tree components into discrete communities must be arbitrary and does not represent a natural separation in the York Woods. White oak, walnut, and perhaps red oak might be suggested as a pioneer community but the disassociation noted between red oak and walnut would suggest that this should be two pioneer communities. On the other end, sugar maple and basswood and hop hornbeam might be regarded as a maple-basswood community but the significant association of red oak and hop hornbeam would suggest that red oak also be included. Since elm also occurs with sugar maple, it ought to be included in such a community but its disassociation from hop hornbeam and basswood suggests a maple-elm association. As an alternative to numerous discrete units in a classification scheme, it is suggested that it is more accurate and more enlightening to view this as a pattern of interconnected species in which the extremes may appear discrete but are connected by a continuous series of intermediate species. Whether the pattern of relations postulated on the basis of the York Woods is unique to it or typical of the deciduous forest of the region remains to be determined. In any study to verify this, it is necessary that adequate attention be given to transitional or intermediate areas, which are commonly slighted, major attention usually being given those areas which are patently discrete.

Summary

This study was made to examine the distribution and interrelations, in one area, of species usually regarded as characteristic of pioneer oak stands, with other species thought of as characteristic of climax maple basswood stands.

A grid of 60 quadrats was used to sample trees over 4″ DBH, each of these quadrats containing 10 smaller quadrats to sample herbaceous species.

Soil depth, the moisture holding capacity, pH, and exchangeable calcium of the A_1 layer, and light intensity were determined in each of the large quadrats.

On the basis of the interrelations of tree species and subordinate species as indicated by Cole's Index of Interspecific Association, it is suggested that the diverse forest elements found are best interpreted as a pattern of species and that separation into two or more discrete communities must be arbitrary.

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LOCAL CLIMATE IN THE HARVARD FOREST[1]

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The interrelationships between local climate and forest composition are basic considerations in forest ecology. Yet the study of local climatic variation in and about the forest has not been exhaustive. A few investigations have dealt primarily with the problem, and many ecological studies have touched upon it. The present study deals with local climate variation within the Harvard Forest at Petersham in central Massachusetts, and is based largely upon data collected by the writer in 1943-45.

The effects of local topography and of forest cover on temperatures near the ground have interested scientists for many years. In recent decades, a number of detailed studies have been made, among which is the classic work of Geiger in 1927, the second edition of which was published in English translation in 1950.

The effect of local topography on local temperature has been studied by Pallman and Frei (1934),

[1] Based on investigations carried on as a member of the staff of Harvard Forest. This paper is derived from a portion of a doctoral dissertation submitted to Yale University, 1950.

Wolfe, Wareham, and Scofield (1943, 1949), Aikman (1934), and Hough (1945) among others. All have found that low concave surfaces tend to radiate heat rapidly on still cold nights and to accumulate cold air which flows in from surrounding higher land. As a result, such sites will frequently have air temperatures near the ground as much as 15°F. lower than that above surrounding terrain. In contrast, relatively high convex surfaces will tend to drain off cold air as radiation from the ground proceeds so that night minima remain fairly high. Similarly, the low concave surfaces tend to accumulate radiation and reach high maximum temperatures near the ground while higher convex surfaces tend to remain cooler during the day. South and west facing slopes are notably warmer than north and east facing slopes, an obvious fact well known to the ancients.

Within the forest, light crown cover and trees without foliage, as in winter, tend to reduce air movement while allowing radiation to penetrate the canopy. Under such conditions, the mean annual temperature may be higher within the forest than outside it (Pearson 1913) and the extremes may be greater (Hursh 1948). When the trees are in full leaf, the extremes within the forest are generally less than outside (Jemison 1934, Vaughan and Wiehe 1947, Burger 1951, Sparkes and Buell 1955; and others), and the diminution of radiation within the forest may result in lower mean annual temperatures (Chapman, *et al.* 1931, Hough 1945, Burger 1951). Within the crowns, the climate is somewhat milder than above them (Australia 1950), but more variable than near the ground (Christy 1952), and minima recorded in conventional shelters tend to be lower than those recorded in the crowns (Fowells 1948).

