A Study of the European pine shoot moth in a young red pine planta-tion in southern Michigan. 1947.

by

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A STUDY OF THE EUROPEAN PINE SHOOT MOTH IN A YOUNG RED PINE PLANTATION IN SOUTHERN MICHIGAN

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(Rex Eugene)
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PREFACE

A large number of our most serious insect pests and diseases of the forest have been introduced into this country from Europe. This was largely due to early importations of European seedlings for ornamental or forest plantings in this country. Many of these insects were brought in without the parasitic or predatory organisms which helped to maintain a balance in the European habitat.

Several such imported insects and diseases have adapted themselves to one or more of our native tree species, and have caused tremendous damage to our forests. Among the more destructive imported pests we find Endothia parasitica, the chestnut blight fungus which, for all practical purposes, has annihilated one of our most valuable Eastern Hardwoods. Others are the Gypsy moth and Brown-tailed moth which have caused the expenditure of millions of dollars for control work in the New England States.

Among the numerous others is Rhyacionia buoliana, Schiff, the European Pine Shoot Moth which was imported into this country prior to 1914 on pine seedlings arriving from Europe. This insect has spread throughout Eastern United States and Canada, and this study was prompted by the great damage it has caused to some small stands of young Red Pine in Michigan.

ACKNOWLEDGEMENTS

I wish to express my gratitude to the several people who assisted in the planning and execution of this study.

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Lastly, I wish to express my most sincere appreciation to Dr. S. A. Graham, under whose guidance this study was undertaken and carried out.

TABLE OF CONTENTS

LIST OF TABLES, MAPS, & GRAPHS

TIME AND PLACE OF STUDY

This study was carried on in plantation compartments 20, 21, 29, 30, 31, and 32 in Block I, and compartment 3 in Block II of Stinchfield Woods owned by the University of Michigan, School of Forestry and Conservation in Washtenaw County, Michigan. This property contains several compartments of uneven-aged hardwoods in addition to coniferous plantings of various ages and species. The topography of this entire property is slightly to steeply sloping. The soil is very sandy, and the coniferous plantings were made on land abandoned for cultivation. See accompanying map for detailed information concerning the plantations on the property.

A fog generator was used in the insect control work because the topography and character of the stands make use of a conventional type sprayer impracticable.

This study began in March 1947, and was continued through August of the same year.

OBJECTIVE

The objective of this study was to determine the development and habits of, the damage caused by, and the practicability of direct control measures against the adult of the European Pine Shoot Moth. Studies of population and environmental resistance factors were also made.

BRIEF HISTORY OF THE INSECT

The European Pine Shoot Moth has been reported in the Old World from the British Isles to Central Siberia and Korea, and from Sweden to Southern Europe and Syria, (Friend, 1931). Its principal host in the Old World is Pinus sylvestris, but it attacks numerous other species there also.

Generally the insect completes but a single life cycle each year, but Escherich has reported that in the Southermost latitudes of its range it may complete two generations per year where the yearly temperature summation exceeds 7260 degrees Centigrade.

The insect was recognized near New York City in 1914 by Busck, and it is now found throughout the Eastern part of the United States and Canada, and West through the Lake States, Ontario, and British Columbia.

In the United States the insect attacks, according to Friend, 1931, Pinus sylvestris, P. laricio, P. pinaster, P. austriaca, P. mugho, P. strobus, P. palustris, P. resinosa, P. taeda, P. contorta, P. banksiana, and P. muricata. In this study it has in addition been observed on P. densiflora, and P. edulis.

RECOGNITION FEATURES

The Infested Stand

A stand heavily infested with the European Pine Shoot Moth shows the effects very conspicuously. Some of the trees will have stopped height growth completely, and will have a dense cluster of killed buds and needles at the top of the leader. All new buds forming on these trees are killed before they have a chance to expand into a shoot. The trees in this category are infested so heavily that they do not have an active bud on any of the upper lateral branches that can grow upwards as the main bole of the tree.

Other trees in the stand will have bayonette tops; where the leading bud has been killed, and one of the laterals was able to take its place. Occasionally a tree will be found with two or more of the laterals beginning to grow upwards. This results in a fork.

