EFFECT OF DEFOLIATION BY THE GYPSY MOTH

Neely Turner, Editor

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The gypsy moth defoliates many acres of trees during its outbreaks. The effects of defoliation on the health of the trees remain a matter of some controversy. When major defoliation occurs, as in 1962, there are insistent demands to determine the losses, both mortality and loss in annual growth.

At least three comprehensive studies have been made in New England. The first was started by Baker (1941) in 1912 and continued until 1921. The second was started by Tierney (1947) in 1934 and continued until 1946. The data of Tierney were used also by Crossman (1948) and supplemented by other records. The third was started in June 1953 by House (1960) and was devoted principally to effects of defoliation on white pine and hemlock.

The results of Baker's study were published in the Journal of Forestry. The reports of the others were issued in the form of typewritten and mimeographed reports by what is now the Plant Pest Control Division of the U. S. D. A. They were distributed to state agencies dealing with the gypsy moth problem. The information they contain is sufficient to answer many of the questions.

THE BAKER REPORT

Baker (1941) established 265 plots in Massachusetts, New Hampshire, and Maine in 1912 and 1915. Records were made of the trees present when the plots were started, and annual records of defoliation, vigor of trees and mortality. In 1921, increment borings were taken from several hundred trees to determine effects of defoliation on annual growth.

By 1921, the 265 plots had decreased to 121 "owing to excessive loss of trees following gypsy moth attack, to fire, and to cutting by property owners." A sample of the "discarded" plots showed 56 per cent mean defoliation and a total mortality of 62 per cent. The remaining plots showed 38 per cent mean defoliation, and 28 per cent mortality.

There was correlation between the degree of defoliation and mortality. Hardwood trees not defoliated died at the rate of about 4 per cent a year. Severe defoliation increased mortality to about 10 per cent a year.

Dominant favored species suffered a 33 per cent mortality in 10 years. Resistant species had a loss of only 7 per cent in the same period.

Mortality of white pines following defoliation was from 10 per cent to 32 per cent; and of undefoliated pines 4 per cent.

Heavily defoliated oaks and pines showed reduced growth in diameter of about 50 per cent as compared with the years before defoliation occurred.

THE TIERNEY REPORT

Tierney established 34 plots in the Connecticut River Valley of Massachusetts in 1934. The data included an estimate of the degree of mortality of the trees in 1947. The estimates were based on judgment, and were given in rather broad ranges.

The sections of the report dealing with four of the 34 areas, and photographs made in the areas, are as follows:

AREA NO. 6

Location: This area is located in Montague Township on both sides of a dirt road paralleling the Sawmill River on the north side, and actually extends from the Sawmill River northward up the south slope of Harvey Hill.

Defoliation: In 1946, the entire area was defoliated from 25 to 50 per cent. Defoliation in 1945 ranged from 75 to 100 per cent. There was no defoliation in 1944, 1943, and 1942. In 1941, there was from 25 to 50 per cent. In 1940, part of the area . . . was from 25 to 50 per cent defoliated. In 1939, the part shown on the eastern edge of the area of killed trees was from 25 to 50 per cent defoliated. There was no defoliation in 1938. In 1937, there was from 25 to 50 per cent defoliation on the eastern edge of the area of killed trees. In 1936, there was from 25 to 50 per cent defoliation in that part of the area well north from the highway on Harvey Hill and 75 to 100 per cent in the same area in 1935. There was no defoliation in 1934.

Damage: There are approximately 100 acres here on which the percentage of dead trees varies from 10 to 80 per cent. Eighty per cent of the oaks are dead on an estimated 20 acres; 50 per cent of the oaks are dead on 20 acres; the remaining 40 acres contain dead oaks ranging from 10 to 40 per cent. See photograph [Fig. 1].

AREA NO. 18

Location: This area is located in Southampton at and within a radius of 1/4 mile of the junction at Glendale and Pomeroy Meadow Roads.

Defoliation: Defoliation ranged from 50 to 100 per cent in 1946; 75 to 100 per cent in 1945; none in 1944, 1943, 1942, and 1941; 25 to 50 per cent in 1940; and none in 1939, 1938, 1937, 1936, 1935, 1934.

Damage: Estimate 90 acres here on which dead oaks are present. Of this area 25 acres have 75 per cent of the oaks dead, and on 65 acres the tree mortality ranges from 10 to 50 per cent [Fig. 2].

AREA NO. 24

Location: This area is located in Westfield Township at the foothills of Mt. Tekoa. It is reached by way of Pochassic Road from Westfield. This area is on the north side of the Westfield River and is bisected by the Boston and Albany Railroad.

Figure 1. Dead oaks in Area No. 6, Montague, Mass., 1947.

Defoliation: This area was defoliated from 75 to 100 per cent in 1946. There was no previous defoliation.

Damage: Estimate approximately 200 acres on 50 acres of which 75 per cent of the trees are dead; also 50 acres with 50 per cent dead and 100 acres with dead trees ranging from 10 to 40 per cent [Fig. 3].

AREA NO. 25

Location: This area is located in Westfield on Russellville Road 6/10 of a mile south of its junction with North Road, which leaves Route 10 at the junction of Routes 202 and 10. This area consists of a beautiful grove of mature white oaks near farm buildings and for years was the recreation spot of successive owners of this property.

Defoliation: This area was defoliated from 75 to 100 per cent in 1946. There was no previous defoliation. This area refoliated very sparsely with very small-sized leaves of heavy texture during the summer of 1946. . . .

Figure 2. Dead oaks in Area No. 18, Southampton, Mass., 1947.

Figure 3. Loss of trees in Area No. 24, Westfield, Mass., 1947.

Figure 4. Loss of trees following defoliation in 1946, Westfield, Mass., Area No. 25, 1947.

Damage: In this grove are upwards of 60 mature white oaks. As a result of this one defoliation, 27 of these oaks are now dead, with definite damage to as many more, some of which will not survive more than one or two years [Fig. 4].

