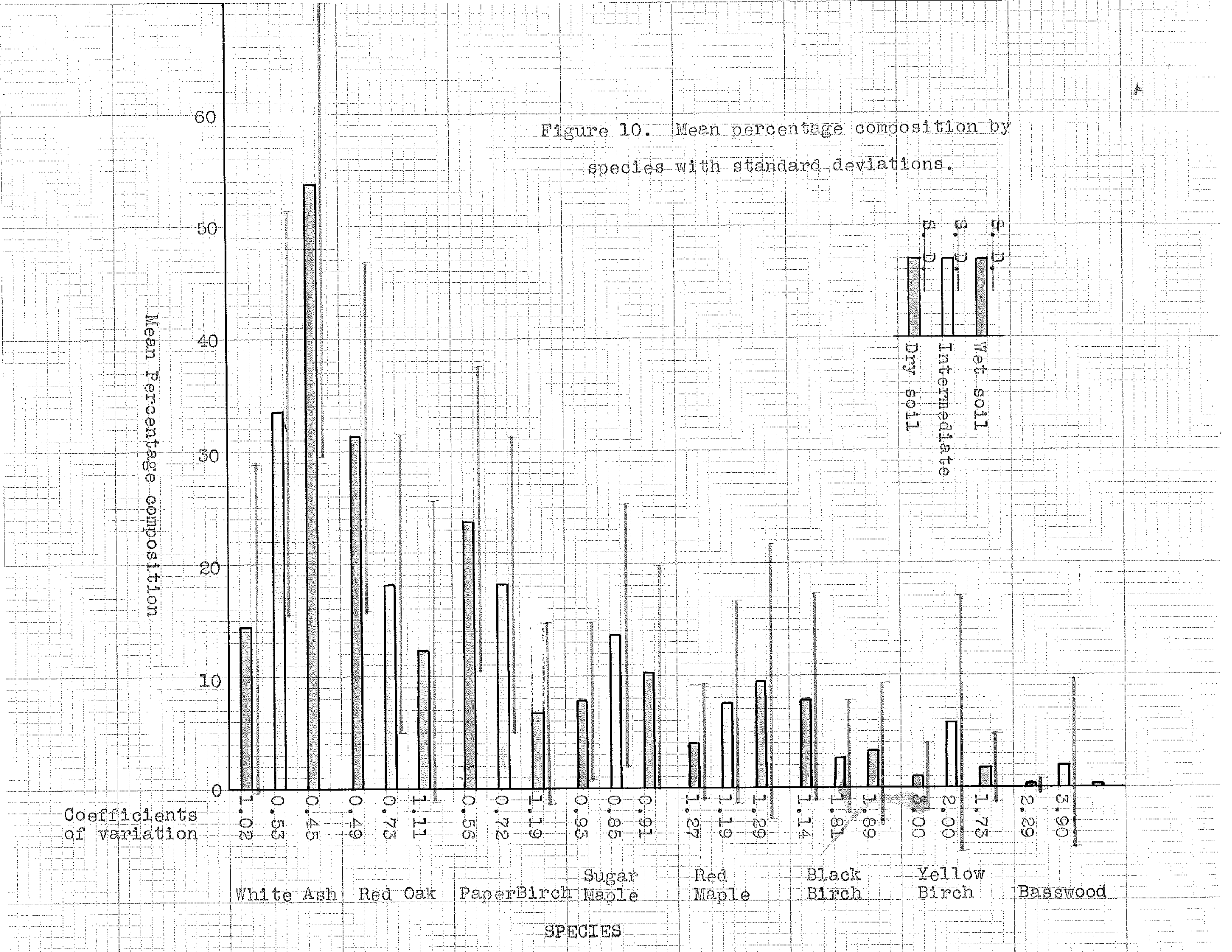


Figure 10. Mean percentage composition by species with standard deviations.
Mean Percentage composition
60
50
40
30
20
10
0
S. D.
S. D.
S. D.
Dry soil
Intermediate
Wet soil
Coefficients of variation
1.02
0.53
0.45
0.49
0.73
1.11
0.56
0.72
1.19
0.93
0.85
0.91
1.27
1.19
1.29
1.14
1.81
1.89
3.00
2.00
1.73
2.29
3.90
White Ash
Red Oak
PaperBirch
Sugar Maple
Red Maple
Black Birch
Yellow Birch
Basswood
SPECIES

dominant position of trees usually present as understory on dry soils leads to the conclusion that the severity of the silvicultural treatments has caused composition changes in this stand.

IV. Possible relationships between stand composition, soil moisture, and initial rooting habit.

Present stands have been shown to roughly reflect the composition of seedling stands in the tallies of 1918. No effort has been made to explain the initial preponderance of certain tree seedlings on the area covered in the inspections of 1918. Such an explanation has become essential to this discussion of the relationships between soil moisture and species distribution, particularly so since evidence has been presented to show that these stands are relatively stable associations.

Seed source and the chance dissemination of seed over cut over land cannot be overlooked as factors in species distribution. However, these factors must be of of minimum importance when they occur almost universally in the transition hardwood region. McKinnon, Hyde, and Cline (1935) found that red oak, white ash, and red maple were invariably major components of one to five year old stands on sites I and II following the removal of the old field pine in Central New England. There is no reason not to believe that these conditions were not effective on the study area.