As part of a broader study designed to evaluate the various factors—historical, environmental, and silvicultural—related to the composition of the Harvard Forest, an experimental tract in central Massachusetts, a study of the variation in local climates was undertaken. Principal attention was paid to variations in minimum and maximum temperature 4 feet above the ground in open locations on various topographic sites. In addition, however, 3 stations were established within a conifer plantation to study the effects of two different degrees of thinning on air temperature 4 feet above the ground and on soil temperatures throughout the year. Supplementary information on variation in annual precipitation, evaporation as measured by Livingston white bulb atmometers, and on frost damage was also obtained.

Method of Study

Weather information has been gathered intermittently at the Harvard Forest for many years. Precipitation records have been taken since 1913 in cooperation with the Metropolitan District Water Supply Commission, and more recently in cooperation with the U. S. Weather Bureau which supplies and maintains a weighing-bucket gauge equipped with wind collar at Station 1, southeast of the Headquarters building. Hygrothermograph records, checked weekly by Weather Bureau type maximum and minimum thermometers have been taken in a standard Weather Bureau shelter at the Headquarters Building intermittently since 1937 and regularly since 1939. Anemometers were installed in 1946.

The present study covered two full years beginning in the fall of 1943. Its principal purpose was to measure air temperature 4 feet above the ground in the open at various topographic sites in the Forest. The stations are identified on Figure 1 and described in Table II. Figure 2 is an east-facing oblique aerial view of the Headquarters area showing the permanent weather station (Station 1) and the location of Stations 2, 3, and 4 in a white pine-white spruce plantation and of Stations 5, 6, and 7 on a south-east cut-over slope.

The thermometers used were of the Weather Bureau type although a few U-type maximum-minimum instruments were also employed. The shelters were home-made of wood with louvers on all four sides and a ventilated base. A single sloping roof with a wide over-hang was utilized. The shelters for the Weather Bureau instruments were approximately 10 inches wide, 12 inches high, and 18 inches long. Those for the U-type instruments were about 12 x 12 inches, in dimensions and 18 inches high. All shelters were painted with two coats of gray-white paint, with a high reflecting capacity. The shelters were mounted approximately 3 to 4 feet from the ground on stakes.

In the open locations, 3 stations were left unmoved for the 2-year period; 4 additional stations were operated for the first year; and 6 additional stations were operated in new locations for the second year, making a total of 13 stations in the open. In addition, 3 stations were operated for the first year under dense forest cover in a conifer plantation; one sampling the uncut stand, one a light thinning, and one a heavy thinning. Current soil temperatures were obtained every Monday morning at various depths in plantation thinning experiment at the time the maximum and minimum air temperatures for the previous week were recorded. A single stack of soil temperatures was