The 34 areas contained 2641 acres. Two showed defoliation in 8 of the 12 seasons. At the other extreme, two were defoliated only once. Area No. 6 was one of those defoliated most frequently, and Areas 24 and 25 had only a single defoliation. About two-thirds of the acreage showed from 10 to 50 per cent mortality, and one-third 40 to 75 per cent.

It is obvious even from the examples given that defoliation was not the sole factor in causing mortality. However, there is no doubt that serious losses of trees did occur. The photographs reveal that the dead trees were not necessarily undergrowth. Dominant trees, some young, others more mature, were affected.

THE CROSSMAN SUMMARY

Crossman (1948) presented his report at the January 15, 1948, meeting of the Northeastern Forest Disease and Insect Pest Control Committee in Boston. He reviewed the previous studies of effects of defoliation, stating:

> The destruction is not as complete as it was before 1900, or during the first 20 years of this century. By the late 20's, several species of introduced parasitic and predaceous insects began to check the increase of the gypsy moth. This helped the situation and aided by occasional outbreaks of wilt disease and adverse climatic conditions, we do have periods of relative scarcity of the pest which gives the trees a chance to recover. Although the devastation is not as complete as earlier, it has spread over a much greater area than during the earlier period. . . .

Crossman refers to the Tierney study, saying:

> Dead and dying oaks, and, of course, many small white pines and a few hemlocks began to appear in many of the more severely defoliated areas after one or more defoliations. A review of the maps shows that the dying was and is in the areas where 100, 75, and 50 per cent defoliation has occurred.
>
> . . .
>
> The dying of oaks during the last few years has not been confined to the Connecticut River Valley towns. It has been observed in many other areas where severe defoliation has occurred, especially in central and southeastern Massachusetts and on Cape Cod. Similar conditions exist throughout many towns in the Sebago Lake area of Maine and around Lake Winnipesaukee in New Hampshire. . . .
>
> Without the injury due to gypsy moth the trees would not have died, and it is probable that in many cases other factors contribute to the injury, such as climatic conditions, frost, lack of moisture, poor soil, the two-lined chestnut borer, and unknown factors.

Crossman lists his estimates of 5,000 acres in central Massachusetts, 25,000 acres on Cape Cod, 15,000 acres in Maine, and 10,000 acres in New Hampshire. This totals 55,000 acres of which Crossman says:

> All of this dying is not recent and in many cases it goes back at least 20 years and is scattered throughout entire townships. From 25 to 50 per cent of the oak is dead on a large part of the acreage mentioned above and in many small pockets it ranges from 75 to 100 per cent, scattered throughout the area.

Crossman accompanied his discussion with photographs (his paper refers to some 70 pictures), some duplicates of those in the Tierney Report.

The airplane photograph reproduced in Figure 5 confirms the statements quoted above. This shows a "spot" in a state forest on Cape Cod in which the continuing infestation of gypsy moths has killed many trees. This sort of "spot" is typical of gypsy moth outbreaks.

The Tierney Report, and Crossman's extension of it, leave no doubt as to the effects of continued gypsy moth defoliation on highly susceptible stands of hardwood trees.

Figure 5. Dead and dying oaks, Brewster, Mass., Sept. 29, 1947.

THE HOUSE REPORT

The report of the gypsy moth appraisal program (Perry, 1955) referred to death of pine and hemlock after heavy defoliation. Most of the field data were obtained in 1952. The Plant Pest Control Division (then the Bureau of Entomology and Plant Quarantine), U. S. D. A. engaged William P. House, consulting forester, to conduct a study of the effects of defoliation by gypsy moth on white pine.

A number of progress reports were issued and distributed, and the final report, dated April, 1960, was sent to entomologists and foresters in states interested in the gypsy moth problem.

The following summary has been prepared from this final report. Much of the material has been quoted directly from the report. The editor has condensed the section on diameter growth.

INTRODUCTION

In the field work involved in the Gypsy Moth Appraisal Program of 1952 clear evidence of extensive killing of white pine was lacking, although intensive search was made in many defoliated areas. It was recognized that pine reproduction disappears rapidly following death and that this might be one explanation for the apparent discrepancies in findings. However, it was clear that detailed data on damage to white pine were inconclusive and that if the gypsy moth were capable of widespread damage more should be known about it considering the great value of this timber tree in New England.

An opportunity to do this occurred in 1953. Almost a million and one-half acres were defoliated by gypsy moth in New England and New York in that year. In Massachusetts 371,324 acres were classed as 50-100 per cent defoliated and 159,569 acres as 75-100 per cent in other states. Early in the outbreak it was noticed that larvae were feeding heavily on white pine and hemlock in many locations. The initiation of this study followed.

PROCEDURES

The study reported on here started with the establishment in June and July, 1953, of 69 plots containing 1723 trees throughout the infested area where severe defoliation of white pine and hemlock was occurring on a substantial percentage of the trees within a stand. These areas were selected at random from reports of gypsy moth officials and from inspection.

The plots in Connecticut and Maine were established with the help of representatives of their respective state entomologists who also actively participated in each of the annual inspections throughout the period of study. In the establishment of all the plots and in later servicing them invaluable assistance was given by Mr. Ralph F. Holbrook until his retirement in 1958. In the later stages of the study personnel of the Concord office, U.S.D.A., A.R.S., Plant Pest Control Division ably assisted in completing the field work and in preparing records for final disposition.

The plots varied from 1/20 to 1/5 acres. Data were recorded when feeding had stopped in late July 1953.

Each tree was numbered and a record made of its species, diameter, crown class and degree of defoliation. Crown classes used were: dominant and codominant combined, intermediate, and overtopped. In addition, an estimation of the site class was made for each plot. Location was described in notes and marked on U.S.G.S. sheets. From information supplied by gypsy moth workers familiar with the areas it was established that no appreciable, if any, defoliation had occurred in these areas the previous year.