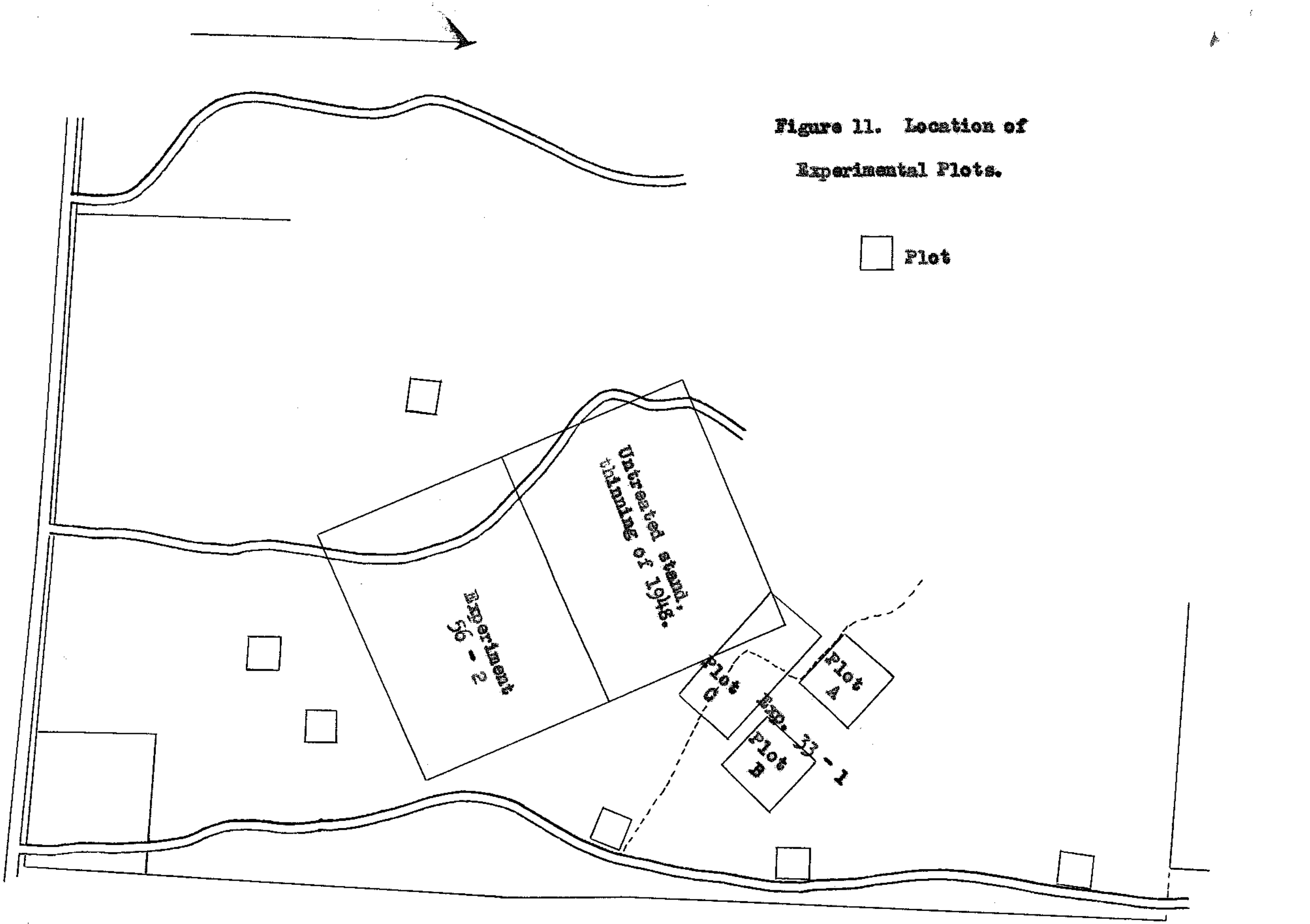
Wright (1935) in his study of the genus Fraxinus, divided the white ash of the eastern United States into three ecotypes; northern, which included New England, intermediate, and southern. The typical seedling of the northern ecotype "has three or four main roots a foot or more in length, with many branches. The result is a fibrous mat offering good anchorage and excellent for supplying nutriments." (Page 124) White ash of the southern ecotype was strongly taprooted with only a few small laterals. Trees of both ecotypes were grown in a Charlton soil nursery on the Harvard Forest. Both transplanted and untransplanted seedlings of the southern ecotypes were severely frost heaved in the winter of 1940 - 41. No frost heaving occurred among the fibrous rooted seedlings of the northern ecotype.

No reference was found as to the ability of red oak seedlings to withstand frost heaving. Moore (1922) states that "its seedlings send down a long, thick taproot the first year". It seems probable that it would be as subject to frost heaving as the southern ecotype of white ash, the initial rooting habits being quite similar.

Conditions for ice formation and frost heaving are most apt to be present in relatively fine textured soils having low noncapillary porosity and a high water table. (Lutz and Chandler, 1947) These conditions are most nearly fulfilled on the wet soils of the study area. It is possible that the taprooted red oak seedlings may be more liable to frost heaving on wet soils than the fibrous rooted ash seedlings. If this situation exists, it may be an explanation of the early predominance in numbers of white ash over red oak on the wet soils.

Diebold (1935) found frost heaving and the resultant slow growth in coniferous plantations serious only on poorly drained to imperfectly drained soils. In this connection, it is of interest to compare figures 3 and 5 to note the relationships of red pine to soil type on the study area. Two successful

Figure 11. Location of Experimental Plots.



red pine plantations grow on dry soil while one grows on dry and intermediate soil. Although widely planted on it, no red pine has achieved dominance on wet soil.

The contrasting development of young root systems of white ash and red oak may also serve to explain the early diminution in numbers of white ash on dry soil. "In general it may be said that the ability of a given species to persist on a given site or to become established in a new region depends very largely on its initial root habit and how closely it is correlated with available soil water from which it draws its supply. Because of the great differences in initial root habit of one species as compared with another, particularly in relation to rapid downward growth, the moisture available for one species may be very different from that for another, even when both are growing in the same soil." (Toumey and Korstian, 1937) Korstian (1927) found that if the taproot penetrates the soil at all the oak seedling is able to withstand considerable dryness while still in its juvenille form. The Harvard Forest records note a considerable accumulation of needles and duff after the removal of the old field pine. The drying out of the organic layers was often given as the cause of death of the shallow rooted white pine seedlings. It seems probable that the red oak seedlings were better adapted to survive drying of the organic and mineral horizons of dry soil than were those of white ash.

Reference to figure 9 shows a remarkable uniformity in the percentage of red maple in all stands except stand 1, a difference insignifigant because of the few trees involved. It is of interest to quote again from Toumey (1937). "When red maple becomes established on dry soils, the initial root is from the start different from what it is when germination takes place in a swamp. In this species the initial root system is extremely plastic. Alomst from the beginning it is short and spreading on the wet soils, rarely reaching a depth of more than two or three inches the first season. On dry upland soil the primary root continues its downward growth throughout the entire season, often reaching a length of 10 or 13 inches. In wet soils lateral roots are abundant and well developed, in dry soils they are relatively unimportant. This species is capable of adjustment for early growth under a wide range of moisture conditions." This adaptibility of the initial root system suggests an explanation of the universal occurrence of red maple on the Harvard Forest.

Holch (1931) performed experiments indicating that each species has an initial root habit that appears to be a hereditary adaptation of the species to sites of more or less specific water content. This finding agrees with the work of the other investigators quoted and with personal observations of seedlings growing on the study area. This line of reasoning indicates a strong possibility that the numbers of each species on a given soil type is closely related to the initial rooting habit of that species. This relationship probably becomes less apparent as the stand ages. Variations in the rates of growth of the more mature competing species would tend to obscure composition differences readily apparent in seedling or sapling stands.

