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Ray C. Friesner
Butler University

J. E. Potzger
Butler University

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Ray C. Friesner

The *Butler University Botanical Studies* journal was published by the Botany Department of Butler University, Indianapolis, Indiana, from 1929 to 1964. The scientific journal featured original papers primarily on plant ecology, taxonomy, and microbiology. The papers contain valuable historical studies, especially floristic surveys that document Indiana's vegetation in past decades. Authors were Butler faculty, current and former master's degree students and undergraduates, and other Indiana botanists. The journal was started by Stanley Cain, noted conservation biologist, and edited through most of its years of production by Ray C. Friesner, Butler's first botanist and founder of the department in 1919. The journal was distributed to learned societies and libraries through exchange.

During the years of the journal's publication, the Butler University Botany Department had an active program of research and student training. 201 bachelor's degrees and 75 master's degrees in Botany were conferred during this period. Thirty-five of these graduates went on to earn doctorates at other institutions.

The Botany Department attracted many notable faculty members and students. Distinguished faculty, in addition to Cain and Friesner, included John E. Potzger, a forest ecologist and palynologist, Willard Nelson Clute, co-founder of the American Fern Society, Marion T. Hall, former director of the Morton Arboretum, C. Mervin Palmer, Rex Webster, and John Pelton. Some of the former undergraduate and master's students who made active contributions to the fields of botany and ecology include Dwight W. Billings, Fay Kenoyer Daily, William A. Daily, Rexford Daudenmire, Francis Hueber, Frank McCormick, Scott McCoy, Robert Petty, Potzger, Helene Starcs, and Theodore Sperry. Cain, Daudenmire, Potzger, and Billings served as Presidents of the Ecological Society of America.

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SURVIVAL OF HEMLOCK SEEDLINGS IN A RELICT COLONY UNDER FOREST CONDITIONS

By RAY C. FRIESNER AND J. E. POTZGER

In previous papers (4, 5) we have discussed the ecological significance of *Tsuga canadensis* in Indiana. We have shown that hemlock occupies island-like sites surrounded by Fagus-Acer communities, that in these isolated stands ecological factors are more rigorous than in surrounding communities and that there is no advance in either size or position of the hemlock colonies. Danbenmire (3) and Moore, et al. (15) have shown that though hemlock communities may occur on sites which have physical appearance similar to those of Fagus-Acer communities, yet the former are always a little more xerophytic than the latter. We have also shown (17) that *Tsuga* seedlings are absent on that portion of the forest floor which is covered with any appreciable depth of forest litter such as invariably occurs on fairly level sites under a deciduous hardwood canopy. They occur in our region only on steeper slopes where there is sufficient moss or other floor covering to give the seeds lodgment, and in more nearly level sites only when the forest litter is not too deep. Study of edaphic and other ecologic conditions shows that every site containing *Tsuga* seedlings has lower growth-water content, greater soil temperature fluctuations, and higher evaporation rates than obtain in sites only a short distance removed from the seedling sites. Soil acidity appears, likewise, to be greater in sites containing *Tsuga* seedlings than in sites short distances away but without seedlings (16) and we have concluded that this is also one of the vital edaphic factors in its reproduction in Indiana.

An essential to the establishment of any forest species is the survival of its seedlings. In some species the first year seems to be the most critical one for survival while in other species early survival seems less difficult than a few years later when seedlings have reached a "sapling" stage. Haig, Davis and Weidman (8) have shown that 50% of the seedlings of western conifers die the first year, but those which survive this critical period have a good chance of future

survival. Losses during the first year were due to biotic factors, insolation and a lack of sufficient moisture (in decreasing importance as named). Williams (20) has pointed out that seedlings of both beech and sugar maple are periodically abundant but beech seedlings do not survive as well in the early stages as maple while the high mortality rate of maple saplings later appears to make up for this great difference. In our earlier study of the factors concerned in hemlock reproduction (17) we found that 88.32% of hemlock seedlings perished during their first year. Toumey and Neethling (18) have shown that surface temperatures due to insolation play a vital role in the survival of hemlock seedlings. Studies made by the Lake States Forest Experiment Station (9) show that soil-surface temperatures in openings on Norway and Jack pine plantations in Minnesota reach as high as 175 degrees F. with continuous temperature of 130 F. for periods as long as 8.5 hours.