Most of the plots consisted of pole- or sawlog-size timber with dense crown canopies and crowded conditions typical of unmanaged stands in the central and transitional hardwood-white pine-hemlock types of New England. Many of them contained much pine reproduction and some consisted entirely of pine reproduction at the edges of or within heavily defoliated oak stands. No attempt was made to estimate total acreage of softwood defoliation or to develop data which would lead to an estimate of the total amount of softwood damage. The aim was to determine only the effect of defoliation in the plots. An exception was a large block in the Southampton area of Massachusetts where one square mile of merchantablesized hemlock and hardwood was defoliated. It was estimated that over 500,000 board feet of merchantable hemlock was killed here. Mortality was evident in the fall following defoliation. Most of the sawlog-sized timber was salvaged by the owner that winter, but the loss in immature timber was substantial.

Since white pine was the major objective of the study main emphasis was devoted to it. However, where defoliated hemlock was found it was included as were also some oaks. In addition, a few other hardwoods such as red maple, ash, beech, and white birch, and some fir and spruce were recorded. The numbers of these were too small to be statistically significant, but they are included in the crown condition and mortality tables for whatever use they might be in any future study involving them.

While heavy defoliation of pine and hemlock in 1953 and '54 occurred locally it was an exceedingly small acreage compared with the acreages of hardwood that were defoliated. It rarely occurred in pure softwood stands except along the edges of heavily defoliated oaks. Most of the defoliation of softwoods occurred when they were in mixture with a high proportion of oak.

At the same time 8 check plots were established where no known defoliation had occurred in 1953 and where site and stand composition conformed reasonably close with those of the study plots.

A total of 1,723 trees was recorded on the sample plots along with 143 trees on the check plots.

In June 1954 it was evident that heavy defoliation was taking place on pine in entirely different locations from the 1953 defoliations—mostly in southeastern New Hampshire and southwestern Maine. This gave an opportunity for checking the results on the 1953 plots and there was also a possibility that two succeeding defoliations might take place which would yield additional valuable data. Therefore, a second set of 30 plots was established in the new areas in 1954 along with four check plots and the same procedure followed as on the 1953 plots.

In the early summer of the year following the initial defoliation both sets of plots were carefully examined for evidences of new feeding—the existence of new egg clusters having suggested this possibility on several of them. Although some feeding took place on the hardwoods and larvae were seen on the foliage of the pine on one of the plots no appreciable feeding occurred on any of the pine except on one tree. This was 100 per cent defoliated a second time and died that summer. On all the plots a combination of wilt disease, predators and in a few cases aerial spraying of DDT caused an almost complete wipe-out before defoliation exceeded more than a trace on the hardwoods.

Detailed information as to the amount of defoliation which might have taken place on individual trees during the year preceding the establishment of each set of plots is lacking. However, there were no reports from gypsy moth field men as to pine defoliation during these years. The writer and regular gypsy moth personnel were actively on the lookout for defoliation in 1953, but did not find any in the areas where the 1954 plots were established the following year. More positive evidence is furnished by study of the increment cores. These showed a marked and fairly uniform reduction in the width of growth rings for the year of defoliation and again for the year following, but no similar reduction for the year preceding the establishment of the plots. Thus, a typical tree 100 per cent defoliated in 1953 showed a much slower diameter growth in 1953 than in 1952 and a slower growth in 1954 than in 1953. There was no comparable reduction in 1952 growth from 1951 growth which study of the increment cores on all the trees indicates would have taken place if there had been appreciable defoliation in 1951. Therefore, as far as is known, the plots received only a single defoliation during the five-year period of study of each. There was no evidence of late killing frosts in any of the years nor of any other severely damaging influences such as prolonged droughts or attacks by other insects and disease. A small amount of browning of the needles on some of the Maine plots occurred in 1955, but the effect this had on mortality or recovery is not known. It probably was slight.

The above two conditions—*a single defoliation and no other major damaging influences*—should be kept in mind in interpreting the data here presented since they differ radically from the conditions reported on in the previous studies cited where successive and often severe defoliation occurred in the same areas and on many of the same trees.

Each fall the plots were examined and record made of the mortality and crown condition of each tree. In addition, a yearly photographic sequence was carried out on a number of the trees showing how their crowns responded to the different degrees of defoliation. Examples of these illustrating the data presented in this study are included in this report. However, to save space complete yearly sequences have been omitted. They can be found in the field and office books for each of the plots photographed.

Five full growing seasons after the initial defoliation—in 1958 and 1959 respectively for the 1953 and 1954 plots—the plots were visited for a final time. Condition of crowns was recorded and increment borings taken from trees over 2 inches in diameter. Height growth measurements were also taken on the smaller pines on the 1953 plots.

Distribution of the species with respect to crown class and site are given in Tables I and II (appendix 1a and 1b of the original report).

After the field work was completed the increment cores were measured and all data were transferred to individual key sort cards and processed to yield the information in this report. Data for the 1953 and 1954 plots were processed separately and the results compared. In most cases the patterns were very similar. For simplicity in presentation they have been combined into a single set of figures for each of the conditions studied. However, the identities of the two

Table I. Crown class, number of trees

	Dominant Co-Dominant	Intermediate	Overtopped	Total
1953				
A—Defoliated Plots (69)				
White Pine	325	264	518	1107
Hemlock	54	65	101	220
Red-White Oak	143	20	16	179
	522	349	635	1506
Other Hardwoods	18	15	9	42
Spruce-Fir	2	2	45	49
	20	17	54	91
TOTAL TREES	542	366	689	1597
B—Check Plots (8)				
White Pine	66	19	30	115
Hemlock	12	6	3	21
Red-White Oak	7	—	—	7
	85	25	33	143
1954				
A—Defoliated Plots (30)				
White Pine	348	218	324	890
Hemlock	23	8	20	51
Red-White Oak	—	—	—	—
	371	226	344	941
B—Check Plots (4)				
White Pine	25	17	72	114
Hemlock	—	—	—	—
Red-White Oak	8	—	—	8
	33	17	72	122
Total 1953 and 1954				
A—Defoliated Plots (99)				
White Pine	673	482	842	1997
Hemlock	77	73	121	271
Red-White Oak	143	20	16	179
Other Hardwoods	18	15	9	42
Spruce-Fir	2	2	45	49
	913	592	1033	2538
B—Check Plots (12)				
White Pine	91	36	102	229
Hemlock	12	6	3	21
Red-White Oak	15	—	—	15
	118	42	105	265

sets of data have been kept separate and are available for independent evaluation of the results and for possible use in comparing them with those of similar studies.