V. Summary and conclusions.

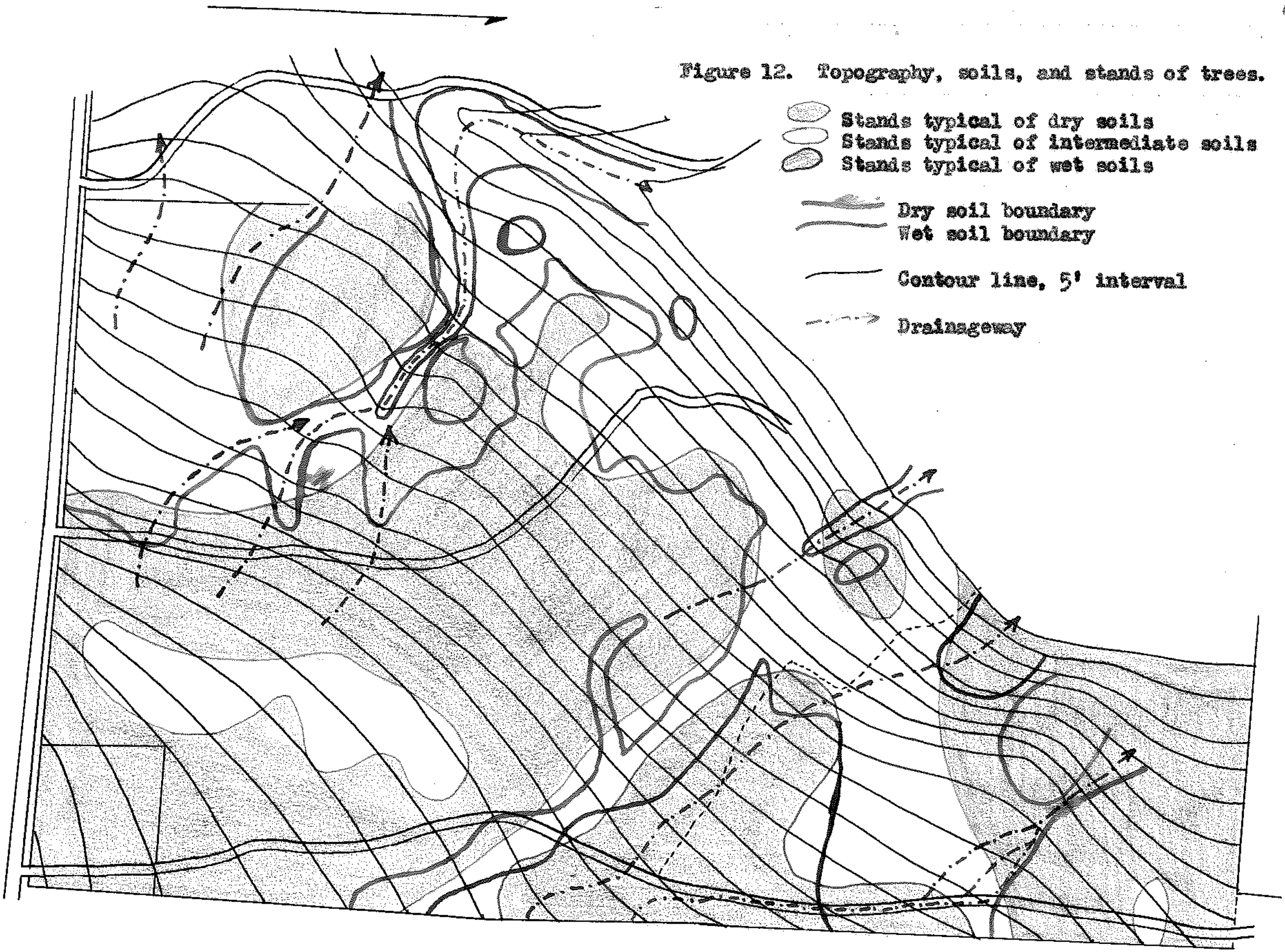
Throughout this study it was evident that differences in soil and in water level flustuations were small as were the corresponding variations produced in stand composition and volumes. The same tree species are present on all soil types and grow at essentially the same rates. The scale of dry, wet, and intermediate soil types covers perhaps one third of the range of conditions from bog to those encountered on an exposed rock ridge. Expansion toward either extreme of drainage should produce more spectacular results.

Data have been presented to show these relationships.

1. Morphological characteristics of the soil profile are an indirect measure of soil moisture regime. The range of conditions from maximum to minimum soil moisture encountered on the study area was arbitrarily divided into a scale of three soil types; wet, intermediate, and dry.
2. Variations exist in both volume and composition of the stands growing on these three soil types.
3. The rate of growth of each of the predominant species was found to be essentially the same for each soil type.
4. Volume differences in the stands growing on the three soil types are attributable to variations in species composition.
5. Man has done comparitively little to alter species composition.
6. Stand records and plot data show little evidence of influence on species distribution by soil moisture during the past 25 years.

A limited amount of reference and of indirect evidence was presented in support of the postulation that soil moisture conditions exerted a maximum influence on species distribution during the initial establishment period of the present stand.

Figure 12. Topography, soils, and stands of trees.



Such a finding fits the concept of the dynamic nature of site quality as stressed by Heiberg and White (1956) who state:
1. Site is the sum of all the effective factors under which the forest community lives. Usually one or more of these factors exercise a dominating influence on the forest vegetation.
2. The relative impact of these factors of site on the forest community may and frequently does change in relatively short periods of time. Other factors then become of critical influence on the forest community. This concept points out the necessity for using caution in isolating any single factor of site as being the decisive influence on stand composition over the entire life span of forest trees.

This study has shown that relatively small areas of a given soil moisture condition have produced an effect on the composition of associated forest stands of trees. It appears that one-tenth acre is the minimum size of area of soil producing a mappable effect on the stands at this point in their life spans. The scale of the map and its intended use are other factors that should determine the minimum size of soil units to be mapped for use in forestry.

Sufficient coincidence exists between units of soil type and of associated forest vegetation to justify the conclusion that soil moisture is or has been a critical factor in species distribution on this portion of Harvard Forest.

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Appendix

Common and scientific names of trees referred to in this paper.