All through the Spring and Fall larval feeding periods, pitch flows from the buds which are being eaten upon. This mass of clear pitch whitens as it hardens, and is very noticeable. Quite frequently rather coarse, light brown frass is found clinging to the needles around an infested bud. This frass is not always present, probably due to the action of wind or rain.

After the moths have emerged, the pupal cases are found sticking out of the buds at various angles. They are generally about three-fourths outside the bud, and so are quite conspicuous.

The Larvae

During the winter the larva, a rich brown caterpillar with a black head, hibernates in the bud in which it fed in the fall. During the spring feeding period it moves from one bud to another, or burrows into a newly expanding shoot. After each moult the head is white to pale translucent green, but becomes black again in a very few hours.

The new larva hatching out in July and August first appears as a long, very slender, pale translucent green worm with a black head. By the end of a week however, the body has become the characteristic brown found in the Winter and Spring.

The Pupae

Upon the completion of the feeding period in the Spring, the larva bores downward toward the base of the expanding shoot where the stem is no longer sucsulent. There it molts again, spins an almost unnoticeable cocoon in that portion of the shoot where it lies, and acquires a membranous sheath over the head and thorax. During the pupal period the abdominal section wriggles quite actively if the insect is disturbed.

The Adult Moth

The moth has a dull tan to grayish body, very shiny light green eyes, bright orange fore wings barred laterally with silver streaks in irregular pattern, and dull gray hind wings. They are found sitting very quietly on the tree during the day, but at dusk they flit around the tree in swarms. The female is somewhat larger than the male, the difference being chiefly in the dimensions of the abdomen.

DESCRIPTION OF INFESTED COMPARTMENTS

The area under intensive consideration consists of 22.75 acres divided into two spray areas for the purposes of the spray experiments in this study.

Spray area I is compartment 32 and contains 5.63 acres of red pine planted in 1937.

Spray area II is made up of compartments 29, 30, and 31. Compartment 29 contains 4.29 acres of red pine planted in the Spring of 1939. Compartment 30 contains 7.68 acres of red pine planted in 1937. Compartment 31 contains 4.97 acres of mixed red, white, jack, and corsican pines planted in the Spring of 1938.

Compartments 30 and 32 are identical as to the type of stand and the degree of infestation by the European Pine Shoot Moth. The planting stock for these two areas was 2-0 seedlings raised in the schools own nursery. These trees are now an average of about 6 ft. tall with the tallest ones being slightly over 8 ft. and the shortest ones 4 ft. They average 1064 plus or minus 19.6 per acre with a probability of 2:1, and portions of this stand are dense enough that they are beginning to close in spite of the retarded height growth. This closing is largely the branches below 4 ft. above ground. A few other portions of the stand are quite open. These spots are mainly on west slopes where the hot afternoon sun soon evaporates moisture from the sandy soil. The openness is not due so much to missing trees as to the small size of the ones present.

Compartments 29 and 31 are very nearly identical in size of red pine trees and degree of infestation, but differ markedly in the number of red pines per acre. They were considered together for census of the infestation per tree, but separate figures were necessary for the infestation on a per acre basis. The trees in both compartments average slightly under 4.5 ft. in height. The talles being 6 ft. and the shortest less than 3 ft.

Compartment 29 averages 910 plus or minus 20.8 trees per acre with 2:1 probability. The planting stock for this compartment was 2-2 transplants grown in the school nursery. This stand is very open.

Compartment 31 has an average of 705 plus or minus 55.5 red pines per acre with 2:1 probability, and approximately an additional 392 white pines, 15 corsican pines, and 3 jack pines per acre. This does not include a small area (less than 1/4 acre) which contains corsican pine exclusively. The planting stock for this compartment was 2-0 seedlings and 2-1 transplants grown in the school nursery. This stand also is open.