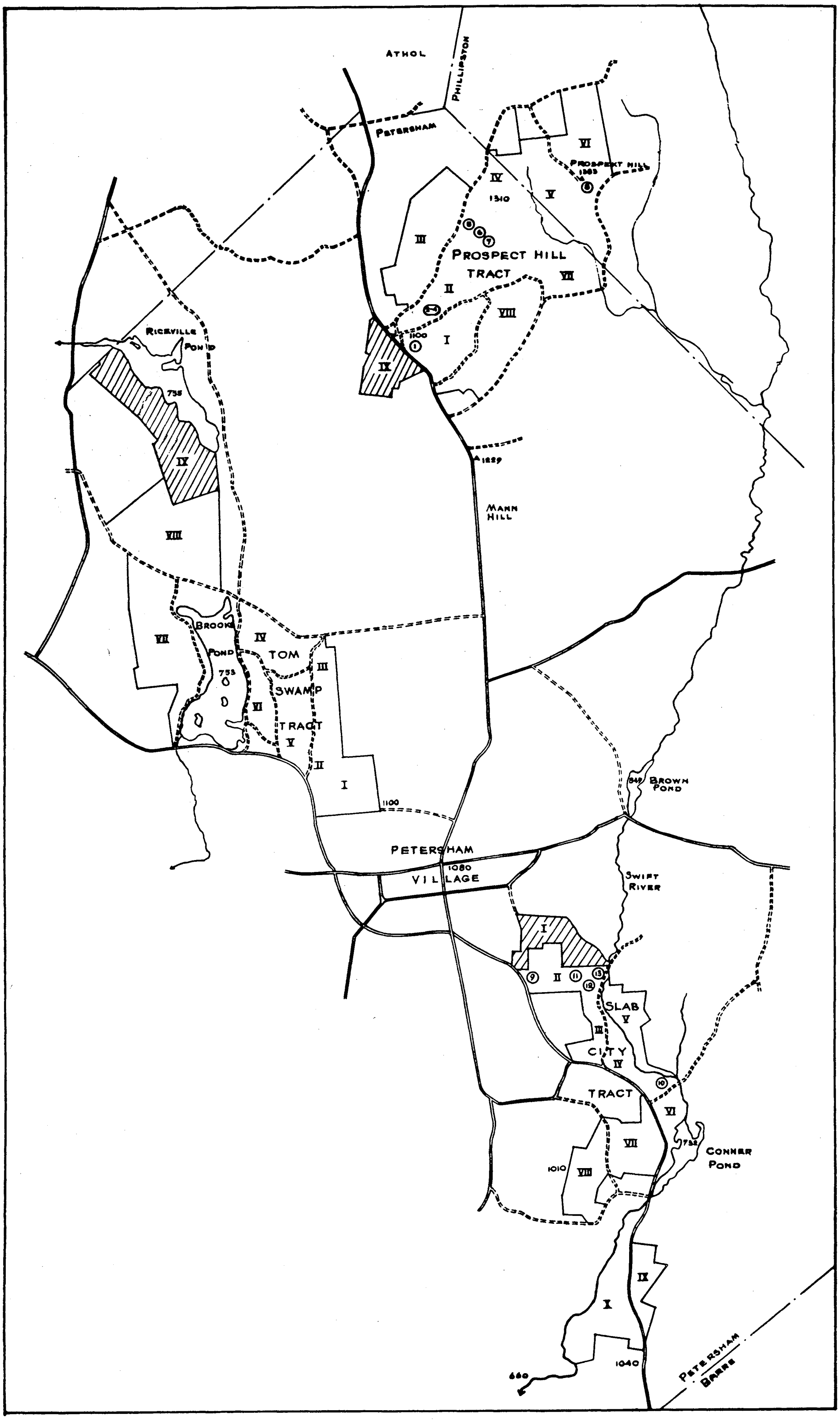

FIG. 1. Map of the Harvard Forest with locations of weather stations in 1943-45 indicated by circled numbers.

FIG. 2. View of the Harvard Forest Headquarters area looking east, showing location of Weather Stations 1 through 7.

taken at each of the 3 stations under forest cover and also in a semi-open clearing adjacent to the plantation in the same soil type.

All instruments were serviced every Monday morning. Livingston white bulb atmometers were maintained at each of the 10 temperature stations throughout the 1944 growing season.

THE PETERSHAM CLIMATE

The annual precipitation as recorded at the Harvard Forest Headquarters over a period of 36 years from 1913 through 1948 averaged 42.36 inches. June is generally the wettest month (4.26 inches) and October the driest (2.97 inches), but the precipitation is generally well distributed throughout the year. In any one year, any month may be characterized by high rainfall or drought (Table I). Monthly rainfall values of around 7 inches or more have been recorded for every month as have droughts of only about one inch or less.

Yearly rainfall also fluctuates considerably. In 28 out of the 36 years recorded, the rainfall has been between 35 and 50 inches, but for 3 years a smaller amount and for 5 a larger amount has been measured. The driest year on record was 1941 with 27.3 inches, followed by 1914 and 1930 with 30.9 and 32.2 inches respectively. The wettest year was 1938 with 60.1 inches, of which 15.79 fell in September immediately preceding the hurricane of September 21, and an additional 15.62 fell in June and July. Other wet years were 1933,

TABLE I. Maximum, minimum and mean precipitation by months, 1913-1948, Harvard Forest Headquarters

