Hemlock and Its Environment

I. FIELD RECORDS

By Barrington Moore, Herbert M. Richards, H. A. Gleason, and A. B. Stout [1]

In the spring of 1922 The New York Botanical Garden undertook a study of its hemlock grove and of hemlock forests in general, with a view to determining, so far as possible, the conditions under which hemlock grows and the causes of this isolated hemlock forest on the Botanical Garden grounds. The information would be of value not only in the perpetuation of the hemlock grove but in practical forestry. A fairly comprehensive plan was adopted, calling for field records of climatic conditions, soil investigations, and laboratory experiments under controlled conditions. The work was started, and such instrumental records secured as the limited facilities would permit. It has not yet been possible to commence the soil and laboratory work, although it is hoped that something of a comparatively simple nature may be under way by next winter. Since the field records, though covering but a single season and only a comparatively small number of environmental factors, are yet a more or less complete unit of the larger project, they are presented by themselves as Part I of the hemlock study. We are fully aware of the fact that we have merely scratched the surface of an extremely interesting and important problem, and hope some day, if the facilities become available, to carry the work further.

Purpose of Part I of the Study

The purpose of the first part of the investigation was to find out something of the climatic conditions under which hemlock grows, and the requirements of hemlock for moisture and temperature. It was also desirable to ascertain, if possible, the position of hemlock forests in the developmental series of the types of vegetation which occur in the region. Botanists recognize that

[1] Hemlock Committee of The New York Botanical Garden. The Committee gratefully acknowledges the helpful coöperation of the Yale Forest School, the New York State College of Forestry at Syracuse University, and the Department of Forestry of Cornell University.

the vegetation which occupies the ground today is not necessarily the same as that which has been there in the past or which will be there in the future, if the area is left undisturbed. Vegetation, or associations of plants, like the individual plants, is subject to the laws of evolution. It progresses from lower and simpler to higher and more complex forms. For example, in Eastern United States, a rock ledge in the open will first become covered with drought-resistant lichens. As the rock weathers, and soil is formed, herbs can establish themselves and enrich the soil with their remains. Then come shrubs, and these are followed by drought-resistant trees. Generally these trees are light-demanding species, such as gray birch, juniper, and so forth. Under these trees the more shade-enduring species establish themselves and eventually crowd out the pioneers. The highest type of forest possible in the region is known as the climax forest. Each successive type creates to a certain extent its own environment, and the climax is the richest, and generally the most moist and densest forest which the climate will produce. In drier climates, like the western plain or semi-arid mountains, the climax vegetation is grassland or brush.

In this particular case we would like to know whether the hemlock or the hardwoods represent the climax forest. The hardwoods are the common growth, and formed a large part of the virgin forests of the region when the earlier settlers arrived. But hemlock is more shade-enduring than any of our hardwoods hereabouts, except for beech and sugar maple, and other things being equal, should be able to crowd out the oaks if there were no fire, cutting, or other disturbance. Theoretically, therefore, from standpoint of shade more especially, the hemlock forest appears to be a higher type than the mixed oaks, and to be the climax. If so, the conditions beneath it, the environment which it makes for itself, should be more favorable than that prevailing under the oak forest. Various authorities consider the hemlock as one of the most important constituents of the climax for this region if forest fires are kept out, although they believe it to be a question whether or not pure hemlock is the climax.

Environmental Factors and Instruments

In this study it was not possible to measure all the factors of the environment which we know influence plants. We were

obliged to select for determination certain conditions which would serve as indicators of others. The two most important sets of conditions are moisture and temperature. As an index of moisture we measured evaporation, because in turn evaporation is influenced by factors which influence transpiration, or water loss, by the plant, such as temperature, relative humidity, and wind movement. Of course no instrument which has been or probably ever could be devised would respond to evaporation in the same way that the plant does. On account of the living protoplasm which it contains, the plant, when exposed to unfavorable external factors, sets up internal resistances which we are unable to imitate in our instruments. Evaporation therefore tells us the conditions to which the plant is subjected, not the rate of water loss or of other life processes of the plant. The instruments selected for evaporation were Livingston porous cup atmometers, the evaporating surface being a white sphere of porous porcelain which draws distilled water up from a reservoir bottle to which it is attached by a glass tube. A mercury seal in the tube permits the upward passage of the water, but prevents its downward flow, and thus keeps out rain. The instruments are read by measuring the quantity of water required to refill the reservoir bottle. This gives the total amount of water evaporated, in cubic centimeters, since the last reading, whenever that may have been. In this case readings were made once a week. The instruments are standardized, so that by the application of a correction coefficient the results are comparable with those from similar instruments anywhere else. It might be added that the instrument is widely used in studying plant environments throughout the country, so that the records taken in this investigation can be compared with those for other vegetation in other regions.

In addition to the white spheres, black spheres were used. The black absorbs sunlight to a certain extent, so that the difference between the readings of the black and white spheres gives a rough measure of sunlight, a very important environmental factor. These sunlight, or solar radiation readings were, however, not entirely satisfactory. Under a forest canopy a fleck of sunlight may strike the white sphere while the black is in the shade, and it is impossible to obtain uniform light for both black and white instruments. Hence the white sometimes gives higher readings than the black, an obvious contradiction.

The atmometers were placed so that the spheres were approximately from six to eight inches above the ground. In this way they show the conditions to which the tree seedlings are subjected in becoming established. This is perhaps the most important level under a forest, because the seedlings are the future generation, on which the forest depends for its perpetuation.

As a further measure of moisture, standard Weather Bureau rain gauges were installed in the forest. Tests by Horton[1] have shown that tree crowns intercept considerable amounts of precipitation which is evaporated and never reaches the soil. The proportion varies with the density of the crown and the duration and intensity of the rain. But he has found an average of about 25 per cent for most trees in heavy rains of long duration. In Europe, observations by Matthieu[2] have shown an interception of 5.8 per cent. in winter and 11 per cent. in summer. Reigler[3] found that beech intercepted 21.8 per cent, oak 20.7 per cent, maple 22.5 per cent and spruce 58.8 per cent. It would obviously be extremely interesting to find out how much hemlock intercepts. There are indications that the slow growth of vegetation under a forest is due not only to shade, but also partly at least to lower moisture resulting from the competition of tree roots and from the interception of precipitation by the crowns.