All percentages in the tables have been rounded out to the nearest whole number for simplicity although calculations were made to tenths.

Table II. Site class, number of trees

	Good	Fair	Poor	Total
1953				
A—Defoliated Plots (69)				
White Pine	220	756	131	1107
Hemlock	74	131	15	220
Red-White Oak	24	95	60	179
	318	982	206	1506
Other Hardwoods	7	24	11	42
Spruce-Fir	44	5	—	49
	51	29	11	91
TOTAL TREES	369	1011	217	1597
B—Check Plots (8)				
White Pine	16	81	18	115
Hemlock	15	6	—	21
Red-White Oak	—	7	—	7
	31	94	18	143
1954				
A—Defoliated Plots (30)				
White Pine	163	628	99	890
Hemlock	42	2	7	51
Red-White Oak	—	—	—	—
	205	630	106	941
B—Check Plots (4)				
White Pine	18	80	16	114
Hemlock	—	—	—	—
Red-White Oak	—	8	—	8
	18	88	16	122
Total 1953 and 1954				
A—Defoliated Plots (99)				
White Pine	383	1384	230	1997
Hemlock	116	133	22	271
Red-White Oak	24	95	60	179
Other Hardwoods	7	24	11	42
Spruce-Fir	44	5	—	49
	574	1641	323	2538
B—Check Plots (12)				
White Pine	34	161	34	229
Hemlock	15	6	—	21
Red-White Oak	—	15	—	15
	49	182	34	265

1. Mortality and Recovery

(a) White Pine

The only serious mortality occurring among white pine was on those 100 per cent defoliated. In the 1953 plots 19 per cent of the 100 per cent defoliated trees died. In the 1954 plots 38 per cent died. Among 90 per cent defoliated pines 4 per cent died on the 1953 plots and 10 per cent on the 1954 plots. Mortality among trees defoliated 80 per cent and less was negligible. Mortality and recovery for the different degrees of initial defoliation in the two sets of plots are shown in Table III. [Appendix 2a of the original report.]

The explanation for the great difference in mortality between 1953 and 1954 is not clear. Among the trees that died about the same proportion grew on good, fair and poor sites respectively. The proportion of trees in the dominant, intermediate and overtopped crown classes was almost identical. There did not seem to be any

Table III. Crown condition and mortality 5 years after original defoliation in 1953 (condition of crown is given as percentage of normal crown missing)

PINE

1953 Plots (1107 Trees)

Original defolia-tion	Crown condition at end of 5th year (1958)							Percentages and number of trees	
	Dead	90%	80%	60-70%	30-50%	10-30%	Normal	%	No.
100%	19%	3	1	3	17	20	37	35	385
90	4	1	1	1	7	32	54	16	179
80	4	1	—	—	7	23	65	6	71
70	—	3	—	—	7	22	68	5	54
60	4	—	—	—	—	16	80	5	57
50	1	—	—	—	2	18	79	9	95
40	—	—	—	—	—	14	86	9	99
30	—	1	—	—	—	7	92	7	83
20	—	4	—	—	—	3	93	4	42
10	—	—	—	—	—	—	100	2	24
0	—	—	—	—	—	—	100	2	18
									1107

1954 Plots (831 Trees)

Original defolia-tion	Crown condition at end of 5th year (1959)							Percentages and number of trees	
	Dead	90%	80%	60-70%	30-50%	10-30%	Normal	%	No.
100%	38	4	2	6	18	10	23	36	304
90	10	2	4	4	33	30	17	32	266
80	1	5	1	3	34	39	17	11	88
70	2	—	—	19	17	21	11	8	69
60	—	—	—	—	5	59	36	3	22
50	—	—	—	—	8	40	52	3	25
40	—	—	—	—	4	48	48	4	33
30	—	—	—	—	16	42	42	2	19
20	1	—	—	—	—	40	59	1	5
10	—	—	—	—	—	—	—	—	—
0	—	—	—	—	—	—	—	—	—
									831