Month	MAXIMUM		MINIMUM		AVERAGE
	Year	Inches	Year	Inches	Inches
January	1936	7.51	1944	1.09	3.55
February	1920	7.44	1943	1.34	3.14
March	1942	6.48	1915	0.07	3.21
April	1933	7.69	1941	0.67	3.48
May	1948	6.01	1944	0.91	3.38
June	1922	11.17	1913	0.89	4.27
July	1915	9.81	1939	0.97	4.02
August	1928	7.70	1944	0.66	3.52
September	1938	15.78	1914	0.29	3.92
October	1917	5.84	1924	0.00	2.97
November	1940	6.96	1939	0.99	3.79
December	1936	6.91	1943	0.72	3.11
Total	1938	60.11	1941	27.33	42.36

1937, 1920, and 1936 with 53.6, 51.8, 51.8, and 50.8 inches of precipitation, respectively.

Temperature values were obtained from a 9-year record at the Headquarters in a standard U. S. Weather Bureau shelter on an open lawn. The mean annual temperature, as computed from the weekly maximum and minimum readings, is 44.0°F., ranging from 20.4 in January to 67.6 in July. The trend of mean weekly maximum and minimum temperatures is shown in Figure 3. The coldest weather occurs in the middle of January and the hottest in the middle of July, with the minima lagging slightly behind the maxima. The maxima remain high for a longer period than do the minima. The maximum averages about 70° from the end of April to the latter half of October, while the minimum averages above 32° only from the middle of May to the end of September. The warmest recorded temperature from 1937 through 1947 was 97°F., and the coldest at the Headquarters was —29°F.

The season when the temperature remains above 32°F. may be taken as an approximation of

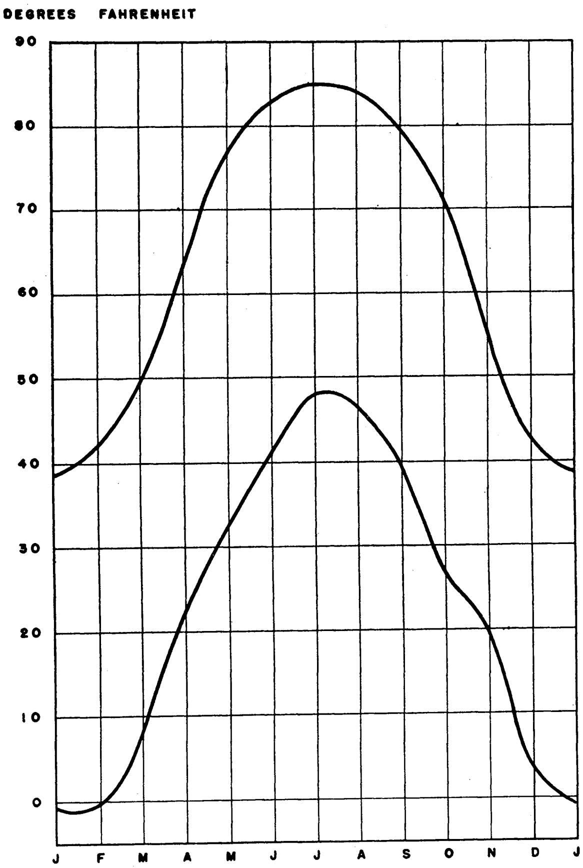

FIG. 3. Mean trend of weekly maxima and minima throughout the year at Station 1, Harvard Forest Headquarters, 1937-1947.

the growing season. For the 11 years from 1936 through 1947, it has varied at the Headquarters building from 103 days in 1944 to 154 days in 1940 and 1942. The average season above 32°F. for this period was 137 days.

Summer winds from the west or southwest prevail, with east winds being next most common. Wind velocity at noon through the summer months averaged 4 miles per hour in 1947.

LOCAL TEMPERATURE VARIATION

In the local climate study, chief emphasis was placed on maximum and minimum air temperatures. The results confirmed studies by others elsewhere in demonstrating that the local climate varies markedly and is largely controlled by local topography and type of vegetation cover. The various weather stations are described in Table II, and the mean weekly maximum, minimum, and

TABLE II. Location of Harvard Forest weather stations, 1943-1945, and habitats sampled

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

mean temperatures are given in Table III for the four seasons. In this table, each seasonal mean is based upon 13 weekly temperatures. The seasons begin on December 21, March 21, June 21, and September 21. The winter temperatures for Station 4 and 9 are based upon the last 9 and 8 weeks of the season only, and the mean temperatures covering the same period at Station 1A are given for comparison. The 1943-44 records include the period from October 25, 1943, to the same date in 1944, while the 1944-45 records likewise begin and end on October 25th.