Since the roots of hemlock seedlings are usually shallow in comparison to those of other tree species, available moisture in the top three inches of soil becomes a critical factor, especially in seasons of subnormal rainfall. In our earlier paper on hemlock reproduction (17) we found that during the summer of 1930 the soil water was below the wilting coefficient in the top three inches of soil in sites containing hemlock seedlings for the entire months of June, July, and August. Rainfall for this summer season was 47.36% of normal and the survival was 17.20% for hemlock seedlings of 1- and 2-year ages (the only age classes studied). Williams (20) has pointed out that even though hemlocks periodically bear abundant crops of seeds, and in years of favorable moisture conditions, a fair amount of germination occurs, yet hemlock reproduction is at a standstill in the Cleveland area. This is apparently due to the fact that a subsequent dry season practically wipes them out. The conclusion that hemlocks are being replaced by beech and maple is inescapable. This is in accord with the view that hemlock is a relict of the Lake Forest. Baldwin (1) has pointed out that hemlock seeds are very erratic in their percentage of germination.

Graham (6) pointed out that while there was considerable hemlock establishment in the first decade following logging, there has been little since. During years when moisture on the forest floor is abundant, seedlings become numerous; but few seedlings become established, establishment being dependent upon the distribution of precipitation for the next few years.

It would thus appear that in areas where hemlock is a component of the climax, and not merely a relict, reproduction is dependent primarily upon a combination of three factors, viz. a good seed year followed by a good germinating year and these in turn followed by several years of favorable moisture conditions.

Maissurow (12) has shown that hemlock does not reproduce on the forest floor in northern Wisconsin but its reproduction often does occur on burned-over sites and all cases of high reproduction were traceable to surface fires. The conclusion was reached that even-aged stands of hemlock are unquestionably of fire origin or due to destruction of nature stands by fire, sleet, or logging.

METHODS

In April 1930, numbered linen tags were attached to wire stakes and placed beside several hundred seedlings of *Tsuga canadensis* growing on steep wooded slopes of Bean Blossom creek about 0.5 mi. southeast of Trevlac, in Brown county, Indiana. During the first summer many of the stakes were pulled and destroyed by passersby so that when observations were made in October of that year only 134 numbered trees remained undisturbed. During the first three October and April readings after the beginning of the project, new seedlings were tagged in less frequented sites of the same general area. During the second year, all linen tags were replaced with numbered metal tags. In October and April of each year for 10 years, observations were made on the number of seedlings surviving and at the end of this period all surviving seedlings were measured both as to diameter and height. The diameter measurements were taken at 5 cm. from the soil line. Sections were also taken from seedlings and from branches of nearby older trees for microscopic measurement of growth rings.

During the entire project a total of 1213 seedling were under observation. Of these, 450 came into the project either as first-year seedlings or as seedlings resulting from 1931 germination, 608 came in either as second-year seedlings or as seedlings resulting from 1930 germination, and 155 came in either as third-year seedlings or as seedlings resulting from 1929 germination.

During the season of 1930, soil moisture, soil temperature and evaporation data were taken weekly from 6 different sites containing hemlock seedlings. These data have been published in an earlier

paper (17) and will be used here only as they have any bearing on the present problem, and to the extent that they were not used in the former paper.

Rainfall data were taken from the reports of the Hickory Hill station of the U. S. Weather Bureau, except for the winter of 1939-40 and the summer of 1940. The Hickory Hill station was about 3 miles from the area under observation. The data for January-March 1940 were taken from the Columbus station, about 25 miles east; and those for the summer of that year were taken from the Kelly Hill station, about 5 miles east of the seedlings.