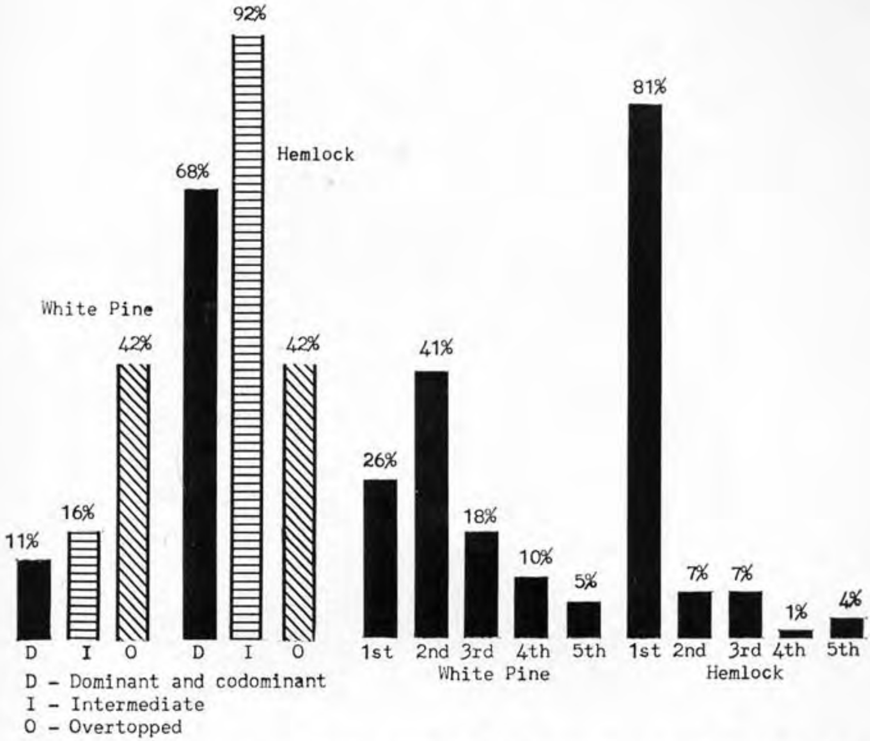

Figure 6a (left). Mortality by crown classes for 5-year period following 90-100 per cent defoliation. The 1953 and 1954 plots have been combined. Figure 6b (right). Mortality by years following 90-100 per cent defoliation. The 1953 and 1954 plots have been combined.

marked weather differences affecting the two sets of plots nor any other identifiable damaging elements.

An explanation may lie in the fact that the greatest percentage of mortality occurred in the overtopped class as shown in Figure 6a. Mortality in this crown class was almost four times as great as in the intermediate and dominants [Fig. 7]. Trees were classed as overtopped if the crown canopy over them was closed. There was no way of classifying as to the degree and period of suppression and it is possible that the suppressed trees on the 1954 plots had suffered a longer period of suppression than those on the 1953 plots and, therefore, were more susceptible to damage after defoliation. It is also possible that even as large a sample as this—189 killed pines—is not large enough to even-out the many variables in nature.

Comparison of the 1953 and 1954 plots in Table IV shows the relative percentages of dominant, intermediate and overtopped trees that died to be about the same for the two sets of plots. White pine does not withstand long suppression well and it is understandable that suppressed trees should be vulnerable to heavy defoliation.

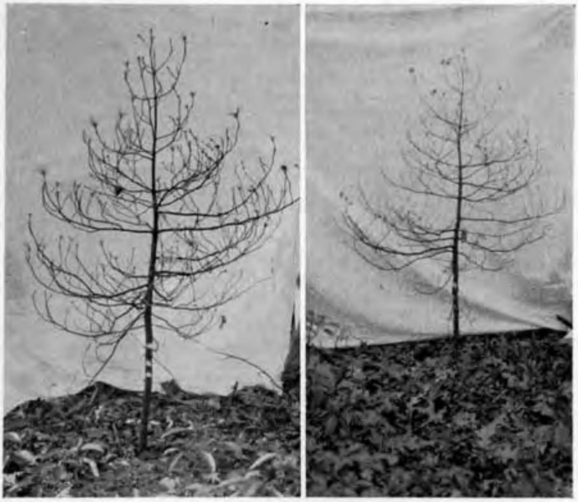

Figure 7. Suppressed pine defoliated in 1953, Granby, Conn. Trace of foliage in 1954 (died 3 years later).

Dominants apparently have a high resistance to 90-100 per cent defoliation—only 11 per cent having died compared with 42 per cent in the overtopped trees [Fig. 8].

Most of the mortality occurred in the first two years following defoliation with a peak in the second year as shown in Figure 6. Comparison of the year of death for the two plot series shows the relationships to be about the same for both series. Mortality did continue right through to the fifth year and it is probable that most or all of the pines now 70-90 per cent defoliated will eventually die. This could add another 8 per cent to the 28 per cent mortality which occurred on the 100 per cent defoliated pine.

In assessing the role of gypsy moth defoliation in the above mortality it seems clear that it played a major role especially in the trees that died in the first and second years. No mortality occurred among any of the pines on the check plots and there was negligible mortality among pines defoliated less than 90 per cent. No other influences except possibly some of the needle browning mentioned earlier could have been very important.

At the same time very little of the overtopped pine could be expected to survive and to grow into saw timber without release—either by cutting of the merchantable trees overhead or by weeding in the younger stands. In the absence of any planned management which characterized practically all these stands, defoliation by gypsy moth merely hastened a natural and widespread process—death of white pine by prolonged suppression.

Recovery of foliage on the pine was spectacular for all degrees of defoliation. Five years after 100 per cent defoliation 31 per cent of

Table IV. Five-year mortality by crown classes 100 per cent and 90 per cent defoliation

A—Pine									
1953	100 per cent defoliated			90 per cent defoliated			100 per cent and 90 per cent		
Crown Class	No. dead	Total live and dead	Per cent dead	No. dead	Total live and dead	Per cent dead	No. dead	Combined total live and dead	Per cent dead
Dominant and Codominant	7	67	10	2	73	3	9	140	6
Intermediate	7	95	7	6	47	13	13	142	9
Overtopped	61	224	27	6	67	9	67	191	35
1954									
Crown Class									
Dominant and Codominant	6	44	14	7	14	50	13	58	22
Intermediate	14	64	17	9	18	50	23	82	28
Overtopped	94	196	47	11	23	48	105	219	48
1953 and 1954 Combined									
Crown Class									
Dominant and Codominant	13	111	12	9	87	11	22	198	11
Intermediate	21	159	13	15	65	23	36	224	16
Overtopped	155	420	37	17	90	19	172	410	42

Figure 8. Dominant pines over red oak saplings defoliated in 1954, Sanford, Maine (lower photo). Above, the same groups in 1959. The two pines to the right also defoliated in 1955, died.

the pine had normal foliage and 47 per cent was missing less than 20 per cent of its foliage. Recovery was least complete on the overtopped heavily suppressed pine. Correspondingly rapid recovery of foliage occurred in all defoliation classes and was consistent with degree of initial defoliation. The conclusions that might be drawn are that a single 100 per cent defoliation of pine uncomplicated by other severe conditions can cause appreciable mortality in pine, but that less than 100 per cent defoliation does not result in significant mortality.