1. Acer rubrum L. - red maple
2. Acer saccharum, Marshall - sugar maple
3. Amelanchier canadensis (L.) Med. - shadbush
4. Betula lenta L. - black birch
5. Betula lutea Michx. - yellow birch
6. Betula papyrifera Marsh. - paper birch
7. Betula populifolia Marsh. - gray birch
8. Carya ovata (Mill.) K. Koch. - shagbark hickory
9. Castanea dentata (Marsh.) Borkh. - chestnut
10. Fagus grandifolia Ehrh. - beech
11. Fraxinus americana L. - white ash
12. Ostrya virginia (Mil.) K. Koch. - hop hornbeam
13. Picea abies (L) Karst - norway spruce
14. Picea glauca (Moench.) Voss. - white spruce
15. Pinus resinosa Ait. - red pine
16. Pinus rigida Mill. - pitch pine
17. Pinus strobus L. - eastern white pine
18. Populus tremuloides Michx. - trembling aspen
19. Prunus pennsylvanica L. - pin cherry
20. Prunus serotina Ehrh. - black cherry
21. Quercus alba L. - white oak
22. Quercus rubra L. - redoak
23. Rhus typhina (L.) Sudw. - staghorn sumac
24. Tilia americana L. - basswood
25. Tsuga canadensis (L.) Carr. eastern hemlock
26. Ulmus americana L. - american elm

Authority - Gray's manual of botany, eighth edition, 1950.

Horizon	Color	Structure			Consistence	Cementation	Horizon depths		Texture
Standard nomenclature	Munsell Color Chart	Grade	Size	Form	Moisture content at or above field capacity		Thickness in inches from surface	Boundary thickness	
A_1	10YR2/1	weak	medium	granular	friable	none	0 - 7	gradual	loam
B_{21}	7.5 YR4/4	weak	coarse	sub ang. blocky	friable	none	7 - 13	clear	fsl
B_{22}	2.5 Y 4/4	weak	coarse	sub ang. blocky	friable	none	13 - 20	abrupt	fsl
C_{1gm}	2.5 Y 4/4	weak	coarse to very coarse	platy	firm in place, weakly firm when removed.	weak	20 +	---	loam

Profile description, hole # 7, intermediate soil.

Horizon	Coarse skeleton	Mottles				Roots	Surface			Remarks
Standard nomenclature		Abundance	Size	Contrast	Color		Slope	Stoniness spacing in ft	Configuration	
A_1	few stones	none	---	---	---	many fine	10% NW	stones 2 - 6 boulders 0-8	uniform	considerable evidence of earthworm activity
B_{21}	few, small stones	none	---	---	---	many, some large				
B_{22}	few stones	few	fine	faint	yellowish	fine only				
C_{1gm}	very stony 1" - 3"	common	coarse	distinct	yellow brown	none				pores few, faint, unglazed.

Horizon	Color	Structure			Consistence	Cementation	Horizon depths		Texture
Standard nomenclature	Munsell Color Chart	Grade	Size	Form	(Moisture content at or above field capacity)		Thickness in inches from surface	Boundary thickness	
A_1	10 YR 2/1	moderate weak	fine to medium	granular	nonsticky, friable	none	0 - 9	clear	loam
B_{21}	10 YR 2/2	weak	medium, coarse	granular	nonsticky, very friable	none	9 - 18	clear	fsl
B_{22gm}	10 YR 3/2	weak	medium	sub ang. blocky	nonsticky, firm in place, friable when removed.	very weak	18 - 25	abrupt	sl
C_{1gm}	10 YR 2/2	Water comes in very fast. Soil collapses when removed from hole. Probably weak platy, nonplastic, very firm in place.				weak	25 +	---	fsl

Profile description, hole 2, wet soil.

Horizon	Coarse skeleton	Mottles				Roots	Surface			Remarks
Standard nomenclature		Abundance	Size	Contrast	Color		Slope	Stoniness, spacing in ft.	Configuration	
A_1	many stones	none	---	---	---	many fine & medium	4 % N W	stones 0-2 boulders 10-20	slightly concave	worms common
B_{21}	few stones	uncertain, may be few	---	---	---	many fine				extensive worm evidence
B_{22gm}	few stones	common	fine	distinct	rusty brown	many fine				noticeably compact heavy flow water
C_{1gm}	appears stone free	many	medium	distinct	yellowish	none				

Horizon	Color	Structure			Consistence	Cementation	Horizon depths		Texture
Standard Nomenclature	Munsell Color Chart	Grade	Size	Form	(Moisture content at or above field capacity)		Thickness in inches from surface.	Boundary thickness	
A_1	5 YR 2/2	moderate	fine to medium	granular	very friable	none	0 - 8	clear	fsl
B_{21}	7.5 YR 4/4	weak	medium	sub ang. blocky	friable	none	8 - 22	clear	sl
B_{22}	7.5 YR 5/6	weak	medium to coarse	sub ang. blocky	Friable. More firm in place than B_{21}.	none	22 - 35	abrupt	sl
C_{1gm}	2.5 Y 4/4	weak	coarse	tending to platy	Friable when removed but firm in place.	weakly	35 +	——	ls

Profile description, hole # 1, dry soil.

Horizon	Coarse Skeleton	Mottles				Roots	Surface			Remarks
Standard Nomenclature		Abundance	Size	Contrast	Color		Slope	Stoniness spacing in ft	Configuration	
A_1	Stony on surface	none	——	——	——	many fine	7% NNW	Stones 1 - 3 Boulders 20-40	gently convex	Little worm activity
B_{21}	stone free	none	——	——	——	many fine				
B_{22}	many small stones	none	——	——	——	few fine				water comes in strongly
C_{1gm}	many small stones	common	medium	distinct	reddish brown	none				pores infrequent, unglazed

Soil drainage classes, page 170, Soil Survey Manual.

Well-drained:

"Water is removed from the soil readily but not rapidly. Well drained soils are commonly intermediate in texture, although soils of other textural classes may also be well drained. Among the podzolic soils, well drained soils are free of mottling (except for fossil gley), and horizons may be brownish, reddish, yellowish, or grayish. They may be mottled deep in the C horizon or below depths of several feet. Well drained soils commonly retain optimum amounts of moisture for plant growth after rains or additions of irrigation water."

Moderately well drained:

"Water is removed from the soil somewhat slowly, so that the profile is wet for a small but signifigant part of the time. Moderately well drained soils commonly have a slowly permeable layer within or immediately below the solum, a relatively high water table, additions of water through seepage, or some combination of these conditions. Among podzolic soils, moderately well drained soils have uniform color in the A and upper B horizons, with mottling in the lower B and in the C horizons."

Somewhat poorly drained:

"Water is removed from the soil slowly enough to keep it wet for signifigant periods but not all the time. Somewhat poorly drained soils commonly have a slowly have a slowly permeable layer within the solum, a high water table, additions through seepage, or a combination of these features. Among the podzolic soils, the somewhat poorly drained soils are uniformly grayish, brownish, or yellowish in the upper A horizons and commonly have mottlings below 6 to 16 inches in the lower A and in the B and C horizons. The growth of crops is restricted to a marked degree unless artificial drainage is provided."