SURVIVAL AND AGE

Data on survival are presented in table I. It will be noted that during the first summer season only 17.2% of the seedlings survived. Unfortunately, this happened to be the most severe season during the entire period of observation, only 47.36% of the normal-expected rainfall being recorded. Nearly twice the percentage of second-year seedlings survived as in the case of first-year seedlings. During the summers of 1930 and 1931, and the winter of 1930-31, the seedlings are listed in the table as 1st-year, 2nd-year and 3rd-year, but subsequent to the summer of 1931, they are listed in columns according to the season of their germination so that during the summer of 1932 the seedlings which were 1st-year seedlings of 1931 were now 2nd-year, while the following year they were 3rd-year and thus increased in succeeding years. Throughout the table, the data of the column (table I) headed "2nd-year" are from seedlings one year older than those of the column headed "1st-year"; and those of column headed "3rd-year" are in turn one year older than those of the "2nd-year" column.

In comparing the survival data of these columns it will be noted that in nearly every instance the percentage of survival is lower in younger seedlings than in seedlings one year older when the data for the same season are compared. Exceptions are found in the summers of 1938 and 1939 when seedlings of the first column (now 7 and 8 years old) survived a little better than those of the second column (now 8 and 9 years old). During these summers the rainfall was above normal, the survival was high in all cases, and the number of seedlings concerned was so small that no particular significance can be attached to the slight difference in survivals. Similar instances of slight differences between survival in columns 2 and 3

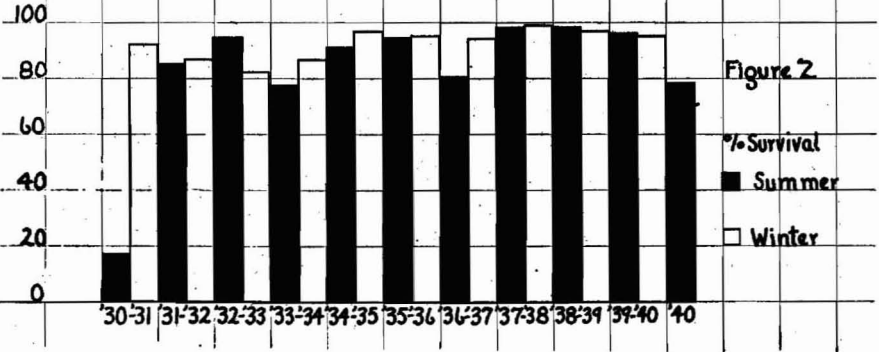
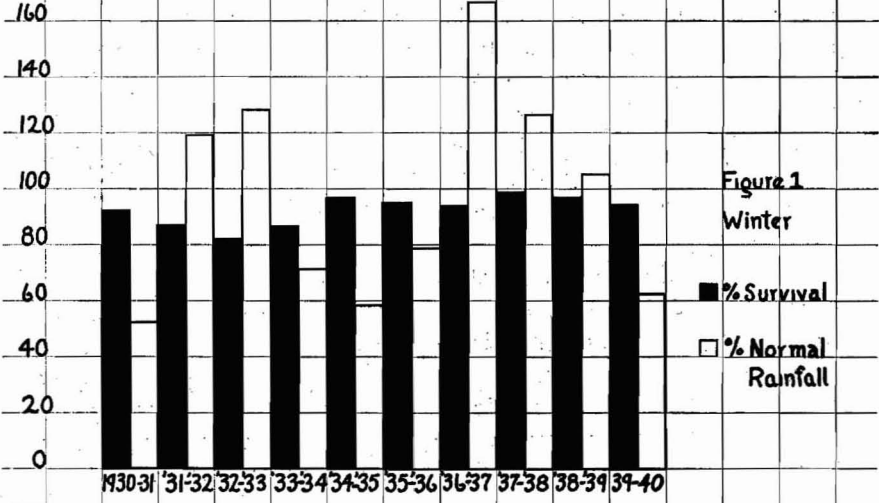
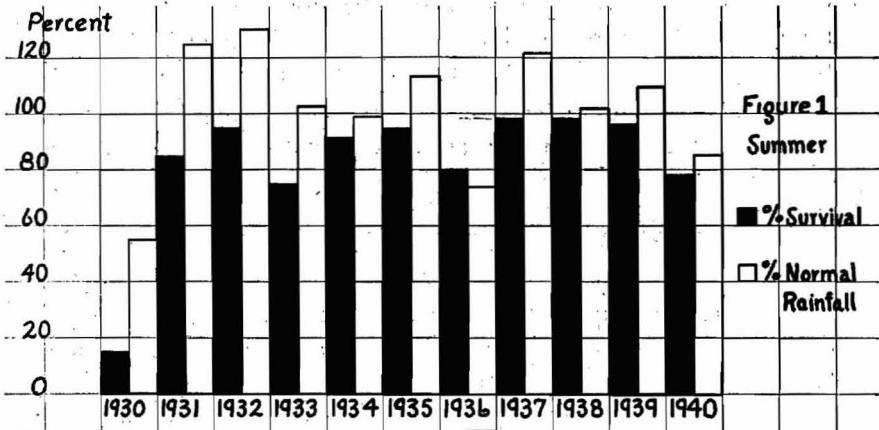
may be similarly dismissed. The essential point that stands out regarding survival in relation to age is that in the first 5 or 6 years of the life of the seedling, each added year of age gives the seedling a little better chance to become established. This point will be observed if the data in table I above the winter of 1936-37 are compared with those below this period. Above this point in the table, the percentages of survival generally show greater differences in the different age groups than they do below this point.