Estimations of site quality were made for every plot as "good," "fair," and "poor." On several plots with a poor rating, mortality was much higher than the average. However, no clear correlation for the data as a whole was found between sites as classified for either year of death, mortality or rate of recovery. This may have been due to imprecise site class distinctions or to the very large number of sites classed as "fair" as compared to "good" or "poor."

As noted before, the areas covered by the sample plots were mostly typically dense unmanaged stands. One area of about 20 acres, however, represented by three plots with 71 trees, had received such markedly different treatment from any of the other plots that data from it were analyzed separately from the others. This was an area on the Townsend (Massachusetts) State Forest where well-stocked natural pine saplings had been released from a heavy overstory of red oak and red maple the winter before its 1954 defoliation [Fig. 9]. Up to this time it had been severely suppressed as indicated by the stunted growth. Fifty-six per cent of the trees were defoliated 100 per cent in June 1954 and all the rest were defoliated 90 per cent. Only 2 of the 71 trees died and all the rest had recovered normal foliage by 1957—a much faster rate than on the areas which did not receive this treatment. The gaps in the canopy left by the removal of the hardwood crowns left the remaining pines well spaced and with plenty of light on all sides. As a result they were all dominants or intermediates with no overtopped trees.

This was the only area where complete release of suppressed pine had been carried out in either plot series although on several others which had been partially released by cordwood and log cuttings 3-4 years prior to defoliation recovery was almost as fast. Therefore, it would be imprudent to conclude that 100 per cent defoliation in such stands would always be followed by so little mortality or as complete a recovery. However, it does suggest that the practice of releasing pine—so necessary to its survival when growing under hardwoods—may have an equally favorable effect in minimizing damage due to heavy defoliation.

In this particular area the almost complete elimination of all the oaks will probably protect the stand from any gypsy moth defoliation in the future.

Figure 9. At left, pines released 1953-54 and defoliated in 1954, Townsend, Mass. At right, the same trees in 1959.

(b) Hemlock

In contrast to pine, mortality in hemlock was heavy after 100 per cent defoliation. As shown in Table V, 74 per cent of the 100 per cent defoliated hemlock died. Below that amount of defoliation mortality fell off rapidly, and none occurred in trees defoliated 80 per cent and less.

Also in contrast to pine, mortality was heaviest in the dominant and intermediate crown classes and least in the overtopped class [Table VI]. After 90-100 per cent defoliation 68 per cent of the dominants and 92 per cent of the intermediates died while only 42 per cent of the overtopped trees died (Fig. 6).

This is significant in terms of economic values. Heavy loss can occur in trees that are or will be timber trees even without management since they are either already dominant or if overtopped are capable of surviving suppression for long periods—as compared with pine where loss was heaviest in the overtopped trees which had little chance of growing into timber without management.

Again, in contrast to pine (Fig. 6), over 80 per cent of the trees that were 90-100 per cent defoliated died in the first year after defoliation. After that a small amount of mortality occurred each year continuing up to the fifth year. Apparently hemlock is so vulnerable to this heavy degree of defoliation that relatively few damaged trees are left to die after the first year.

This is significant in that it indicates that 100 per cent defoliation occurring under the conditions of this study is justification for immediate salvage of sawlog-sized trees since most of these can be expected to die in the first year [Fig. 10]. In pine, although there was appreciable mortality after 100 per cent defoliation, this did

Table V. Crown condition and mortality 5 years after original defoliation, 1953 and 1954 plots combined

B—Hemlock (269 Trees)

Original defoliation	Crown condition at end of 5th year following defoliation in percentage of normal crown missing							Percentages & no. of trees	
	Dead	90%	80%	60-70%	30-50%	10-20%	Normal	%	No.
100%	74%	2	1	—	8	3	12	42	115
90	9	—	—	3	18	18	52	13	32
80	—	—	—	—	13	13	74	6	14
70	—	—	—	—	17	23	60	6	15
60	—	—	—	—	—	21	79	5	14
50	—	—	—	—	3	21	76	10	28
40	—	—	—	—	—	—	100	7	20
30	—	—	—	—	—	9	91	4	11
20-0	—	—	—	—	—	5	95	7	20
									269

Table VI. Five-year mortality by crown classes 100 per cent and 90 per cent defoliation

B—Hemlock									
1953	100 per cent defoliated			90 per cent defoliated			100 per cent and 90 per cent		
Crown Class	No. dead	Total live and dead	Per cent dead	No. dead	Total live and dead	Per cent dead	No. dead	Combined total live and dead	Per cent dead
Dominant and Codominant	15	25	63	—	—	—	15	24	63
Intermediate	39	44	89	—	—	—	39	44	89
Overtopped	14	25	56	2	10	20	16	35	46
1954									
Crown Class									
Dominant and Codominant	11	13	85	2	4	50	13	17	76
Intermediate	4	4	100	—	—	—	4	4	100
Overtopped	2	8	25	—	—	—	2	8	25
1953 and 1954 Combined									
Crown Class									
Dominant and Codominant	26	37	70	2	4	50	28	41	68
Intermediate	43	48	90	—	—	—	43	48	92
Overtopped	16	33	43	2	10	20	18	43	42

Figure 10. Block of 600 acres of hemlock, pine, and red oak defoliated in 1953, Southampton, Mass. (upper photo). Below, salvage of sawlog-sized hemlocks following defoliation. There was also heavy loss of pole-sized trees.

not reach its peak until the second year following defoliation and was concentrated on overtopped, suppressed trees. Also, in pine dominants and intermediates—the potential or actual sawtimber trees—the greatest mortality did not occur until the second year following defoliation—thus giving more time to assess damage and to salvage sawtimber trees and more time for release operations to save the overtopped pine.