Compartment	29	31	30 & 32
No. 1/20 A. Samples	9	11	20
Min. No. Trees Per Plot	40	38	47
Max. No. Trees Per Plot	49	62	59
Av. No. Trees Per Plot*	45.5	35.3	53.2
St. Error of Mean ≠ or-*	1.05	2.75	0.98
Av. No. Trees per Acre*	910	705	1064
Range of Heights in Ft.	3-6	3-6	4-8
Av. Height in Ft.	4.5	4.5	6

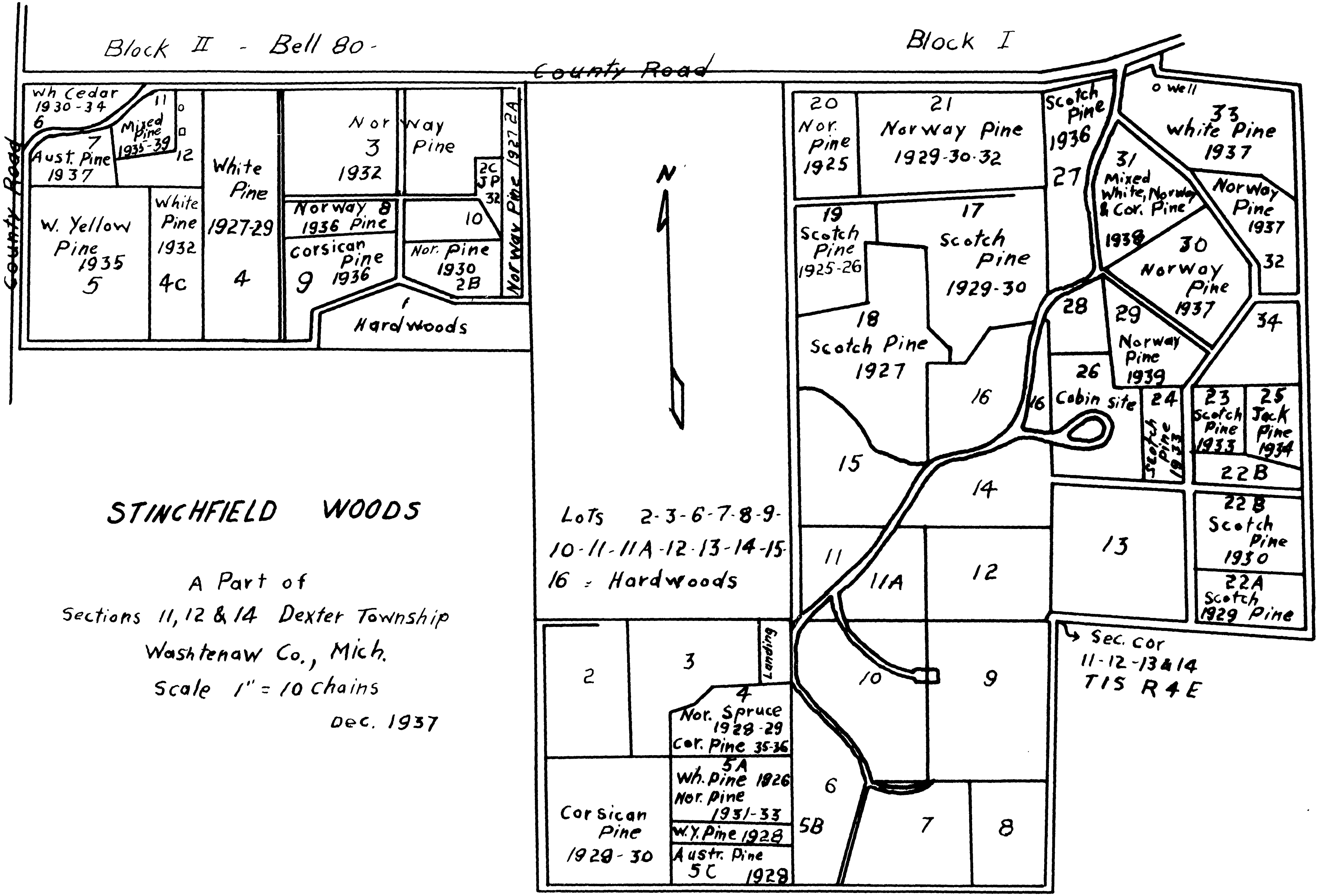
Table I. Stand Description Information

*Applies to Red Pine only. See paragraph above table for additional trees in plot 31.