At the end of the project, 19 of the 450 first-year or 1931 seedlings were living; 101 of the 608 second-year or 1930 seedlings were living; 49 of the 155 third-year or 1929 seedlings were living. This gives a final survival of 4.22%, 16.44% and 31.61% respectively. At the end of 10 years 13.85% of the total original seedlings were still living.

SURVIVAL AND RAINFALL

The relation of seedling survival to rainfall is shown graphically in fig. 1 where the solid columns represent percentage of survival and the empty columns represent rainfall in percentage of normal. It will be noted that there is a definite relationship between percentage of survival during the summer and percentage of normal rainfall. It will be noted that there is a definite relationship between percentage of survival during the summer and percentage of normal rainfall during the same season, during those years when the summer rainfall is below normal, e.g., summers of 1930, 1934, 1936, and 1940. This is also true for the summers when rainfall is above normal during the earlier years of life of the seedling and also when the above-normal rainfall follows a year when the summer rainfall was below normal. This will be noted in fig. 1 if 1931-1933, and 1935 are compared and if 1934 and 1935 are compared. Summer data for 1937, 1938, 1939, when the seedlings are older and when rainfall is above normal, do not show the relationship between survival and rainfall that is shown during the years 1931, 1932 and 1933 when the rainfall is also above normal but the seedlings are younger.

The extraordinarily low percentage of survival during the summer of 1930 (fig. 1) is correlated with an unusually dry season during which the soil water in the top 3 inches of soil was below the wilting coefficient during the entire months of June, July and August. This was discussed fully in our earlier paper (17) and will not be commented upon further here. Lutz (11) has shown that the initial



root system of hemlock is without a tap root, only laterals being present. The roots are weak and grow slowly, hence death frequently results from lack of moisture during critical periods.

Figure 1 shows no correlation between percentage of survival during the winter seasons and percentage of normal rainfall for the same seasons.

SURVIVAL IN SUMMER AND WINTER

In general the percentage of survival is lower for the summer than for the succeeding winter. This is graphically illustrated in figure 2. The most striking exception to this is found in 1932 when the percentages of normal rainfall for summer and winter are very nearly the same and both are above normal. Summer survival is a little over 12% higher than that for the succeeding winter. There are also minor exceptions in 1938 and 1939. In all of these cases the summer rainfall is above normal. The rainfall is also above normal during the winter of 1938-39 but is considerably below normal in 1939-40. It is not difficult to understand how either of the seasons may at times be more critical than the other. During the summer both available moisture and temperature are vital factors. However, on the sites under study in this case, temperature during summer would be vital only in case of deficient moisture because all of the sites were well protected from the effects of insolation. It happens that in all three of the seasons when summer survival is higher than winter, the summer rainfall is above normal. Thus, the winter environmental factors have a chance to become more critical since those of the summers in question were more nearly optimum, or at least not critical.