Poorly drained:

"Water is removed so slowly that the soil remains wet for a large part of the time. The water table is commonly at or near the surface during a considerable part of the year. Poorly drained conditions are due to a high water table, a slowly permeable layer within the profile, to seepage, or to some combination of these conditions. In the podzolic soil region, poorly drained soils may be light gray from the surface downward, with or without mottling."

"Soil drainage, as a condition of the soil, refers to the frequency and duration of periods when the soil is free of saturation or partial saturation." (page 165, Soil Survey Manual)

Soil survey of Tom Swamp Block, Harvard Forest. (Simmons, 1939)

Charlton stony loam, page 10:

"This soil has developed in well drained situations from weathered till derived largely from bluish gray or bluish green schist. In most places there is a very thin accumulation of organic matter, most of which is litter, on the surface. The surface soil, to a depth of 5 or 7 inches, is a dark brown friable loam or light silt loam. Coarse mull is weakly developed. The subsoil, to a depth of 12 or 20 inches, is brown to yellowish brown silt loam. The deeper subsoil, to a depth of 20 or 30 inches, is brownish yellow loam. The substratum is olive-gray to grayish yellow, smooth, fine grained glacial till that contains many fragments of schist. In some places the subsoil is not as brown as the subsoil of typical Charlton soils found in other parts of New England. In a few places a small amount of reddish brown schist has been included in the petrographic composition, making a yellow or grayish yellow till. The degree of stoniness varies from almost arable to stony land. Many of the stones and boulders found on Charlton soil are granite."

Sutton silt loam, page 15:

"This soil has developed in imperfectly drained situations from weathered glacial material derived principally from schist. The surface soil, to a depth of about six inches, is dark grayish brown silt loam that is strongly to very strongly acid in reaction. In most places this is a coarse mull that has a high content of organic matter. The subsoil, to about fourteen inches, is mottled grayish brown, grayish yellow, gray, and rust brown silt loam and, to about twenty inches, is highly mottled gray, grayish brown, and rust brown silt loam. These subsoil horizons are very strongly acid in reaction. The substratum is highly mottled gray or rust brown clayey till in some places, but in other places it is olive or grayish yellow, silty till. It is medium acid in reaction. In some places the upper part of the subsoil is brownish yellow silt loam that is faintly mottled with gray or grayish brown. In a few places this horizon is unmottled brownish yellow to a depth of about twelve inches. This soil is normally associated with Charlton soils and is derived from similar materials, but in this forest areas of Sutton soil are found associated with Brookfield and Gloucester soils. In these places, thesubstratum is composed of the same materials as that of the associated soils. Most areas have many stones and boulders but a few are very stony and have little soil in the crevices between the rocks. Most areas of this soil are situated in slight depressions or on concave slopes that have slight relief. The average slope gradient is less than five percent but in some places it is as much as seven percent."

Whitman stony silt loam, page 20:

"This soil has developed in poorly drained situations associated with all the soils of this region that have developed from weathered glacial till. The surface soil, to a depth of ten inches, is very dark gray to nearly black silt loam or mucky silt loam that is medium to strongly acid in reaction. The subsoil is a compact gray or mottled gray, grayish brown or rust brown silt loam or sandy till that is slightly to medium acid in reaction. In some places the dark colored surface extends to a depth of eighteen inches. In many places there is a layer of unmottled gray loam or silt loam above the compact, mottled substratum. There are many stones on the surface and in the soil and in many places are the true Lithosols as there is very little soil between the rocks. Most areas of this soil are traversed by intermittent drainage channels and there is some alluvial material here and on the surface. In a few places, especially near the roads, several inches of sand and gravel have been washed from the road and deposited on the soil."

Summary of 22% cruise of study area.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Red oak	22.5	642	98	48'	3,211.27'	5.00'	141.553'	6.4"
White ash	30.2	863	132	40'	1,229.67'	1.43'	66.401'	3.7"
Paper birch	19.7	565	87	45'	1,525.41'	2.68'	76.251'	5.1"
Black birch	4.7	134	21	41'	235.46'	1.76'	12.704'	4.2"
Sugar maple	12.1	346	53	38'	378.04'	1.09'	22.381'	3.5"
Red Maple	5.4	156	24	37'	186.48'	1.19'	11.879'	3.7"
Yellow birch	2.4	68	10	44'	96.01'	1.41'	6.044'	4.0"
Basswood	0.7	19	3	40'	29.13'	1.53'	1.623'	3.9"
White pine	1.0	30	5	35'	98.25'	3.28'	4.864'	5.5"
Hop hornbeam	0.1	3	0.5	37'	1.85'	0.62'	0.135'	2.8"
White oak	0.2	6	1	32'	7.88'	1.31'	0.600'	4.3"
White spruce	—	1	—	38'	2.80'	2.80'	0.115'	4.6"
Gray birch	0.3	9	1.5	36'	9.48'	1.05'	0.616'	3.5"
Hickory	0.7	20	3	40'	35.50'	1.78'	1.805'	4.1"
Elm	—	1	—	28'	0.60'	0.60'	0.056'	3.2"
Beech	—	1	—	30'	2.10'	2.10'	0.126'	4.8"
TOTALS	100.0%	2,864	439.0	42'	7,049.93'	2.46'	347.153	4.7"

Results of 100% cruise of minor stand components on study area.

Species	Upper crown class	Lower crown class	Suppressed crown class	Totals
Basswood				
Dry	2	3	7	12
Inter.	20	19	17	56
Wet	8	7	1	16
Hickory				
Dry	15	20	100	135
Inter.	11	13	68	92
Wet	0	0	2	2
White oak				
Dry	0	14	139	153
Inter.	0	2	39	41
Wet	0	4	30	34
Hop hornbeam				
Dry	1	0	57	58
Inter.	0	3	13	16
Wet	0	0	3	3
Black cherry				
Dry	0	1	2	3
Inter.	0	0	1	1
Wet	0	2	2	4
American elm				
Dry	0	1	0	1
Inter.	0	0	0	0
Wet	1	1	2	4
Beech				
Dry	0	1	4	5
Inter.	0	2	1	3
Wet	0	0	0	0
Shadbush				
Dry	0	0	1	1
Inter.	0	0	2	3
Wet	0	0	0	0
Totals	58	92	491	641

Acres cruised - 30.