The stations may be considered in three groups: (1) the stations at the Headquarters, (2) the sta-

TABLE III. Mean seasonal temperatures at local weather stations, Harvard Forest, 1943-1945. Mean weekly maxima, minima, and mean temperatures by 13-week quarters

Station	Winter			Spring			Summer			Fall		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1943-44												
1A	41.1	−1.2	20.0	73.1	28.1	50.7	85.4	46.6	66.0	57.5	18.8	38.2
2	38.1	1.8	19.9	70.2	30.9	50.6	79.9	49.8	64.8	53.0	22.1	37.5
3	36.8	1.9	19.3	67.9	31.5	49.7	78.0	49.4	63.8	51.8	21.8	36.8
4	(38.7)[1]	(3.1)[1]	(21.0)[1]	68.8	30.5	49.6	79.7	48.4	64.0	52.1	22.0	37.0
1A	(42.9)[1]	(0.8)[1]	(21.8)[1]									
5	40.6	1.9	21.3	75.1	31.5	53.3	90.0	51.0	70.5	58.5	21.3	39.9
6	42.8	0.8	21.8	77.0	30.8	53.9	93.4	49.4	71.5	61.5	20.3	40.9
7	43.3	−1.3	21.0	76.0	26.9	51.5	89.8	45.0	67.5	60.3	17.7	39.0
8	40.8	2.7	21.8	75.9	33.4	54.7	92.1	52.1	72.1	59.6	21.9	40.8
9	(46.5)[2]	(−4.0)[2]	(21.2)[2]	79.2	22.9	51.0	92.5	40.8	66.7	....	....	....
1A	(43.1)[2]	(−0.2)[2]	(21.4)[2]									
10	46.8	−6.3	20.3	80.5	23.6	52.0	94.3	42.7	68.4	64.0	15.5	39.7
1944-45												
1A	42.4	−1.3	20.5	73.6	30.7	52.2	84.7	45.8	65.3	62.7	19.8	41.3
1C	43.3	0.2	21.8	73.8	31.5	52.7	86.9	46.5	66.7	61.2	20.8	41.0
1D	43.0	−0.5	21.3	74.3	31.5	52.8	86.8	46.5	66.7	61.2	20.8	41.0
1E	42.5	−0.9	20.8	76.7	30.4	53.5	89.3	45.8	67.6	63.0	19.9	41.5
9	47.8	−8.8	19.5	78.2	26.5	52.4	91.8	41.2	66.5	67.2	16.2	41.9
10	47.8	−9.2	19.3	80.4	26.5	53.4	94.6	43.3	69.0	67.8	15.8	41.8
11	48.1	−4.4	21.8	79.9	28.2	54.1	93.2	42.2	67.7	67.7	16.2	41.9
12	46.5	−5.5	20.5	80.5	27.8	54.1	90.2	42.8	66.5	64.5	16.4	40.4
13	44.2	−6.2	19.0	77.3	27.8	52.5	90.1	43.2	66.6	64.5	16.8	40.7

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

tions in the open or in small clearings throughout the Forest, and (3) the three stations under the forest canopy in the thinning experiment.

Variation in temperature with type and height of shelter

The first year's results indicated that higher maxima were obtained during the warm weather in the small shelters around the forest than were recorded in the large shelter at the headquarters area (Station 1). In order to determine how much of this variation was due to the size of the shelters, and also to evaluate the effect of height of shelter above the ground on temperatures, a series of small shelters were placed next to the large shelter at the Headquarters during the second year. Of these, one was a small upright shelter with a U-type (Six's) maximum-minimum thermometer, while 3 were small horizontal shelters with Weather Bureau type instruments placed at 6, 3, and 1 feet above the ground. The small Six's type instrument and shelter (Station 1B) was found to give comparable results to the Weather Bureau type instruments in small shelters at the same distance from the ground (Station 1D) and was discontinued after several months.