There are certain difficulties in measuring the interception of precipitation by a forest canopy, because the rain which reaches the forest floor is not uniformly distributed. Probably more drips off the end of the branches than comes through the crown, so that a part of the forest floor may receive more than the open, and another part under the crown considerably less. Obviously it would require a large number of rain gauges distributed with reference to the crowns to determine just the amount received by the forest floor. This was impracticable in the present study.

The temperature conditions were measured by taking weekly readings of the maximum and minimum temperature of the air about 8 inches above the ground, and of the soil at depths of 6 inches and 18 inches. Each reading represented the coldest and

[1] Horton, R. E. Rainfall interception. Mon. Weath. Rev. 47: 603–623. 1917

[2] Matthieu, A. "Metéorologie comparée agricole et forestière," 1878.

[3] Quoted by B. E. Fernow, "Forest Influences." U. S. Dept. Agriculture, Forestry Division, Bull. 7: 131. 1902.

warmest temperatures at these important points during the past week.

Selection of Stations

The selection of stations was made with a view to covering as wide a range of conditions as practical considerations would permit. Thanks to the generous coöperation of the Yale Forest School, the Department of Forestry at Cornell University, and the State College of Forestry at Syracuse, it was possible to secure a distribution of stations which represented fairly well the northern and southern as well as middle portions of the range of the hemlock type. In this particular project we are interested rather in the distribution of hemlock forests than in the range of the tree as a botanical specimen, which, of course, is wider than the range of the forest.

The hemlock grove on the grounds of The New York Botanical Garden represents the most southerly extension of this type of forest along the Atlantic Coast. Accordingly this was taken as the southerly point in the series. It should be pointed out, however, that in all probability the reasons why this grove is the most southerly representative of the type along the coast are not wholly climatic. There seem to be also physiographic causes. South of New York the coastal plain forms a wide belt extending back from the Atlantic ocean. New York is the most southerly point at which the older crystalline rocks come close to the sea. Hemlock is primarily a tree of rocky places and rugged slopes, rather than of deep soils and level stretches such as characterize the coastal plain.

The middle points, or optimum, in the hemlock type were taken at Ithaca and near New Haven. Although New Haven is at about the same latitude as New York, it is distinctly cooler, and is in the midst of thriving hemlock forests which seem to do almost as well as anywhere outside of the well-known stands in Pennsylvania which it was impracticable to include. The northerly point selected was at Cranberry Lake in the Adirondacks, where the tree no longer forms pure stands, but occurs in groups in the predominant northern hardwoods and spruce forest.

Description of Stations

At The New York Botanical Garden the above-mentioned records were taken not only in the midst of the hemlock grove but at three other stations for comparison. The first station was placed in the open about 300 yards west of the hemlock grove, and about 100 yards north of the Museum building. The aim was to measure the conditions themselves, uninfluenced by the forest. This gives a basis or starting point from which we can tell how the forest has changed conditions. It also represents the environmental factors which the forest must encounter in becoming established.

The second station was in the hemlock grove proper. In order to have it as fairly representative as possible, and avoid local variations due to slopes which cut off the wind and so forth, it was placed approximately on top of the ridge with exposure on all sides, but completely surrounded by hemlock. There is a small proportion of oak scattered through the hemlock forest, and the station happened to be near a white oak. This probably does not appreciably affect the results. There was no undergrowth, and the forest floor was the usual mat of hemlock needles with a sprinkling of oak leaves. There was no young growth of hemlock.

The third station was on the transition line between the hemlock and hardwood types. It was on a gentle slope about 200 yards south of the hemlock station. On one side the forest was predominantly hemlock. The instruments were placed under a mixture of hemlock and beech. There was very little undergrowth, and the forest floor was covered with a thin layer of hemlock needles and beech leaves.

The fourth station was under a typical hardwood forest about 150 yards south of the transition station, on the east side of a low gently sloping ridge. The instruments were beneath the outer crown of a large white oak about 30 inches in diameter at 4½ feet above the ground. There was an understory of dogwood and witch hazel, with a considerable amount of herbaceous undergrowth on the leaf-covered forest floor. There was also a small amount of oak reproduction. The contrast between this light-green deciduous forest with its variety of different species, and the rather sombre pure hemlock such a short distance away was indeed striking.

The hemlock forest on the Botanical Garden grounds is mature, well over 100 years old. While it may be second growth following a former stand which was cut or burned many

years ago, it has never been disturbed except for the removal of dead trees and the trampling of the ground by numerous visitors. This apparently unavoidable trampling, and the absence of mossy logs which form such a favorable seed-bed for hemlock, are probably in large part responsible for the lack of reproduction.

The oak forest seems to be very old, and has the appearance of being a remnant of the virgin forest which clothed the region when the first white men arrived. The trees are, of course, not the same ones, but their direct successors, and are probably well over 100 year's old.

For the vicinity of New Haven it was originally planned to have a station in a pure hemlock forest and another under hardwoods. It was finally decided, however, on the recommendation of Prof. Hawley and Dr. Nichols, to have two hemlock stations on markedly different sites, one on a moist north slope, and another on a dry ridge top, in order to determine the actual differences between the extremes for the type. Prof. Hawley and Dr. Nichols are of the opinion that in all probability the climax in general would be a mixed forest of hemlocks and hardwoods, with hemlock commonly predominant and frequently forming pure stands. Certainly the hemlock formerly was much more widely distributed than now; probably it predominated over large areas where today it is absent. An examination of the forest on Saltonstall Ridge, which has been protected from fire by the New Haven Water Company for the past 15 years or so, revealed hemlock reproduction coming up everywhere under the hardwoods. It would seem, therefore, that records under a hardwood forest would merely show conditions in a stage in the successional series leading up to the hemlock climax. Extremes for the hemlock were considered of more interest. Both stations were established on Saltonstall Ridge under forests of pure hemlock. The one on the north slope was young and thrifty, with practically no undergrowth near the instruments, and the usual cover of needles. The soil here was a fairly deep reddish brown glacial till. The ridge top stand was mature, but the trees were short and rather small. The canopy was less dense than on the north slope, and there was a little shrubby and herbaceous undergrowth. The soil was very shallow, and the trap rock which forms the back-bone of the ridge cropped out here and there. Hemlock reproduction was abundant in the openings near both stations.