Studied to a lesser degree were compartments 20 and 21 in Block I and compartment 3 in Block II.

Compartments 20 and 21 contain trees planted in 1925, 1929, 1930, and 1932. The stands are well closed, and range in height from 15 to 30 feet.

Compartment 3 in Block II contains red pine planted in 1932. The stand is well closed and contains trees ranging in height from 20 to 45 feet.



STINCHFIELD WOODS

A Part of
Sections 11, 12 & 14 Dexter Township
Washtenaw Co., Mich.
Scale 1" = 10 chains
Dec. 1937

SAMPLING PROCEDURES

Because a determination of the insect population per tree and per acre was desired, it was necessary to make counts to determine the number of trees per acre, the number of infested buds per tree, and the number of larvae per infested bud in each type.

It was also necessary to make counts of the adult moths from time to time to determine when to spray, and to keep a check on the population after spraying.

TREE STOCKING

In each of the types, something near 10 percent of the area was examined to determine the density of tree stocking. This was done in one-twentieth acre plots by running one-half chain wide strips through each type and tallying the number of trees in each full chain of length.

For each type the average stocking for all of the sample plots was calculated and the standard error of this mean determined. Table I shows these averages and the standard errors by number per one-twentieth acre plot. On a percentage basis the standard errors are 2.28% for compartment 29, 7.86% for compartment 31, and 1.85% for compartments 30 and 32.

In compartment 31 which is mixed, only the red pine is considered because the other species are infested with R. buoliana so slightly that they have practically no effect on the insect population. The high standard error of the average red pine stocking is due to the occurrance of these other species throughout the compartment in varying concentrations. This compartment contains one area of about one-fourth acre which contains corsican pine only, and this was not taken into consideration in the tree census.

LARVAL ABUNDANCE

After the number of trees per acre in each type were determined, it was necessary to find the average number of larvae in each tree.

Preliminary inspection showed a decidedly heavier infestation near the tree tops. For this reason the counts of infested buds and larvae were separated into different tree levels. Counts on the compartments containing older and much larger trees were confined to the leaders and top 6 feet of the trees.

The trees to be inspected were selected mechanically by taking each 10th tree in each 10th row. Then for each of the levels - 18 inches, 18 in. -3 ft., 3 ft. - 6 ft., and 6 ft. - 9 ft., the number of tips, the total number of buds, the number of currently infested buds, and the number of previously infested buds were counted. As these counts were made a few sample infested buds from each level were removed and taken to the laboratory for more careful examination. Generally for each tree, five buds from each level were opened and the live and winter killed larvae within counted. This procedure was confined to compartments 29, 30, 31, and 32.

For compartments 29 and 31, 15 trees in each were inspected and averaged separately. These averages were so nearly identical that the two compartments were considered as one for expressing the infestation per tree. An additional 30 trees were later inspected in these compartments.

Compartments 30 and 32, having been planted in the same year and separated only by a fire lane are essentially the same stand. Fifty trees in these two compartments were inspected.

The sample trees in compartments 20 and 21 were inspected for infested leaders and the percentage of the buds infested in the top 6 feet of the tree.

The trees in compartment 3 Bock II were inspected for infested leaders only.

The results of all these counts are discussed in a later section of this report.

THE ADULT MOTHS

After the moths began emerging frequent checks on their population were necessary to determine the time to fog. Counts were also necessary after the fogging to determine the effectiveness of the insecticide, and to determine if another application was needed.

Moths were counted most successfully while they were sitting still in the hot part of the day. To do this the tree was approached and circled with as little disturbance as possible, and the moths on each branch counted.

Doubtless some moths were missed, but it is impossible to make a satisfactory count if the tree is disturbed and the moths are flitting from one branch to another or to other nearby trees. As the census was intended to determine the comparative population from time to time, and not necessarily the exact numbers present, it was found to be satisfactory.