The role of heavy defoliation by the gypsy moth in mortality of hemlock is quite clear. No mortality occurred to hemlock on any of the undefoliated check plots. The abrupt death of a high percentage of 100 per cent defoliated hemlock the year after defoliation and practically no mortality to neighboring hemlocks defoliated less than 90 per cent indicates that the gypsy moth was the major factor in mortality.

Recovery of foliage on hemlocks defoliated 90 per cent and less was almost as spectacular as in the pine. Even in the 90 per cent defoliated class 70 per cent of the trees had recovered either to normal or within one-fifth of their normal foliage within 5 years.

Despite this, the size of the sample of hemlocks defoliated 90 per cent and less (58 trees) is too small to justify the conclusion that expectable mortality is slight. Therefore, it would be wise to watch closely any timber stands defoliated in the neighborhood of 90 per cent so that prompt salvage could be carried out if necessary.

(c) Red and White Oak

Although hardwoods were incidental to the study, the comparison with softwoods is interesting. Of the 125 oaks that were 100 per cent defoliated only 5 per cent died—half of them within the first year and the rest spread out equally over the remaining 4 years. The larger percentage of the 90 per cent defoliated oaks which died (6 per cent) is based on too small a sample to be significant but does fit in with the opinion expressed by many men familiar with gypsy moth that mortality is apt to be highest when most, but not all, the leaves are stripped away. The sample of white oak was too small to determine whether its performance bore out the general feeling that white oak is more susceptible to damage by defoliation than red oak. Too few oaks were included in the 1954 plots to yield significant comparisons between the two years.

Recovery of oaks from even the most severe defoliation was very rapid. After the first year only a very small percentage were lacking more than 20 per cent of their foliage and a large majority had normal foliage. Evidence of the former condition were numbers of dead branches—mostly small—throughout the crown.

The conclusion that might be drawn is that a single heavy defoliation of red and white oak uncomplicated by other factors, such as late frosts, severe droughts, or recent heavy defoliations, causes little mortality. The addition of a second consecutive defoliation and/or killing of leaves by late frosts or other factors can have much more serious effects as previous studies have shown.

II. Diameter Growth*

Increment cores were taken from 952 trees in defoliated plots, and in check plots. These were measured using a low-power binocular microscope. If rings could not be determined positively, the core was discarded.

The width of the rings from trees in the 1953 plots was measured back to 1944, and those in the 1954 plots back to 1939.

The actual width of all rings in each group was totalled, and compared with similar totals from other years. In Table VII these totals have been used to compute the loss in growth the year of defoliation compared with

* Discussion in this section condensed by Neely Turner.

Table VII. Effect of a single defoliation on growth in diameter of white pine

Per cent defoliation	Per cent loss in growth: Year of defoliation[1]	Year following[2]	Five years following[3]
100	24	38	33
90	29	42	39
80	20	39	32
70	19	28	24
60	24	16	17
50	15	27	22
0-40	19	23	17
None	10	13	17

[1] Average loss in growth in year defoliated compared with previous year.
[2] Average loss second year compared with first.
[3] Average loss on a five-year basis before and after defoliation.

the year before defoliation; the year after defoliation compared with the year of defoliation; and the 5 years following defoliation compared with the 5 years before.

It is obvious that the growth of undefoliated trees was decreasing. Nevertheless, the growth of defoliated trees decreased still more. On a 5-year basis, only the pines with 80 to 100 per cent defoliation showed more than 10 per cent net loss.

The reasons for this situation can be seen in Table VIII. In the dominant and codominant class is a group of three plots from which hardwoods were removed during the winter of 1953-54, releasing the pines. In spite of serious defoliation in 1954, growth of these trees improved in 1955, and the average annual growth 5 years after defoliation increased by about 30 per cent. Growth of crowded dominant trees decreased by about the same percentage in the same period without defoliation.

Effects of defoliation on the growth of hemlock have been summarized in Table IX. There were only 72 trees; therefore, the results cannot be

Table VIII. Average annual growth in diameter on 1954 white pine plots

Crown class	Average annual growth—inches: 1939-48	1949-53	1954	1955	1954-58
Dominant and Codominant					
Defoliated	.213	.190	.138	.071	.102
Check	.216	.190	.195	.160	.155
Released	—	.169	.165	.180	.220
Intermediate					
Defoliated	.190	.170	.160	.084	.100
Check	.193	.150	.140	.125	.120
Overtopped					
Defoliated	.136	.119	.080	.074	.074
Check	.125	.076	.080	.065	.066

Table IX. Loss in growth of hemlock because of defoliation

Per cent defoliation	Per cent loss		
	Year defoliated	Year following	5-year period
100	50	50	47
90	23	36	30
80	41	17	37
70	34	20	17
60	6	38	19
50	7	23	23
1-40	12	20	30
None	10	23	19

analyzed in detail. The net loss in growth of defoliated, as compared with undefoliated, trees was somewhat larger than in white pine.

The few figures available for red and white oak showed a loss the year of defoliation, and a very small loss on the 5-year basis.

Summary

1. Purpose of the study was to determine the effect of heavy defoliation by the gypsy moth in 1953 and 1954 on white pine survival and growth rates.

2. Ninety-nine plots were established in areas where pine was heavily defoliated in 1953 and 1954 in all the New England states except Rhode Island. These included 1,938 white pine, 269 hemlock, 184 red and white oak, and 91 miscellaneous species.

3. Twelve check plots totalling 265 trees, mostly pine, were established in areas where no known defoliation of the softwoods was known to have taken place and which were similar in character to the defoliated plots.

4. The degree of initial defoliation for each tree, its subsequent death or extent of recovery of foliage over a 5-year period were recorded. Diameter growth measurements were made from increment cores extracted from trees large enough to yield usable cores.