Readings in the small shelter at 6 feet (Station 1C) yielded hot weather maxima averaging 2.2° higher than were obtained in the large shelter, but under other climatic conditions yielded fairly comparable results. Practically identical readings were obtained in the small shelters at the 3- and 6-foot heights, indicating that the practice of placing the instruments in the field at a 3-foot height did not produce any large error. The 1-foot readings (Station 1E), though, were quite different, the hot weather maxima being 2.5° higher and the minima throughout the year averaging 0.75° lower than at the 3-foot level.

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

Variation in temperature with topographic location

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

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

The intermediate stations (1D, 6, and 12) proved to be intermediate in temperature range. The relatively high maxima at Station 6 were thought to be related to the facts that the slope has a southeasterly aspect and that a pocket had formed around that station by rapidly growing hardwood sprouts which sheltered the instrument from winds without providing shade. Cutting back these sprouts noticeably reduced the high maxima.

Although highly significant differences were found between maximum and minimum temperature readings at various points, the high maxima and low minima found in frost pockets tended to compensate so that relatively little variation in mean annual temperature was found. The maximum difference in mean annual temperature between the stations in the open in 1943-44 was 0.9° and in 1944-45 was 1.5°. It thus appears that mean annual temperatures are fairly free of influence of relative elevation and that their values may safely be compared in determining the influence of latitude and altitude on climate. This finding was drawn upon in the determination of long-term climatic trends previously published (Spurr 1953). It should be noted, however, that south slopes and north slopes were not included in the present study.

The length of the period above 32°F. proved to be much shorter in the frost pockets than at points of good air drainage. The length of this season is a highly variable quantity and the present study is sufficient to give only an indication and not to supply any valid averages. In 1943-44, the longest period above 32°F. was 161 days at the tops of Prospect and Little Prospect Hills and also at Station 6. At the Headquarters, the period was 156 days; at the edge of the peat bog (Station 7), it was only 126 days; at Burns Bridge, 104 days; and at Station 9, it was only 77 days, temperatures below 32°F. being observed on August 25 at that point. The following year, the period above 32°F. was shortened by two late frosts in June, but the variation in length of the period at the different stations was generally consistent with the previous year's findings. The longest season, 119 days, was at the headquarters; while at the various Slab City stations, the period ranged from 91 to 112 days.

Variation in temperature within a plantation

The three stations in Plantation 24C, a 20-year-old white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) plantation, provide some data on temperatures under dense conifers, and on changes in temperatures brought about by thinning. In general, lower maxima and higher minima were obtained throughout the year under the spruce-pine cover than in the open. The mean temperatures were a little lower at all seasons than at the nearby Headquarters, never by more than 2°, and usually by less. In other words, the spruce-pine overstory greatly modified the temperature extremes, but exerted relatively little effect on average temperatures. Very little difference was observable between the uncut stand, light thinning and heavy thinning. Maxima in the uncut stand were somewhat lower than under the thinned stands, but minima did not differ significantly.

Soil temperatures were made directly every Monday morning and at other times during the 1943-44 period in the reserve stand, the heavily-thinned stand, and in a nearby semi-open area (clearing created in adjacent stand by hurricane blowdown). Readings were taken from mercurial laboratory-type thermometers imbedded 6 inches horizontally into the earth from a square shaft set into the ground and lined with lumber. The shaft was approximately 10 x 12 inches in diameter, was filled between readings with excelsior, and sealed with an insulated lid 4 inches thick. Readings were taken above the mineral soil at 12, 6, and 2 inches, at the top of the mineral soil, and 2, 6, and 10 inches below the surface of the mineral soil. Throughout the fall and winter, the soil remained warmer than the air, and the air temperatures increased toward the ground. The surface of the soil at all three stations fell below freezing for the first time about December 12, while the temperature at the 10-inch depth fell below freezing on January 3. At no time did the temperature at the 10-inch depth fall below 31° at any station. The minimum winter temperature at the 2-inch depth was 28° in the reserve stand, and 26° in the semi-open station. Snow cover measurements were taken weekly. Snow began to accumulate in late November, reached a maximum depth of about one foot in January and February, and disappeared in late March or early April.