Summary of 22% cruise of stand #1.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Red maple	50	8	296	34'	6.61'	0.83'	0.466'	3.3"
White ash	37.5	6	222	38'	8.55'	1.43'	0.476'	3.8"
Black birch	12.5	2	74	39'	2.55'	1.28'	0.069'	2.5"
TOTALS	100.0%	16	592	38'	17.71'	1.11'	1.011'	3.4"

Volume figures taken from "Studies of Connecticut hardwoods. The form of hardwoods and volume tables on a form quotient basis" by Hawley, R. C. and Wheaton, R. G. 1926. Page 35, table 18, Yale University: School of Forestry, bulletin 17.

Summary of 22% cruise of stand #2.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Black birch	11.0	21	52	44'	37.73'	0.83'	1.920'	4.1"
Yellow birch	18.0	35	87	45'	53.43'	1.53'	2.881'	3.9"
White ash	12.0	22	55	41'	31.43'	1.43'	1.712'	3.8"
Paper birch	25.0	47	117	48'	129.61'	2.76'	5.846'	4.8"
Red maple	5.0	9	22	43'	33.95'	3.77'	1.167'	4.9"
Red oak	22.0	42	105	51'	245.95'	5.86'	10.987'	6.9"
Elm	0.4	1	4	28'	.60'	.60'	.056'	3.2"
Hop hornbeam	0.4	1	4	39'	.50'	.50'	.034'	2.5"
White spruce	0.4	1	4	38'	2.80'	2.80'	.115'	4.6"
White oak	0.4	1	4	35'	2.10'	2.10'	.136'	5.0"
White pine	0.4	1	4	22'	1.20'	1.20'	.087'	4.0"
Sugar maple	5.0	9	22	33'	10.80'	1.20'	.590'	3.5"
TOTALS	100.0%	190	476	46'	550.10'	2.89'	25.531'	4.9"

Summary of 22% cruise of stand # 3.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal Area	Average DBH
White ash	32.5	308	162	41'	514.84'	1.67'	26.530'	4.0"
Red oak	19.1	187	98	46'	930.30'	4.99'	41.872'	6.4"
Black birch	3.6	36	19	40.5'	62.21'	1.73'	3.313'	4.1"
Paper birch	19.1	187	98	45'	564.21'	3.02'	31.022'	5.5"
Sugar maple	13.9	137	72	39'	142.92'	1.04'	8.308'	3.4"
Red maple	5.5	64	34	35.5'	71.33'	1.11'	5.592'	4.0"
Yellow birch	2.0	19	10	46'	26.35'	1.39'	2.108'	4.5"
Grey birch	0.2	2	1	35'	1.85'	.93'	.127'	3.4"
White oak	0.1	1	0.5	28'	.90'	.90'	.067'	3.5"
Basswood	1.6	16	8	29'	22.88'	1.43'	1.288'	3.9"
Hickory	0.7	7	4	32'	10.15'	1.45'	.494'	3.6"
Hop hornbeam	0.2	2	1	36'	1.35'	.68'	.101'	3.1"
White pine	1.5	15	8	36'	51.65'	3.44'	2.487'	5.5"
TOTALS	100.0%	981	515.5	42'	2400.94'	2.45'	123.309'	4.8"

Summary of 22% cruise of stand # 4.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
White ash	59.1	298	444	39'	402.07'	1.35'	21.979'	3.7"
Black birch	1.4	7	10	34'	9.90'	1.41'	.586'	3.9"
Sugar maple	16.4	83	124	37'	75.93'	.92'	4.778'	3.2"
Red maple	5.1	26	39	38'	25.62'	.99'	1.574'	3.3"
Red oak	9.5	48	72	46'	189.01'	3.94'	8.503'	5.7"
Basswood	0.2	1	2	42'	1.50'	1.50'	.079'	3.8"
Paper birch	7.9	40	60	40'	73.72'	1.84'	3.662'	4.1"
Yellow birch	0.4	2	3	38'	2.15'	1.08'	.152'	3.7"
TOTALS	100.0%	505	754	39'	779.90'	1.54'	41.313'	3.9"

Summary of 22% cruise of stand # 5.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Paper birch	25.5	13	167	44'	31.15'	2.40'	1.339'	4.3"
Red oak	31.5	16	205	50'	87.08'	5.43'	3.552'	6.4"
White ash	9.8	5	64	41'	4.23'	.85'	.270'	3.2"
Red maple	1.9	1	13	40'	.70'	.70'	.052'	3.1"
Yellow birch	15.7	8	103	40.5'	9.53'	1.19'	.604'	3.7"
Black birch	13.7	7	90	41'	8.08'	1.35'	.480'	3.5"
Hickory	1.9	1	13	42'	1.10'	1.10'	.056'	3.2"
TOTALS	100.0%	51	655	44.5'	141.87'	2.78'	6.353'	4.8"

Summary of 22% cruise of stand # 6.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Paper birch	27.4	224	120	45'	596.03'	2.67'	28.158'	4.8"
Red oak	35.4	290	155	48'	1383.53'	4.77'	60.350'	6.2"
White ash	15.2	124	66	40'	181.15'	1.46'	10.057'	3.8"
Sugar maple	8.6	70	37	39'	92.43'	1.32'	5.263'	3.7"
Black birch	6.0	49	26	42'	95.08'	1.94'	5.093'	4.4"
Red maple	3.9	32	17	37'	34.36'	1.07'	2.120'	3.5"
Yellow Birch	.3	2	1	39'	3.20'	1.60'	.193'	4.2"
Hickory	1.2	10	5	45'	21.35'	2.14'	1.091'	4.5"
White oak	.5	4	2	33'	4.88'	1.22'	.397'	4.3"
Basswood	.3	1	.5	38'	.70'	.70'	.046'	2.9"
White pine	.5	4	2	36'	16.70'	4.18'	.780'	6.0"
Gray birch	.7	6	3	35'	6.53'	1.09'	.418'	3.6"
TOTALS	100.0%	816	435.5	44'	2437.94'	2.98'	133.966'	5.1"

Summary of 22% cruise of stand # 7.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Sugar maple	17.2	34	127	39'	37.76'	1.11'	2.382'	3.6"
Paper birch	23.2	46	171	39'	78.59'	1.64'	4.155'	4.1"
White ash	39.0	77	286	35'	57.64'	.75'	3.947'	3.2"
Red oak	13.6	27	100	48.5'	98.15'	3.63'	4.750'	5.7"
Red maple	5.0	10	37	38'	7.93'	.79'	.528'	3.1"
Black birch	1.0	2	7	39'	3.65'	1.83'	.250'	4.8"
Hickory	0.5	1	4	32'	.60'	.60'	.043'	2.8"
Gray birch	0.5	1	4	40'	1.10'	1.10'	.071'	3.6"
TOTALS	100.0%	198	736	38.5'	285.42'	1.44'	16.126'	3.9"

Summary of 22% cruise of stand # 8.