During the winter, temperature is more likely to be more critical than rainfall since, even when soil moisture is abundant, a frozen soil may render the soil water unavailable to the roots. Furthermore, alternate freezing and thawing would have a serious mechanical effect upon the seedling roots which are noted for their shallow penetration. The fact that hemlock seedlings occur in our area on sites with little surface litter would increase the severity of freezing and thawing of the soils. The fact that these seedlings are usually in soils a little more acid than other forest soils might have a slight mitigating influence.

GROWTH RATE IN SEEDLINGS

The ability of hemlock to hang on for long periods of time with little or no growth is well known. A consideration of the actual performance of the 168 individuals surviving after 10 years of observation bears eloquent testimony to this ability. This is shown in table III where it will be noted that the majority of the seedlings produced a height growth of from 10 to 50 cm. and a diametral growth of from 1 to 6 mm. The slowest growth recorded was that made by one seedling which attained a height of 10 cm. and a diameter of 1 mm. during the 11 years of its life. The most rapid growth recorded was that by one individual which attained a height of 76 cm. and a diameter of 17.9 mm. during the 12 years of its life. The greatest height reached by any individual was 88 cm. but this seedling attained a diameter of only 5 mm. Of the total number of survivors, 120 were growing on steep slopes under a heavy canopy of deciduous trees and 48 were in an opening on a steep north-facing slope which was well carpeted by mosses and protected from insolation by surrounding deciduous trees. On the whole, those growing in the opening made better growth than those under the forest canopy. The range of growth was greater under the forest canopy. The growth range under the forest cover was from 10 cm. in height and 1.0 mm. in diameter to 76 cm. in height and 17.9 mm. in diameter; while that in the opening was from 11 cm. in height and 1.3 mm. in diameter to 88 cm. in height and 5 mm. in diameter. The final percentage of survival among the seedlings occurring in the opening was 41.93% as compared with a survival of 13.85% for all sites.

Merrill and Hawley (14) have shown that hemlock can stand long periods of suppression as an understory tree and then grow normally when the hardwoods overhead are removed. They found that growth rate after suppression averages 2.5 times that during suppression. Zon and Scholz (21) have shown that hemlock growth increases 85% during the 20-year period following release from suppression. Lutz (11) also calls attention to the remarkable ability of hemlock to withstand suppression for long periods of time, and notes that their power of rapid recovery is remarkable. Graham (6) has shown that all hemlock seedlings which develop in shade show more or less suppression, with a minimum of 20 and a maximum of 40 year rings per radial inch. This would mean that growth rings

would average 0.8 to 1.6 mm. in width. Our data in table III show the 10-year average to range from 0.1 to 1.5 mm. in diameter per year. Disregarding the fact that our measurements include both pith and bark we still have a maximum ring-width of less than 0.75 mm., which is less than one-half the minimum shown by Graham's data.

In order to secure some accurate data on width of annual rings in some of these severely suppressed seedlings, portions of two seedlings, one measuring 2.2 mm. in diameter and the other 3.3 mm., were sectioned and measured with an ocular micrometer. Sections were also taken from branches of older trees, one being near each of the seedlings. The data are presented in table II. It will be seen that ring width in the seedlings ranged from 0.042 mm. to 0.142 mm. These ring-widths vary much less than the averages cited above by Graham for suppressed seedlings. Ring-width in the branches taken from older, but still severely suppressed, trees varied from 0.142 to 0.480 mm. Griggs (7) has shown that seedlings of Sitka spruce are able to survive long periods of suppression after which they may grow vigorously to become mature trees. He relates that one tree 25 inches in diameter, with 281 rings, made only 2.5 inches in diameter during the first 35 years of its life. Allowing for pith which would also be put down during this period, the 35 year rings would have averaged about 0.8 mm. in width per ring. Comparing this with our data in table II where the maximum ring-width in the first 10 years of life of the hemlock seedlings was 0.142 mm., it again stands out that we are dealing with extreme suppression.