Cornell established two stations also, one in hemlock and the other in hardwoods. They were about two miles east of the University, just below the general plateau level in a shallow valley. The hemlock station was in a stand of over 90 per cent. hemlock, the trees being from 12 to 24 inches in diameter at 4½ feet above the ground, and averaging 80 feet in height. The only hardwoods, but not right at the station, were an ash and two sugar maples. Around the instruments the forest floor was the usual bare covering of needles, with practically no undergrowth. The hardwood station was about 250 yards away on a moderate slope with a general northerly exposure. The stand was composed principally of fair-sized beech, white oak and sugar maple; there were scattered hemlocks, but not nearer than 100 feet from the instruments. The instruments were placed under a beech tree. A hemlock seedling was found not far from the instruments, and a little scattered hardwood reproduction, with a sparse growth of herbs and shrubs on the leaf mat. It is not unlikely that if protected from fire or other disturbance the hemlock would seed in under the hardwoods and eventually form a considerable if not a preponderant part of the stand. Thus this hardwood forest may be a stage in the successional series leading to the hemlock climax or to a mixture of hemlocks and hardwoods.

The State College of Forestry station was selected with Dr. Bray in a piece of virgin forest on the New York State Forest Preserve near Cranberry Lake in the western Adirondack Mountains. The forest is predominantly a mixture of beech, yellow birch, sugar maple, and red spruce, with only a comparatively small amount of hemlock and an occasional group of magnificent towering old white pines. Some difficulty was experienced in finding a pure hemlock group containing a sufficient number of trees close enough together to form a typical hemlock canopy. Finally, however, a group of half a dozen very large old trees was selected under which the forest floor was very much like that in a typical hemlock forest. It was on a saddle of a small ridge about 200 feet vertically above the lake, and about a quarter of a mile from it.

Records and Interpretation

The New York and New Haven stations were established shortly after the middle of April. The Cranberry Lake station

was set up on May 4, and in digging the holes for the soil thermometers, frozen ground was encountered a few inches below the surface. The Ithaca stations were established May 12. All the stations were read once a week on the same day until October 5, except for the Cranberry Lake station which was discontinued after September 21.

All the records have been plotted on cross-section paper so as to bring out the relations between the different stations graphically. For each environmental factor, all the New York stations were plotted together, but without the other stations, in order to show the relations between conditions in the open, in the hemlock forest, and in the hardwoods. On another set of charts were plotted for each factor, the two New Haven stations, the two Ithaca stations, Cranberry Lake, and the New York hemlock station. All these stations, it will be noticed, were in the hemlock type, except the hardwoods at Ithaca. Therefore this second set of charts should show the environmental relations between examples of the hemlock type in different parts of its range. They should give us a picture of the differences between certain environmental factors in different hemlock forests. With the range of conditions covered we should have some indication of range of requirements of the type. Since the records cover only a single season, it is impossible to say that they represent definite limits, but they do have a distinct relative value, and bring out some rather interesting and unexpected relationships.

The plotting of these two sets of charts for each factor which had to be examined required the plotting of a total of 24 charts, including 120 curves.[1] It will be impossible to reproduce more than a limited number of charts which are typical, or illustrate special features. The detailed records are also too voluminous to publish in full, so only the totals and averages will be presented.[2]

Evaporation

The average daily evaporation for each week from May 12th to October 5th at the four stations on The New York Botanical Garden grounds is shown graphically in figure 1. The relation-

[1] For this laborious and painstaking task thanks are due to Miss Hester M. Rusk of The New York Botanical Garden staff.

[2] The records are on file at The New York Botanical Garden, which will furnish copies to qualified persons at the cost of reproduction.

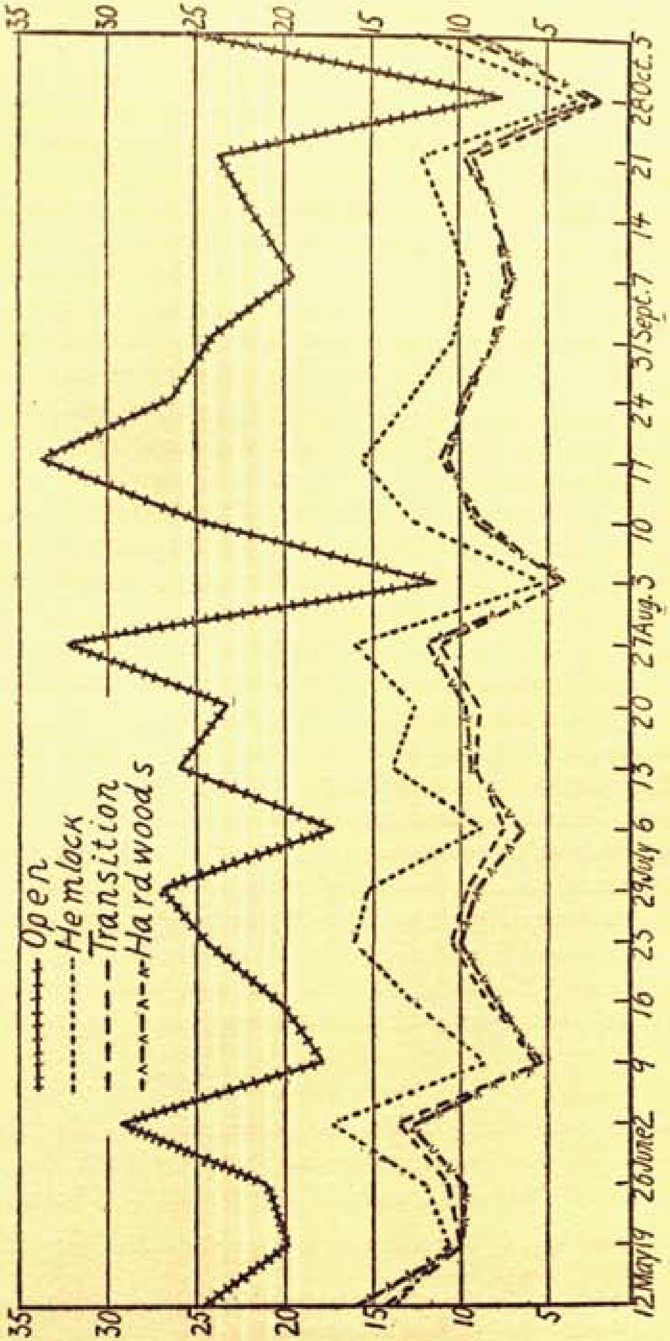

FIGURE 1. Average daily evaporation in cubic centimeters, by Livingston white atmometers. New York stations.

ships between the different forest types stand out very clearly, and are consistent throughout the season.