Species	Percent	Number	Density, per acre	Average height	Total volume	Average volume	Basal area	Average DBH
Paper birch	7.5	8	26	51'	50.10'	6.24'	2.069'	6.9"
Red oak	29.8	32	103	53'	277.25'	8.66'	11.539'	8.1"
White ash	21.4	23	74	37'	29.76'	1.26'	1.430'	3.2"
Black birch	9.3	10	32	37'	16.26'	1.63'	.993'	4.3"
Red maple	5.6	6	19	35'	5.98'	1.00'	.380'	3.4"
Beech	1.0	1	3	30'	2.10'	2.10'	.126'	4.8"
Yellow birch	2.0	2	6	32'	1.35'	.68'	.106'	3.1"
Sugar maple	12.1	13	42	39'	18.20'	1.40'	1.060'	3.8"
White pine	9.3	10	32	33'	28.70'	2.87'	1.510'	5.3"
Basswood	1.0	1	3	46'	4.05'	4.05'	.210'	6.2"
Hickory	1.0	1	3	48'	2.30'	2.30'	.121'	4.7"
TOTALS	100.0%	107	343	42.5'	436.05'	4.08'	21.170'	6.0"

Height and diameter distribution of red oak by soil types.

Height classes	Dry	Inter.	Wet	Diameter classes	Dry	Inter.	Wet
68 - 70'	0	1	0	11.5 - 12.0"	0	1	0
66 - 68'	0	1	0	11.0 - 11.5"	1	1	0
64 - 66'	0	3	0	10.5 - 11.0"	2	0	0
62 - 64'	1	4	1	10.0 - 10.5"	5	5	0
60 - 62'	5	5	0	9.5 - 10.0"	9	6	0
58 - 60'	16	4	1	9.0 - 9.5"	17	10	1
56 - 58'	33	16	0	8.5 - 9.0"	18	2	0
54 - 56'	65*	22	4	8.0 - 8.5"	21	10	1
52 - 54'	52	18	8	7.5 - 8.0"	26	11	1
50 - 52'	41	31*	5	7.0 - 7.5"	30	14	4
48 - 50'	47	25	10*	6.5 - 7.0"	44*	14	4
46 - 48'	31	20	2	6.0 - 6.5"	35	24*	5
44 - 46'	23	18	5	5.5 - 6.0"	27	10	5
42 - 44'	12	12	2	5.0 - 5.5"	27	23	13*
40 - 42'	14	6	2	4.5 - 5.0"	27	19	2
38 - 40'	16	9	1	4.0 - 4.5"	32	12	4
36 - 38'	8	4	1	3.5 - 4.0"	24	11	1
34 - 36'	5	2	2	3.0 - 3.5"	20	18	3
32 - 34'	8	9	2	2.5 - 3.0"	12	13	1
30 - 32'	2	3	1	2.0 - 2.5"	3	3	3
28 - 30'	1	1	0				
26 - 28'	0	0	1				
Total trees	380	214	48		380	214	48
Average height	52'	46'	46'	Average diameter	6.5"	6.3"	5.7"
Acres, each soil type	3.658	2.20	.672				

* Modal dimension

Height and diameter distribution of paper birch by soil types.

Height classes	Dry	Inter.	Wet	Diameter classes	Dry	Inter.	Wet
68 - 70'	0	1	0	11.0 - 12.0"	1	0	0
66 - 68'	0	1	0	10.0 - 11.0"	0	0	0
64 - 66'	0	4	0	9.0 - 10.0"	2	2	0
62 - 64'	0	3	1	8.0 - 9.0"	7	6	1
60 - 62'	3	3	1	7.0 - 8.0"	13	11	2
58 - 60'	6	1	2	6.0 - 7.0"	6	1	2
56 - 58'	14	14	0	5.0 - 6.0"	58	32	3
54 - 56'	35*	21	2	4.0 - 5.0"	56	50	3
52 - 54'	22	18	0	3.0 - 4.0"	72*	65*	9
50 - 52'	28	18	2	2.0 - 3.0"	55	39	19*
48 - 50'	22	27*	0	1.0 - 2.0"	2	3	1
46 - 48'	22	19	4				
44 - 46'	32	17	0				
42 - 44'	23	11	2				
40 - 42'	17	15	3				
38 - 40'	18	17	4				
36 - 38'	23	7	5				
34 - 36'	10	16	6*				
32 - 34'	4	8	3				
30 - 32'	9	5	3				
28 - 30'	4	5	2				
26 - 28'	0	2	0				
Total trees	292	233	40		292	233	40
Average height	46'	46'	40'	Average diameter	4.8"	5.3"	4.1"

* Modal dimension

Height and diameter distribution of white ash by soil types.

Height classes	Dry	Inter.	Wet	Diameter classes	Dry	Inter.	Wet
62 - 64'	0	1	0	8.0 - 8.5"	0	0	1
60 - 62'	0	1	0	7.5 - 8.0"	0	0	2
58 - 60'	0	0	0	7.0 - 7.5"	0	5	1
56 - 58'	0	1	1	6.5 - 7.0"	2	4	10
54 - 56'	1	7	7	6.0 - 6.5"	5	7	4
52 - 54'	3	12	9	5.5 - 6.0"	6	17	7
50 - 52'	3	26	10	5.0 - 5.5"	6	15	15
48 - 50'	11	33	14	4.5 - 5.0"	11	34	22
46 - 48'	11	34	21	4.0 - 4.5"	20	36	11
44 - 46'	20	38	24	3.5 - 4.0"	21	55	34
42 - 44'	21	32	33	3.0 - 3.5"	46*	50	36
40 - 42'	23	26	26	2.5 - 3.0"	34	83*	65
38 - 40'	28*	35	28	2.0 - 2.5"	20	66	69*
36 - 38'	18	33	23	1.5 - 2.0"	3	19	21
34 - 36'	14	44*	36*				
32 - 34'	14	23	26				
30 - 32'	4	24	18				
28 - 30'	2	11	14				
26 - 28'	1	9	5				
24 - 26'	0	1	3				
Total trees	174	391	298		174	391	298
Average heights	40'	40'	39'	Average diameter	3.8"	3.8"	3.7"

* Modal dimension

Height and diameter distribution of sugar maple by soil types.