Evidence of complete omission of an entire year of growth is difficult to determine. It would appear from table II that seedling number 35c has omitted two years of growth. Our charts show that this seedling resulted from 1931 germination which would mean that it should have shown 10 growth rings instead of the 8 actually revealed under the microscope. Since, however, the section was taken 5 cm. above the base of the plant, it is possible that one or both of the missing rings occurred below the point where sections were taken. This seedling had attained a total height by the end of the observations of only 14.2 cm. Turberville and Hough (19) have shown that a hemlock tree, known to be 123 years old, showed 39 rings missing during the last 70 years of its life. This ability of hemlock to withstand suppression accords well with its tolerance of minimum light conditions. Burns (2) has shown that the minimum light requirements for hemlock are only a little higher than those for

beech and maple. Both beech and hemlock have high abilities to withstand suppression.

SUMMARY

1. This paper reports results obtained from a 10-year survival study of hemlock seedlings under the forest conditions pertaining in a relict colony near Trevlac in Brown county, Indiana.

2. Each added year of age, other things being equal, gives hemlock seedlings a little better chance for survival.

3. When the summer rainfall is below normal, there is a definite relationship between percentage of seedling survival and percentage of normal rainfall.

4. There is a similar relationship in years when the summer rainfall is above normal during the earlier life of the seedling and also when the above-normal rainfall follows a year of below-normal rainfall, but the relationship is lacking when rainfall is above normal during later life of the seedlings.

5. There is no relationship between percentage of survival and percentage of normal rainfall during the winter seasons.

6. The percentage of survival is generally lower during the summer than during the winter, but when summer rainfalls are above normal, the winter conditions may become more critical and result in a lower percentage of survival than during the summer.

7. At the end of ten years, 13.85% of the total number of seedlings observed were still living. The original first-year seedlings showed 4.22%, the second-year 16.44% and the third-year 31.66% of the original seedlings alive.

8. The growth rate exhibited by these seedlings during the 10-year period of observation well illustrates the ability of hemlock to withstand suppression. Height range of survivors (varying from 11 to 13 years of age) was 10 to 88 cm. with a diametral range from 1 to 17.9 mm.

9. Annual rings of suppressed seedlings ranged from 0.042 to 0.142 mm. in width. Ten year average for over-all radial growth of all seedlings ranged from 0.05 to 0.75 mm. per year. This is considered to be extreme suppression.

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TABLE I

Showing percentage survival in Hemlock seedlings for 10 winters and 11 summers in relation to rainfall, expressed in inches and in per cent of normal, at Trevlac, Brown County, Indiana. Rainfall data from the Hickory Hill station.

Season	Seedlings alive beginning of season			Percentage survival			Percentage Survival Total	Rainfall	
	1st yr.	2nd yr.	3rd yr.	1st yr.	2nd yr.	3rd yr.		Inches	% Normal
Summer ¹ 1930	60	74		11.67	21.62		17.20	10.20	47.36
Winter ² 1930-31	158	191	21	88.61	95.29	95.25	92.43	9.79	52.49
Summer 1931	172	224	30	82.97	87.06	90.00	85.45	27.07	124.94
	1931	1930	1929	1931	1930	1929			
113 Winter 1931-32	304	446	145	74.34	90.37	89.65	87.37	22.34	119.82
Summer 1932	265	443	133	92.46	95.94	96.24	94.89	29.02	130.89
Winter 1932-33	264	446	126	77.28	82.96	90.56	82.30	24.40	128.90
Summer 1933	199	379	117	64.32	81.53	87.18	77.56	22.74	102.57
Winter 1933-34	126	302	106	83.33	87.08	89.62	86.70	13.37	71.69
Summer 1934	97	248	93	86.66	91.93	93.55	91.55	21.47	96.84
Winter 1934-35	86	232	83	94.19	95.74	100.00	96.75	10.82	58.02
Summer 1935	72	223	81	89.66	95.55	97.53	94.68	25.23	113.81
Winter 1935-36	69	218	79	89.85	96.79	92.40	95.58	14.90	79.89
Summer 1936	62	211	73	67.74	82.94	84.91	80.63	16.42	74.06
Winter 1936-37	42	166	62	88.09	94.00	98.30	94.07	31.16	167.08