The open station, as would be expected, shows a much higher rate of evaporation than any of the forest stations, and gives a measure of the protection which the forest canopy offers against heavy drains upon moisture. It must be remembered of course that the favorable influence of shelter from forces which raise the transpiration of plants is counterbalanced by the unfavorable effect of shade.

TABLE I.

EVAPORATION, PRECIPITATION, TEMPERATURE, AND SOLAR RADIATION FOR STATIONS INCLUDED IN THE HEMLOCK STUDY, MAY 12 TO SEPTEMBER 21, 1923, INCLUSIVE

Evaporation is the average daily in cubic centimeters for white atmometers; precipitation is the total in inches; temperature the average in degrees F.; solar radiation average daily in c.c.

	Open N. Y. 1	Hemlock N. Y. 2	Transition N. Y. 3	Hardwoods N. Y. 4	N. Haven Ridgetop	N. Haven North Slope	Cranberry Lake	Ithaca Hemlock	Ithaca Hardwoods
Evaporation	23.3	12.2	9.0	8.9	12.0	10.3	7.5	11.8	11.8
Precip. Totals									
Open	10.05	10.05	10.05	10.05	9.09	9.09	11.78	9.00	9.00
Forest Stations		9.16	9.77	10.20	4.64	5.53	7.82	6.18	5.37
Interception		.89	.28		4.35	3.45	3.96	2.82	3.63
Interception %		9%	3%		48%	38%	34%	31%	43%
Temperatures									
Air									
Max.	89.9	85.0	84.7	81.6	80.6	80.1	75.4	81.7	81.7
Min.	49.2	53.1	53.8	53.7	50.1	48.2	37.8	42.3	43.6
Mean	69.5	69.0	69.3	67.7	65.4	63.7	56.6	61.9	62.6
Soil									
Soil 6 in.									
Max.	78.1	66.4	66.7	68.4	65.6	62.6	59.3	62.8	62.5
Min.	62.4	58.7	58.9	59.7	56.8	55.6	47.5	51.4	51.8
Mean	70.3	62.5	62.8	64.0	61.2	59.1	53.4	57.1	57.2
Soil 18 in.									
Max.	67.4	61.9	61.2	62.5	59.5	57.2	51.6	56.1	57.2
Min.	62.6	57.7	56.6	59.1	57.6	53.9	46.9	51.8	52.7
Mean	65.0	59.8	58.9	60.8	58.5	55.5	49.2	54.0	55.0
Solar Radiation	7.4	1.0	0.9	1.1	0.9	0.3	0.36	0.45	0.7

The most interesting and significant feature of the chart is that it shows the evaporation under the hemlock forest to be distinctly and consistently higher than that under the hardwoods throughout the entire season. So far as evaporation is concerned—and it is a pretty fair index of moisture—the hemlock type is drier than the mixed oaks. This is contrary to all expectations, and its bearing on our conception of developmental trends in vegetation will be discussed more fully below.

The Ithaca hemlock and hardwoods, we see from Table I, had exactly the same average daily evaporation for the season, so that they neither corroborate nor contradict the New York results. But the hemlock at Ithaca was consistently a little higher than the hardwoods for an uninterrupted period extending from June 2 to August 24, or the longest and most important part of the growing season. Furthermore, in describing the stations we hinted that this particular piece of hardwoods may possibly be merely a stage in a successional series leading to the hemlock type or to a stand with a considerable proportion of hemlock in mixture.

The explanation of the higher evaporation under hemlock as compared with hardwoods is probably to be found in the practically bare needle-covered forest floor of the hemlock which, in spite of its shadiness, is rather dry. Under the oak type, the shrubby and herbaceous vegetation may lower the rate of evaporation by checking the circulation of air, and also by raising the relative humidity through the moisture they give off as transpiration. Measurements of the relative humidity would be needed to determine this point.

The hardwood forest and transition between hardwoods and hemlock have nearly the same rate of evaporation, the curves almost coinciding throughout (See FIGURE 1). At the end of the season the transition averaged only .1 c.c. per day higher than the hardwoods. This amount is too small to warrant consideration: but is in agreement with the higher rate for hemlock.

The average daily evaporation for all stations, given in Table I, shows that, aside from Cranberry Lake, the evaporation under hemlock forests is almost the same, even when the forests are hundreds of miles apart. The markedly lower evaporation at Cranberry Lake is to be expected because of the northerly location of the station. The difference between the evaporation under the New York hemlock and the New Haven ridge top station is only .2 c.c. per day. The fact that New Haven is a

trifle lower than New York in spite of its drier appearance, is probably accounted for by the slightly lower air temperature. The evaporation at the Ithaca hemlock station was only .2 c.c. lower than the New Haven ridge top, possibly accounted for by being a little cooler, and only .4 c.c lower than New York.

The similarity between the evaporation in widely separated hemlock forests is rendered all the more striking by the small difference between such extreme examples of the type as the two stations on Saltonstall Ridge near New Haven. The ridge top was about as dry looking a hemlock site as one could find, while the north slope was moist and obviously favorable. In fact, as noted above, the stations were selected to bring out the contrasts between dry and moist hemlock forests. Yet the difference between the rate of evaporation under the two sites was only 1.7 c.c. per day for the season. Expressed in terms of percentages, the evaporation on the favorable site was only 14 per cent lower than that on the dry site. In terms of New York hemlock as 100, the New Haven ridge top was 98, and the north slope 84. Thus, excluding Cranberry Lake for the moment, the total range between extreme hemlock sites about 300 miles apart was only 1.9 c.c. per day, or 16 per cent. Yet the difference between the hemlock and hardwood forests on the New York Botanical Garden grounds about the same number of yards apart was 3.3 c.c. per day, or 29 per cent.

Even when Cranberry Lake is included, the difference in rate of evaporation between the extreme north and south examples of hemlock is only 4.7 c.c. per day. In terms of New York as 100, Cranberry Lake is 62.