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

Variation in Evaporation with Topography

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

Frost Damage in May, 1944

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

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

Thus, the minimum temperature ranged from 17 to 30° at a time when the leaves were out. Frost damage varied accordingly. At the top of Prospect Hill, of the 11 species examined, only two trees of *Quercus rubra* L. showed damage, with two small individuals sustaining injury to approximately 20 per cent of the foliage. At the other extreme, around Station 9, *Quercus rubra, Castanea dentata* (Marsh.) Borkh., *Rhus typhina* L., *Q. alba* L., *Acer rubrum* L., and *Betula alleghaniensis* Britton were 90 per cent or more defoliated; *Prunus virginiana* L. and *P. pensylvanica* L. were 35 per cent defoliated; and *Betula populifolia* Marsh., *B. papyrifera* Marsh., *P. serotina* Ehrh., *Piceas abies* (L.) Karst, and *Populus grandidentata Michx*. exhibited 10 to 20 per cent injury. The other stations provided intermediate results. The severe frost injury of *Quercus rubra* and *Castanea* was at least partly due to the fact that the leaves and branchlets of these species were at a much earlier stage of development than those of the other species. They were light yellow green and less than one-half of mature length. Most species listed were observed at all locations.

As a result of these observations, it was possible to construct a tentative list of species with regard to frost susceptibility early in the growing season. Class A, the most resistant species which showed less than 10 per cent leaf injury following long exposure to 20°F. This class includes hawthorn (*Crataegus* spp.), black cherry (*Prunus serotina* Ehrh.), aspen (*Populus tremuloides*), and gray birch (*Betula populifolia* Marsh.) Class B, including paper birch (*B. papyrifera* Marsh.) and pin cherry (*P. pensylvanica* L.), showed slight injury at 26° but less than 40 per cent defoliation at 17°. Class C, comprising red maple (*Acer rubrum* L.) and large-toothed aspen (*P. grandidentata* Michx.), was highly variable, but showed less than 50 per cent defoliation following long exposure to 20°. Class D, showing severe but not complete defoliation, includes white oak (*Quercus alba* L.), yellow birch (*Betula alleghaniensis* Britton) and staghorn sumac (*Rhus typhina* L.). Finally, class E consisted of species largely or completely defoliated at 26°. These included red oak (*Quercus rubra* L.), chestnut (*Castanea dentata* Marsh.) Borkh., hickory (*Carya* spp.), and white ash (*Fraxinus americana* L.).

Influence of Local Climate on Forest Composition

The data presented here indicate that the local climates differ significantly from place to place throughout the Harvard Forest. In concave areas, both high and low in relative elevation, where air drainage is poor, the maximum temperatures are higher, the minimum temperatures are lower, and the frost-free season is a great deal shorter than in convex areas characterized by good cold air drainage. Under forest cover, the local climate is modified to an even greater extent. The temperature extremes under forest are moderated without the means being greatly changed.

It might be expected, therefore, that forest composition is influenced by local climate to a major extent. Actual proof of the effect of local climate on stand composition, however, is not at all ample. Other variables such as land-use history, forest management history, and forest soils all exert obvious and masking effects, and an extremely detailed study would be needed to isolate the importance of local climatic factors. That local climate is highly important in influencing plant distribution, however, cannot be doubted. A few illustrations will suffice.

First, it has been demonstrated in an earlier paper (Spurr 1956) that forest composition in the Harvard Forest is closely related to soil water drainage. Local climate varies with varying soil water drainage. The same factors, especially the existence of convex surfaces, that make a soil very well drained are apt to insure good drainage of cold air and to indicate a site with lower maximum and higher minimum temperatures than would be indicated by a regional climatic average. Thus, a very well-drained site is apt to have a moderated climate suitable to plants of a generally southern distribution. Likewise, a very poorly drained soil is apt to result from a concave land surface that inhibits the drainage of cold air as well as of water. Thus, the very poorly drained sites are apt to be characterized by temperature extremes and a short growing season, and thus might prove suitable for plants of a generally northern distribution.