TABLE I (Continued)

Showing percentage survival in Hemlock seedlings for 10 winters and 11 summers in relation to rainfall, expressed in inches and in per cent of normal, at Trevlac, Brown County, Indiana. Rainfall data from the Hickory Hill station.

Season	Seedlings alive beginning of season			Percentage survival			Percentage Survival Total	Rainfall	
	1st yr.	2nd. yr.	3rd. yr.	1st yr.	2nd yr.	3rd yr.		Inches	% Normal
Summer 1937	37	156	61	97.30	98.08	98.36	98.03	26.91	121.37
Winter 1937-38	36	153	60	97.22	98.69	98.33	98.39	23.56	126.33
Summer 1938	35	151	59	100.00	97.35	100.00	98.59	22.64	102.12
Winter 1938-39	35	147	59	94.28	97.28	98.31	97.10	19.66	105.42
Summer 1939	33	143	58	100.00	94.40	98.27	96.15	24.63	111.10
Winter 1939-40	33	135	57	93.93	96.30	92.98	95.11	11.63 ³	62.36
Summer 1940	31	130	53	61.29	77.10	92.46	78.51	18.88 ¹	85.16
Final Survival	19	101	49	4.22	16.44	31.61	13.85		

1. Summer=April-September

2. Winter=October-March

3. Due to closing of the Hickory Hill station, data for January-March 1940 were taken from the Columbus station which is approximately 25 miles from the location of the seedlings.

4. Data for summer 1940 taken from the Kelly Hill station.

TABLE II

Comparing radial growth of 2 severely suppressed seedlings with that of branches from nearby older trees. Diametral measurement of seedling was taken 5 cm. above the ground.

Year	% Normal Rainfall		Growth in Radius			
	Summer	Winter	Seedling 16A 42 cm high 3.3 mm dia.	Branch of Tree near 16A 2.2 m high	Seedling 35C 14.5 cm high 2.2 mm dia.	Branch of Tree near 35C 6 m high 7 cm dbh
1940	85.16		0.09 mm	0.382 mm	0.042 mm	0.162 mm
1939	111.10	62.36	0.142	0.480	0.070	0.218
1938	102.12	105.42	0.114	0.462	0.046	0.214
1937	121.37	126.33	0.098	0.416	0.048	0.264
1936	74.06	167.08	0.108	0.392	0.056	0.336
1935	113.81	79.89	0.128	0.344	0.078	0.354
1934	96.84	58.02	0.066	0.296	0.050	0.268
1933	102.57	71.69	0.128	0.248	0.118*	0.244
1932	130.89	128.90	0.11			0.192
1931	124.94	119.82	0.11			0.172
1930	47.36	52.49	0.146*			0.142
1929	111.17	87.02				0.324

*Measurement included medulla. Xylem formed was approximately one-half of this measurement.

TABLE III

Showing size classes by height and diameter of all seedlings surviving at end of 10-year period

Height Classes	Diameter Classes in mm									
	1-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	9-9.9	12.4	17.9
5-9 cm	3									
10-14	10	8	1							
15-19	20	13	3							
20-24	14	18	2	5						
25-29	4	12	11							
30-34	1	7	4	2	1					
35-39	1	1	2	6						
40-44			3	1	2	2				
45-49					2					
50-54		1								
55-59							2		1	
60-64				1						
65-70							1			
75-79										1
80-84								1		
85-89					1					
Total	53	60	26	15	6	2	3	1	1	1

Total Seedlings surviving 10-year period—168 or 13.85%