5. At the conclusion of the study all numbered trees were freshly painted, permanent metal tags wired to the smaller ones and the areas accurately plotted on the U.S.G.S. sheets to facilitate any use that might be made of them in future outbreaks. Records were put into permanent form and deposited in the Concord office of the Plant Pest Control Division.

6. Conditions of the study involved a *single* defoliation uncomplicated as far as is known by any known defoliation for at least 4 years preceding and none following. No late killing frosts were known to have damaged the hardwoods and weather conditions during the two five-year periods were normal. Previous studies of mortality and growth loss involved successive years of heavy

defoliation in the same areas which imposed far more severe conditions than occurred during the period of this study.

7. Under the above conditions and at the end of the five-year period for each set of plots it was found that:
   a. One hundred per cent defoliation by the gypsy moth resulted in 28 per cent mortality of white pine, 74 per cent mortality of hemlock, and 5 per cent mortality of red and white oak.
   b. Defoliation of 90 per cent caused mortality of 8 per cent in white pine, 9 per cent in hemlock, and 6 per cent in the oaks.
   c. Defoliation less than 90 per cent caused very little mortality among any of the species studied and by the end of the five-year period most trees had recovered normal foliage or were within 20 per cent of it.
   d. Greatest mortality in white pine occured during the second year following 100 per cent defoliation, but was appreciable in each of the other 4 years. Practically all the mortality in the hemlock occurred in the year following defoliation and very little in any of the years after that.
   e. Mortality was most serious in the overtopped pine where 42 per cent of the 90 per cent and 100 per cent defoliated trees died.
   f. Substantial sawtimber losses occurred in merchantable hemlock stands and the mortality figures would have been much higher if some of the heavily defoliated hemlock had not been cut by the owners immediately after defoliation, thus preventing positive evidence of death.
   g. Very little mortality occurred in merchantable pine stands.
   h. Only a few cases were observed where pine mortality after defoliation was heavy enough to adversely affect future timber yields. In almost all cases there was sufficient stocking of pine after mortality to produce a good timber crop providing the pine was released from suppression.
   i. Appreciable diameter growth losses occurred in all species in the year of, and that following, defoliation and for the five-year periods before and after. Appreciable growth losses for the same years and periods were also found on the undefoliated trees on the check plots.
   j. Net diameter growth loss from the preceding year occurred in all species for the year of defoliation and for the year following but was substantial only on trees that were more than 80 per cent defoliated. Losses for 100 per cent defoliated trees were as follows:

	Pine	*Hemlock*	*Oaks*
Loss year of defoliation from preceding year	14%	40%	24%
Loss year following defoliation from year of defoliation	25%	27%	28%

k. Average net annual growth loss for the five-year period following defoliation from that of the five-year period preceding it occurred on all species, but was appreciable only on trees defoliated 80 per cent or more. Losses for 100 per cent defoliated trees were: pine, 16 per cent; hemlock, 28 per cent; red and white oaks, 7 per cent.

l. Net average annual growth loss for the ten-year period 1949-1958 from that of the 1939-1948 period for pine 100 per cent defoliated in 1954 was 10 per cent and that for 90 per cent defoliated pine was 9 per cent. Below those levels of defoliation loss attributable to defoliation was negligible between the two ten-year periods.

m. Significant growth losses were found to have occurred for the same years and periods above described on the undefoliated check plots. Growth loss on these for the ten-year period 1949-1958 from the 1937-1948 period averaged 28 per cent—almost three times the amount of net loss that could be attributed to defoliation.

n. The 28 per cent natural growth loss on undefoliated trees is probably attributable to increasing crowding and competition —practically all the stands being characterized by closed crown canopies with no logging or cultural treatment having been carried out.

o. An area of previously overtopped 90-100 per cent defoliated pine that had been completely released showed a 30 per cent *increase* in diameter growth for the five-year period following defoliation from the five-year period preceding it as well as substantial annual growth increases dating from the year when the trees had been defoliated—the pine having been released by cutting overtopping hardwoods the winter before.

8. Some practical applications and conclusions from data found in this study are as follows:

a. Areas of mixed hemlock and oak showing a substantial build-up of gypsy moth infestation should be watched closely since severe damage to hemlock can result from heavy defoliation.

b. Merchantable hemlock that has been 90-100 per cent defoliated once should be salvaged as soon as possible since high mortality can be expected in the year after defoliation.

c. Merchantable pine 90-100 per cent defoliated once has a good chance of surviving given normal weather conditions providing it is not badly suppressed.

d. Accepted practices of white pine management such as release from suppression and maintenance of healthy crowns and root systems by periodic thinning appear to be effective in greatly reducing losses through mortality and in growth following heavy defoliation. In addition, where release is accomplished by elimination of overtopping oaks the probability of future gypsy moth outbreaks is lessened.

e. The generally slow and steadily decreasing diameter growth rates found on both the undefoliated check plots and on lightly defoliated trees suggest that substantial losses in timber production have been and are occurring from lack of management in the wild timber stands covered by this study.

Literature Cited

Baker, W. L. 1941. Effect of gypsy moth defoliation on certain trees. Jour. For. 39:1017-1022.

Crossman, S. S. 1948. Dead and dying trees in the gypsy moth defoliated areas. Progress Report, Bur. Ent. and Pl. Quaran., U.S.D.A.

House, W. P. 1960. Gypsy moth-white pine damage study. Final Report. U.S.D.A. Plant Pest Control Division.

Perry, C. C. 1955. Gypsy moth appraisal program and 1952 proposed plan to prevent spread of the moths. Agr. Res. Service, U.S.D.A. Technical Bulletin No. 1124.

Tierney, G. C. 1947. Death of trees following defoliation by gypsy moths in Connecticut Valley towns of Massachusetts. Progress Report, Bur. Ent. and Pl. Quaran., U.S.D.A.