The natural tendency would be to discount a considerable part of these results on the ground of their covering only a single season, if it were not for similar work on Mt. Desert Island, Maine, covering three seasons representing extremely dry and unusually wet summers. The Mt. Desert results showed that the relations between the forest types remained nearly the same throughout the different seasons. The actual amount of evaporation was different, though not very much so in the two dry years, but the percentage relations of the forest types held consistently. For example, the evaporation at the spruce station during the three years, expressed in terms of the pitch pine forest as 100, was 28, 24 and 29. The middle number represents the moist year. The differences in evaporation between different forest types on Mt. Desert Island less than 4 miles apart, were very much greater than the differences in evaporation in the hemlock type, even including Cranberry Lake. For example, taking white pine and spruce, both with complete forest canopies casting practically full shade similar to hemlock; white pine was 11.6 as against 4.0 for spruce in the wet year, and 17.4 as against 7.0 for spruce in the dry year. Compare these figures with a range of only from 12.2 to 7.5 for hemlock at The New York Botanical Garden and the Adirondack Mountains. Furthermore, it is of more than passing interest that the hemlock evaporation, taking the stations as a whole, fits remarkably well into the Mt. Desert island series, being distinctly higher than spruce and lower than white pine, just as we would expect.

The similarity between the different hemlock stations shows not only in the seasonal averages, but on the chart of weekly evaporation. Cranberry Lake stands out on account of being the lowest, but the others criss-cross inextricably. We can perhaps get some of the relationships by counting the number of times (weekly readings) each station was the highest of all.

The chart covers 22 weeks, from May 12 to October 5 inclusive. Cranberry Lake does not begin till May 19 and ends September 21, but this does not affect the following figures. The New Haven ridge top was highest 6 out of the 22 weeks, Ithaca was highest 5 times, New York 4 times, and Cranberry Lake twice. During the other 4 weeks the Ithaca hardwoods were highest. The north slope at New Haven was never highest. This gives an indication of how the curves cross and re-cross. The averages given in Table I represent conditions fairly well.

Precipitation

The total precipitation at each station from May 12 to September 21 is given in Table I. The charts of precipitation need not be reproduced. The curves for the stations outside of New York, and New York hemlock, across and recross owing to the different time at which the precipitation occurs. The New York curves run along close together.

We were fortunate in being able to secure figures for the precipitation in the open near the other stations as well as at New York. For the New Haven stations the Water Company has a

rain gauge near Saltonstall ridge, the records of which were kindly supplied by Mr. Leonard M. Tarr of the Weather Bureau. For Ithaca, Mr. W. M. Wilson kindly furnished us with records for a station two miles east of Ithaca, and therefore rather near to the Cornell stations. These gauges nearer our stations gave slightly higher readings than the ones of the Weather Bureau in the towns of Ithaca and New Haven.

The amounts of precipitation in the open have been inserted in Table I, and from them the amounts under the forest subtracted. The differences represent the net interception by the forest canopy for the particular spots where the rain gauges were placed. The weekly records, which are not reproduced in this report, show that some of the readings under the forest were actually higher than in the open. This happened with 19 of the readings at the New York stations, where we fortunately have daily as well as weekly records. It also occurred occasionally at New Haven. These higher readings under the forest must have been due for the most part to dripping from the ends of the branches which may have been more pronounced under some conditions than under others.

Except at the New York stations, the net interception was considerable, running from 31 per cent at the Ithaca hemlock to 48 per cent. for the New Haven ridge top, or from nearly a third to nearly a half. At New Haven the north slope interception is decreased by two periods during which the gauge at this station showed considerably more than in the open. If the excess for the north slope station in these periods were eliminated, the interception would be 47 per cent, or practically the same as the ridge top. At New York, even if we eliminated the amounts in excess of the open readings, the interception would still be small, only 13 per cent. for hemlock, 11 per cent. for the transition and 6 per cent. for the hardwoods. Just why interception at the New York stations is so much less than at the others is not clear, unless the gauges at all three of these stations were nearer the edge of the crowns than at the five other stations. This hardly seems probable. It may be that the character of the precipitation, in particular the prevalence of short heavy showers near New York, has something to do with the lower interception here.

Temperature

The temperature readings for the season at all stations have been averaged, and the results are presented in Table I. The weekly records themselves are too voluminous to include.[1] In order to bring out the relationships between the stations, which could not be found without a great deal of poring over the figures, some of the values are shown graphically in Figures 2 to 4.

It is impracticable to reproduce all of the 18 charts which were plotted to compare the weekly readings of the different stations throughout the season. Three charts, the mean soil temperature at 6 inches for the New York stations, the mean soil temperature at 6 inches for the coöperating stations and New York hemlock, and the mean soil temperature at 18 inches for the other stations and New York hemlock, are shown as Figures 2 to 4 In general, the charts on which the New York stations alone appear are clear and have comparatively little crossing of the lines. The mean 6-inch soil temperature for the New York stations, Figure 2, is a good example. With the other stations and New York hemlock there is a good deal of crossing back and forth, making it difficult to follow out the different stations. The 6-inch mean soil temperature for all coöperating stations and New York, Figure 3, is a fair example of this. As would be expected, the criss-crossing is most with the air temperatures, and least at 18 inches in the soil.

The air temperature records show, among other things, the influence of the forest canopy in moderating extremes. On the maximum chart the open station was consistently highest throughout, and on the minimum chart it was consistently the lowest. The higher maxima and lower minima at the open station offset each other, so that the mean temperature for the season was only very slightly above that under the forest. This illustrates the importance of obtaining maximum and minimum readings in studies of plant habitats. In this case the mean fails to show the severer temperature stresses to which the plants are subjected in the open as compared with those under the shelter of the forest.

The maximum air temperatures at New York show that the hemlock forest was noticeably and consistently warmer than the

[1] As with the evaporation records (see footnote 6), copies can be obtained by qualified persons at the cost of reproducing.