Height classes	Dry	Inter.	Wet	Diameter classes	Dry	Inter.	Wet
56 - 58'	0	1	0	6.0 - 6.5"	3	2	0
54 - 56'	0	2	0	5.5 - 6.0"	1	1	1
52 - 54'	2	3	2	5.0 - 5.5"	5	5	4
50 - 52'	3	3	5	4.5 - 5.0"	12	11	3
48 - 50'	4	8	2	4.0 - 4.5"	12	23	4
46 - 48'	7	13	3	3.5 - 4.0"	16	25	9
44 - 46'	7	15	9	3.0 - 3.5"	18	32	13
42 - 44'	10	19	5	2.5 - 3.0"	20*	34*	21
40 - 42'	11	21	5	2.0 - 2.5"	5	32	22*
38 - 40'	12*	17	7	1.5 - 2.0"	0	6	6
36 - 38'	10	18	9				
34 - 36'	11	28*	7				
32 - 34'	9	10	13*				
30 - 32'	2	11	11				
28 - 30'	2	1	4				
26 - 28'	2	1	1				
Total trees	92	171	83		92	171	83
Average height	45'	39'	37'	Average diameters	3.7"	3.4"	3.2"

* Modal dimension

Summary, 100% cruise, plot A, experiment 33 - 1.

	Upper crown class					Lower crown class					Totals	
Species	Number	% of stand	Basal area	% of BA	Average DBH	Number	% of stand	Basal area	% of BA	Average DBH	Numbers	Basal area
White ash	39	43.9	2.901	24.3	3.7"	226	49.2	3.662	44.3	1.7"	265	6.523
Sugar maple	18	20.4	1.600	13.3	4.0"	186	40.5	2.755	33.5	1.6"	204	4.355
Red maple	1	1.1	.136	1.1	5.0"	1	.2	.006	.1	1.0"	2	.142
Red oak	8	8.9	2.989	25.0	8.3"	7	1.5	.296	3.5	2.8"	15	3.285
Paper birch	13	14.6	2.350	19.7	5.8"	5	1.0	.164	1.9	2.5"	18	2.514
Basswood	10	11.2	1.981	16.6	6.0"	10	2.1	.162	1.9	1.7"	20	2.143
Black birch	0	0	0	0	0	6	1.3	.437	5.3	3.7"	6	.437
White pine	0	0	0	0	0	17	3.6	.669	8.1	2.7"	17	.669
Yellow birch	0	0	0	0	0	2	.4	.109	1.3	3.2"	2	.109
Hickory	0	0	0	0	0	1	.2	.006	.1	1.0"	1	.006
TOTALS	89	100.0%	11.957	100.0%	5.0"	461	100.0%	8.226	100.0%	1.8"	550	20.183

Percent of trees in upper crown class - 16.1
" " " " lower " " - 83.9

Percent of B. A. in upper crown class - 59.2
" " " " " lower " " - 40.8

Area of plot - 105' square or .253 acres

Size tree of average DBH - 2.5"

Summary, 100% cruise, plot B, experiment 33 - 1.

	Upper crown class					Lower crown class					Totals	
Species	Number	% of stand	Basal area	% of BA	Average DBH	Number	% of stand	Basal area	% of BA	Average DBH	Numbers	Basal area
White ash	52	41.8	2.882	24.4	3.2"	259	43.4	3.600	43.6	1.6"	311	6.482
Sugar maple	27	21.8	1.617	13.7	3.3"	207	34.7	2.500	30.4	1.5"	234	4.117
Red maple	9	7.3	.491	4.2	3.2"	23	3.8	.326	4.0	1.6"	32	.817
Red oak	10	8.1	2.502	21.2	6.8"	17	2.8	.279	3.4	1.7"	27	2.781
Paper birch	24	19.4	4.048	34.1	5.6"	15	2.5	.401	4.9	2.2"	39	4.449
Black birch	0	0	0	0	0	6	1.0	.084	1.0	1.6"	6	.084
Yellow birch	1	.8	.136	1.2	5.0"	14	2.3	.159	1.9	1.4"	15	.295
White pine	0	0	0	0	0	48	8.0	.732	8.9	1.7"	48	.732
Basswood	1	.8	.136	1.2	5.0"	1	.2	.006	.1	1.0"	2	.142
Red pine	0	0	0	0	0	8	1.3	.150	1.8	1.8"	8	.150
TOTALS	124	100.0%	11.812	100.0%	4.2"	598	100.0%	8.327	100.0%	1.6"	722	20.049

Percent of trees in upper crown class - 17.2
" " " " lower " " - 82.8

Percent of B. A. in upper crown class - 58.9
" " " " " lower " " - 41.1

Area of plot - 105' square or .253 acres

Size of average tree - 2.3"

Summary, 100% cruise, plot C, experiment 33 - 1.

	Upper crown class					Lower crown class					Totals	
Species	Number	% of stand	Basal area	% of BA	Average DBH	Number	% of stand	Basal area	% of BA	Average DBH	Number	Basal area
White ash	134	45.1	6.912	25.2	3.1"	356	35.0	4.636	37.9	1.6"	490	11.548
Sugar maple	82	27.6	3.815	13.9	2.9"	521	51.2	5.580	45.5	1.4"	603	9.395
Red maple	6	2.0	1.497	5.4	6.8"	40	3.9	.545	4.5	1.6"	46	2.042
Red oak	38	12.8	10.272	37.4	7.0"	14	1.4	.164	1.3	1.5"	52	10.436
Paper birch	29	9.8	4.393	16.0	5.3"	8	.8	.203	1.7	2.2"	37	4.596
Black birch	5	1.7	.359	1.3	3.6"	45	4.4	.860	7.0	1.8"	50	1.219
Yellow Birch	2	.7	.136	.5	3.5"	7	.7	.074	.6	1.4"	9	.210
White pine	1	.3	.087	.3	4.0"	15	1.5	.090	.7	1.0"	16	.177
Red pine	0	0	0	0	0	8	.8	.048	.4	1.0"	8	.048
White oak	0	0	0	0	0	1	.1	.006	.1	1.0"	1	.006
Hickory	0	0	0	0	0	1	.1	.022	.2	2.0"	1	.022
Shadbush	0	0	0	0	0	1	.1	.006	.1	1.0"	1	.006
TOTALS	297	100.0%	27.471	100.0%	4.1"	1017	100.0%	12.234	100.0%	1.5"	1314	39.705

Percent of trees in upper crown class - 22.6
" " " " lower " " - 77.4

Percent of B. A. in upper crown class - 69.2
" " " " " lower " " - 30.8

Area of plot - 105'x 210' or .507 acres

Size of average tree - 2.4" DBH.