Of the species that occur near the southern limit of their range in the Harvard Forest, red spruce (*Picea rubens* Sarg.) black spruce (*Picea mariana* (Mill.) B.S.P.) and tamarack (*Larix laricina* (Du Roi) K. Koch) are all largely confined to peat bog sites, sites which are characterized by low minimum temperatures throughout the year and a very short growing season. The implication is strong that these trees are localized in the Petersham region in localities where the season above 32°F. is shorter and the minimum temperatures are lower than the regional average.

There is less evidence that species occurring near the northern edge of their range are found on the well-drained high slopes. It is true that the various oaks are apt to be found at the northern limits of their range in New England on high south-facing aspects. In the Petersham area, however, only the hickories and black gum (*Nyssa sylvatica* Marsh.) are near the northern edge of their range. The former occur on the hills, but also on the imperfectly-drained sites. They are not found in the Forest on the poorly-drained (and the colder) sites. Black gum is found chiefly in the Proespect Hill peat bog in close association with red spruce.

The climatic data, however, do tend to explain why white ash is found only infrequently on the poorly-drained and very-poorly-drained sites. As noted above, this species is extremely susceptible to frost injury, a fact frequently noted in connection with the many small white ash plantings in the Forest. Apparently, the late spring and early fall frosts of the low-lying poorly-drained soils are sufficient to inhibit the successful development of white ash past the juvenile stage on these sites, even though the species may be abundant in the reproduction. Understory white ash require opening of the forest canopy to grow. The localized cutting of overstory trees to free such white ash, however, will frequently result in such a configuration of the forest canopy that a local frost pocket is formed, cold air flows into the clearing on clear still nights and radiation frosts injure the small white ash.

Summary

A two-year study of local climatic variations (1943-45) in the Harvard Forest in central Massachusetts, coupled with other weather data over a period of 36 years, indicate that temperatures vary considerably from place to place. Concave areas are characterized by greater temperature extremes and shorter growing seasons; convex areas by lesser extremes and longer growing seasons. In a dense plantation, the extremes are greatly moderated. In all cases, however, the mean annual temperature is little affected.

The variation in local climate tends to explain the concentration of northerly species such as red spruce, black spruce, and tamarack in the bogs characterized by extremes of cold and short grow-

ing seasons. It seems correlated with the absence of mature white ash on the frosty sites, and it may help explain some features of the distribution of species having a southerly range.

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APPLICATIONS OF ECOLOGY IN FOREST MANAGEMENT

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Plant ecology in general, and forest ecology in particular, provides the biological foundation of silviculture. The silviculturist, concerned as he is with the culture and regeneration of forest crops, is actually a practitioner of applied ecology. It is important that the dependence of silviculture on ecology be appreciated; just as a spring can rise no higher than its source, so also silviculture can be no better than the ecology on which it is based.

Recognition of the intimate relation between ecology and silviculture is not new. It was in the early part of this century that Dr. Gifford, at Cornell, coined the word "silvics," which may be defined as the life history and general characteristics of forest trees and stands, with particular reference to environmental factors (Fernow 1914). For the past half-century or so, at least one course in "silvics," or perhaps better, forest ecology, has been a part of the training of nearly every forester in America. Formal recognition of the basic nature of ecology in silviculture is also found in the titles of numerous textbooks, for example Heinrich Mayr's "Waldbau auf naturgesetzlicher Grundlage," published in 1909, Konrad Rubner's "Die pflanzengeographischen Grundlagen des Waldbaus," 1924; James W. Toumey's "Foundations of silviculture upon an ecological basis," 1928; and Alfred Dengler's "Waldbau auf ökologischer Grundlage," 1930.

Applications of ecological concepts and principles in silviculture are many, but only a few examples can be considered here. In my opinion, one of the most important contributions of ecology is what may be termed the ecological point of view —the seeking of cause and effect relations between environment on the one hand and vegetation on the other. Many years ago Livingston (1929) at the Johns Hopkins University, stated, "It is well-nigh axiomatic . . . that every process has its antecedent set of causal conditions and also its subsequent