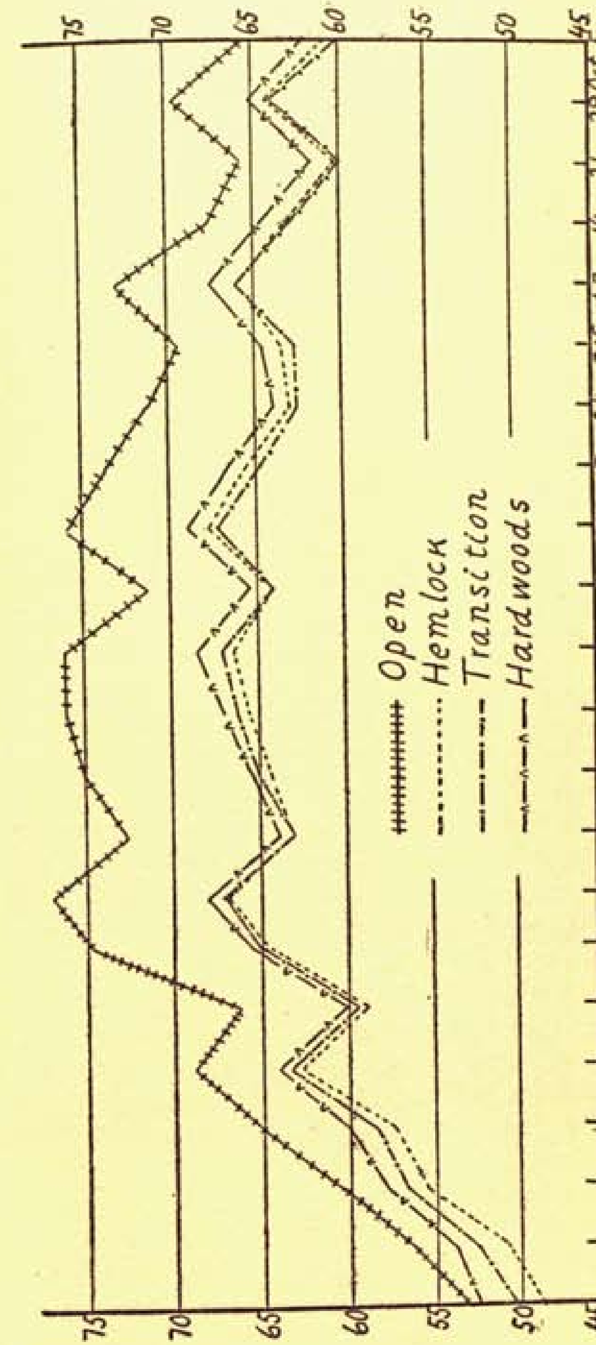

Figure 2. Mean soil temperature (degrees F.) at six inches. New York stations.

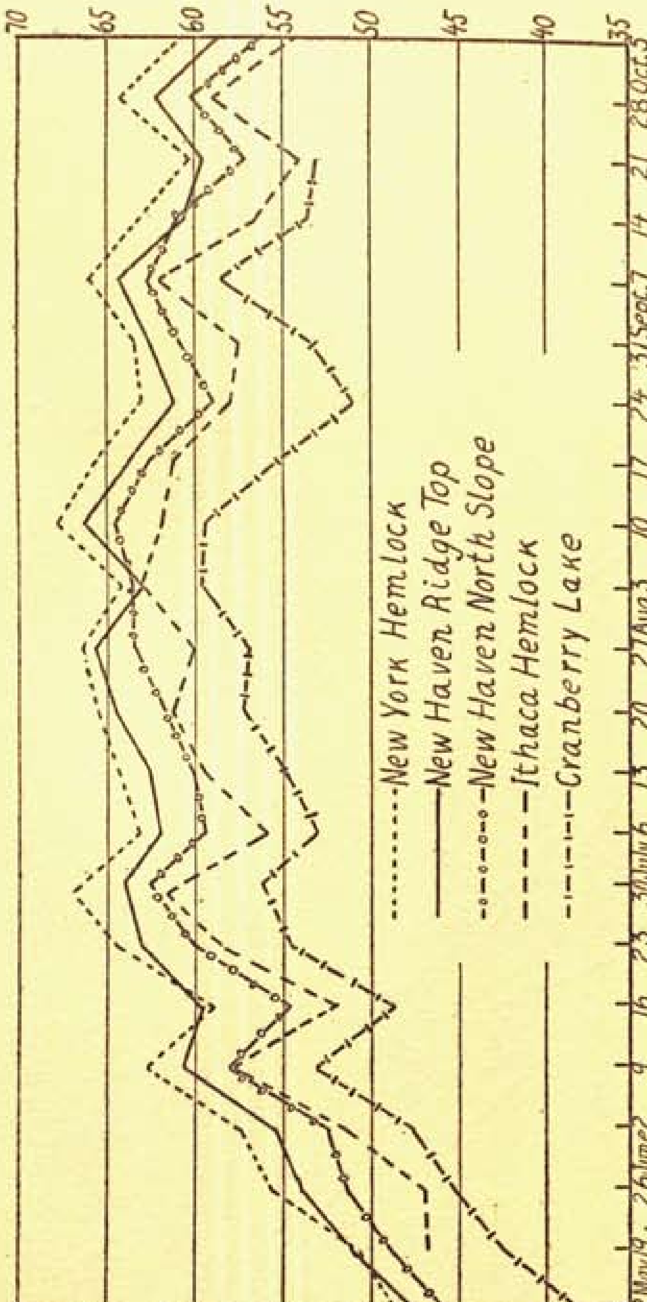

FIGURE 3. Mean soil temperature at six inches. All hemlock stations.

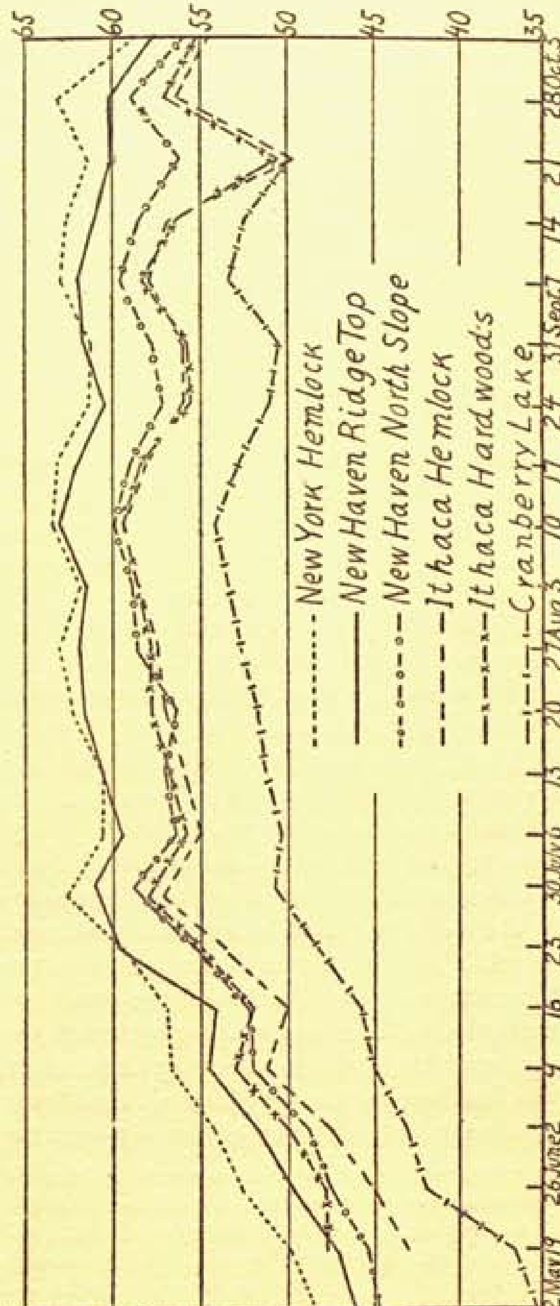

FIGURE 4. Mean soil temperature at eighteen inches. All hemlock stations and Ithaca hardwoods.

hardwoods from May 26 to September 14 inclusive. The transition forest closely resembled the hemlock in this respect, although with respect to evaporation we have seen that it was more like the hardwoods. In minimum temperatures there seems to have been little difference between the New York forest stations,[1] although the hemlock was slightly colder than the hardwoods. Therefore, in the means the hemlock remains warmer than the hardwoods.

The air temperature in the hemlock forests near New Haven was distinctly cooler than in any of the forests at New York. The north slope had a slightly lower maximum than the ridge top, and a distinctly lower mimimum, resulting in a lower mean.

The Ithaca stations show the influence of their greater distance from the moderating influence of the sea. Both stations have higher maximum air temperatures than New Haven, but considerably lower minima. These greater extremes average up somewhat in the means, but still leave Ithaca colder than New Haven.

Cranberry Lake, as would be expected, is the coldest station in all respects. Its continental climate is shown by the greater spread between its average maximum and average minimum as compared with New York, amounting to 37.6° F. against 21.9° for the New York hemlock. In this respect it is slightly exceeded by the Ithaca stations, which showed spreads of 39.4° and 38.4° for the hemlock and hard woods respectively.

In soil temperature both at 6 and 18 inches the relation between hemlock and hard-wood is the reverse of the above noted for air temperature. The soil under the hardwoods is warmer than it is under the hemlock. This is in accordance with what we would expect from the geographic distribution of the two types. The apparent contradiction with air temperature is probably explained by the fact that, while the maxima under the hemlock are higher than under the hardwoods, the hemlock minima are slightly lower. The maxima may come from higher temperatures which

[1] The minimum thermometers used for air temperatures at New York gave a good deal of trouble with breaking up of the spirit column, after the first part of August. This has necessitated interpolating a number of the New York minimum air temperature readings. The interpolations were made on the curves, with the trends of the other stations and past readings as a guide, and it is thought do not involve serious errors. In any case they do not affect the relative position of the stations, or the conclusions.

last for only brief periods, not long enough to warm up the soil. This goes to indicate that the temperature conditions under the hardwood, with their slightly warmer soil and slightly cooler air, and with less spread between the maxima and minima, are a little more favorable than under the hemlocks. In addition, the moisture under hardwoods is more favorable on account of the lower evaporation.

The relation between the hemlock and hardwoods at Ithaca with respect to the 18 inch soil temperature is the same as at New York. At 6 inches the differences between the two Ithaca stations are extremely small.

At New Haven, the ridge top hemlock forest was warmer in all respects than that growing on the north slope. In soil temperature at both depths, as with mean air temperature, the New Haven stations were intermediate between New York and Ithaca. It is interesting that at 18 inches all the figures, and at 6 inches the maxima, show the ridge top to be closer to New York, and north slope closer to Ithaca. Thus the difference in site tends to bring about differences in certain environmental factors resembling differences produced by considerable distances. This is merely another example, on a much smaller scale, of the well-known site differences between north slopes and south slopes which occur in the mountains of the southwest.

Considering the New York hemlock grove as roughly approximating the southern point in the range of the hemlock type, and Cranberry Lake the northern point, the temperature figures in Table I give an indication of the temperature range of the type for the growing season. For convenience these figures have been brought together in Table II, to which has been added the number of degrees of spread in the range.

A glance at Table II shows that the range of temperatures covered by the hemlock type is not large, 12° for mean air temperature, 10° for mean soil temperature at 6 inches, and 11° for mean soil temperature at 18 inches. It is possible that more widely separated stations would extend this range somewhat, but probably not very much.

Fortunately we have a comparison for the northern limit. On Mt. Desert Island, Maine, soil temperatures were taken at the same levels in the same manner under a series of forest types. The coldest of the series was a spruce type distinctly more

TABLE II

APPROXIMATE TEMPERATURE LIMITS OF THE HEMLOCK TYPE, BASED ON RANGE BETWEEN NEW YORK AND CRANBERRY LAKE. IN DEGREES F.

	South (N. Y.)	North (Cran. Lake)	Range
Air Temperature			
Maximum	85	75	10
Minimum	53	38	15
Mean	69	57	12
6-inch Soil Temperature			
Maximum	66	59	7
Minimum	59	48	11
Mean	63	53	10
18-inch Soil Temperature			
Maximum	62	52	10
Minimum	58	47	11
Mean	60	49	11

northern in its affinities than the hemlock at Cranberry Lake, and growing not far from the crowberry (*Empetrum nigrum*), an arctic-alpine plant which here comes down to sea-level because of the cold waters. The Cranberry Lake 6-inch mean, when reduced to the same period as that covered by the Mt. Desert records (June 9 to September 21) was 56.1° as compared with 55.5 for Mt. Desert, and the 18-inch mean was 51.8 as against 51.2 for Maine. Thus for the same period the Cranberry Lake hemlock soil was only .6° warmer at both 6 and 18 inches than the soil at the same depths under a spruce type on a markedly cold situation. It is, therefore, reasonable to consider that the conditions at Cranberry Lake approach pretty closely to those at the northern extension of hemlock.

We have no similar comparisons to check the southern limit, but it is not likely that hemlock forests inland further to the south would be much warmer than at New York.

On the whole, the temperature differences between the different stations, like evaporation, are remarkably small, especially when we consider the general climatic differences between New York and the Adirondack Mountains.

The narrow range of temperature limits found in this study seem to indicate that comparatively small differences in temperature may be of considerable importance to vegetation. There were similar indications in a study of different forest types on

Mount Desert Island, Maine. This does not, of course, in any way detract from the importance of the moisture relations.

Solar Radiation

As already explained in the section on instruments, the difference between the readings of the black and white atmometers does not give a wholly satisfactory measure of the light conditions under the forest canopy. When the values were plotted, the curves, except of course for the open station, crossed and recrossed in apparently hopeless confusion. Yet when the records were averaged for the whole season, the rate per day seems to correspond in a general way with the density of the forest canopy. For the New York stations the hardwoods are a little higher, and the canopy is slightly less dense, as shown by the richer undervegetation. But all the New York forest stations are very much alike in respect to crown cover, and the solar radiation values run close together. The New Haven ridge top gives about the same value as the New York stations, though we would have expected it to be a little higher since the stand seems to be a little more open. The north slope shows a much lower solar radiation value than the ridge top, which agrees with its denser shade. The lower value for the Ithaca hemlock as compared with the hardwoods agrees with the denser canopy. The Cranberry Lake station was in a very shady spot, and shows a correspondingly low value.

POSITION OF THE HEMLOCK TYPE IN THE SUCCESSIONAL SERIES

The records show that the hardwoods, so far as evaporation is concerned, are moister than a forest of pure hemlock. It is true that records in other hardwood stands might show a higher rate of evaporation, but this could not be determined one way or the other without a considerable number of additional stations. For the present we will have to take the results we have, recognizing that they are tentative, although supported by indications from another study. There has been a common tendency to consider moisture as the criterion of the climax forest, the climax representing the highest degree of moisture. Nichols, however, considers that the climax is not necessarily any more moist than certain other stages, and that exactly the opposite may be true. "Ecological advance," or in common parlance the stage of progress, "as determined by various factors, which may be quite different in different successional series, should be the criterion." If shade is the critical factor, the climax might well be less moist than a preceding stage.[1]

The hemlock type well illustrates the above conception. Hemlock can stand much more shade than the oaks; hence when protected from fire, it is able to survive under their crowns and eventually come up and crowd them out. Two hardwoods only, beech and sugar maple,[2] are more tolerant of shade than hemlock, but are less abundant around here than the oaks. It is reasonable, therefore, to consider hemlock as the climax forest.

Since hardwoods make up the climax forest further south, and hemlock is the climax to the east and north of New York City, it has been suggested that perhaps we have on the Botanical Garden grounds two climax forests existing side by side.

Whatever may be the cause, the two types have not mixed appreciably in the long period that they have lived in contact with each other, with every opportunity for the mutual interchange of seed and for either to invade the other.

The climatic differences which the above records show between the two types of forest do not seem sufficient to account for the distinctness of the two, unless the hemlock grove is at the absolute limit of the warmth which this type of forest will endure. If this were the case, any increase of temperature would prevent the establishment of hemlock. But the soil temperatures in the hardwoods had a maximum of only 2° F. higher at 6 inches, and only .6° higher at 18 inches, which seems so small as to require a dividing line much sharper than appears reasonable. It will be necessary to look elsewhere for the cause of the difference, and soil conditions appear to offer the most promising line of attack.

SUMMARY

Representative examples of hemlock forests, and two examples of hardwoods, were selected to cover roughly the north and south range of the hemlock type. The southerly representative was

[1] Nichols, G. E. "A Working Basis for the Ecological Classification of Plant Communities." Ecology, 4: 11–23; 154–179. 1923. The quotation is from a letter written by Dr. Nichols about this particular study.

[2] Burns, George P. "Minimum Light Requirements Referred to a Definite Standard." Vermont Agr. Exp. Sta. Bull. 235, 1923.

the hemlock grove on the grounds of the New York Botanical Garden, in addition to which stations were established in an adjoining mature hardwood forest, in the transition between hemlock and hardwoods and in the open. With the coöperation of Yale University, Cornell University, and the State College of Forestry at Syracuse, two stations were established near New Haven representing favorable and unfavorable hemlock sites, two at Ithaca representing a hemlock and a hardwood type, and one at Cranberry Lake in the Adirondack Mountains under a group of hemlock in the northern hardwood and spruce forest.

At each station weekly readings were taken during the summer of 1923, covering evaporation (with Livingston atmometers), solar radiation (black and white atmometers), precipitation, and maximum and minimum temperature of the air and of the soil at 6 and at 18 inches depth.

The evaporation under hemlock was higher than that under hardwoods, 12.2 c.c. per day as against 8.9 c.c.

The evaporation under the five hemlock stations was very similar. It was, in c.c. per day, New York, 12.2; New Haven ridge top 12.0, New Haven north slope 10.3, Ithaca 11.8, and Cranberry Lake 7.5

The difference in evaporation between extreme hemlock sites near New Haven was less than the difference between hemlock and hardwoods at New York; only 1.7 c.c. as against 3.3 c.c. Hemlock forests 300 miles apart have a closer resemblance with respect to evaporation than hemlock and hardwoods 300 yards apart.

The rate of evaporation under hemlock is intermediate between that found for spruce, 7.0, and for white pine, 17.4, on Mt. Desert Island, Maine, during approximately the same period.

The air temperature under hemlock had a higher maximum and mean, but a slightly lower minimum than under the hardwoods.

The soil temperature under hemlock at both 6 and 18 inches is colder than under hardwoods.

The extreme range of temperature between the north and south limits of hemlock included in this study is small: 12° F. for the mean air temperature, 10° for the mean soil temperature at 6 inches, and 11° for the same at 18 inches.

The stations probably include the coldest growing season conditions at which the hemlock type can occur naturally. The

Cranberry Lake mean soil temperatures at 6 and 18 inches were only .6° higher than temperatures at the same depths for the same period under a distinctly cold spruce forest on Mt. Desert Island, Maine.

The comparatively small range in temperature appears to indicate that small differences in temperature may be of considerable importance to vegetation.