STATUS OF INFESTATION

The severe damage to the red pine in compartments 20, 21, 29, 30, 31, and 32 is quite obvious to even the casual observer. The leading shoot of practically every tree is either club topped or bayonette topped. In the former case, the tree has no active leader at all, and the apex of the tree is a heavy mass of killed buds and densely clustered needles. In the latter case the original leader has been killed and a lateral bud has turned up and replaced it. This gives the tree top the appearance of a fixed bayonette. On some trees this performance has been repeated two or more times, giving a zigzag appearance to the bayonette tip.

Compartments 30 and 32

Table II indicates that the average tree in this stand had 89.3 larvae up to the 6 foot level, and those trees over 6 feet tall averaged 162.5 larvae. A breakdown of these figures from Table II lists the occurrance of 18.9 larvae per tree below 18 inches, 34.2 between 18 inches and 3 feet, 36.2 between 3 and 6 feet, and 73.2 between 6 and 9 feet. The leading shoots were 100% infested.

The standard errors for the average number of infested buds and the number of larvae per bud are given in Table II.

The above figures demonstrate the preference of the insect for the tree tops, and a further demonstration of this is in the percentage of the buds infested at the various levels, being 46.7% below 18 inches, 85.8% between 18 inches and 3 feet, and about 92% of all buds above 3 feet. The difference between the 3 to 6 and the 6 to 9 feet levels is small enough to be ignored. Another illustration of the tree top preference of the shoot moth is again found in Table II in the number of live larvae occurring per bud at the various levels. There were 0.68 larvae per bud below 18 inches, 0.88 between 18 inches and 3 feet, 0.92 between 3 and 6 feet, and 1.23 between 6 and 9 feet.

When observed at dusk the moths were flitting almost exclusively about the upper half of the trees.

On an acre basis, with 827 trees 6 feet tall or under, each containing 109 larvae, and 237 trees over 6 feet each containing 206 larvae, there were a total of 139,400 larvae per acre in this stand in the Fall of 1946. This figure is obtained by adding the numbers of live and winter killed larvae counted in the Spring.

In making the preliminary investigation before censusing, quite a large number of larvae killed by winter were observed. Therefore, in making the census these winter killed larvae were counted too. In Table II it can be seen that there was quite a marked difference in the percentage of winter mortality at the various levels of the trees. The very heavy mortality near the tree tops may be due to either one or both of two factors.

First, the buds higher in the trees are more exposed to elements, and will quite likely undergo more rapid changes in temperature as weather changes occur. This more rapid fluctuation and probably greater extremes reached in temperature of the buds higher in the tree would seem very likely to cause a heavier winter mortality of the larvae within.

The second factor concerns the higher population of larvae at the higher levels. It would seem that with the greater number of larvae occurring in each bud, the protection from weather for the larvae would be decreased. The figures in Table II however dispute the importance of this factor; as from 3 to 6 feet there was an average of 0.92 larvae per bud with a 25.2% mortality, and above 6 feet an average of 1.23 larvae per bud with 24.9% mortality. The mortality at these two levels was for all practical purposes identical; while there was 0.31 more larvae per average bud at the 6 to 9 foot level.

The standard errors for the winter mortality averages are given in Table II.

Also during the preliminary investigation and during the early part of the census work, quite frequently, infested buds contained some very small insects other than the larvae of the European Pine Shoot Moth. These were suspected of being parasitic upon the shoot moth, but no effect of them was noticed until rather late in the spring feeding period.

Just after pupation began, a large number of infested buds were taken to the laboratory to hasten emergence of the adults. From a portion of these buds 180 larvae and pupae were extracted, and among these were 17 larvae that had apparently been killed by parasites. These dead larvae comprised 9.45% of the total number extracted.

No record was made of where these buds were obtained in the stands; so this percentage was applied to all levels in all compartments as representing an approximate average for parasitism.

Another cause of mortality in the larvae thought to be quite important is bird predation. However, due to the difficulty of obtaining quantitative information of this kind, qualitative observation only was attempted.

Three different areas, each of about one-half acre were observed. Each area was observed from a point giving a good view, for 3 hours on one day only between the hours of 8:30 and 11:30. The total number of birds apparently searching for food seen on the three days were as follows:

Goldfinch	57	Meadow Lark	3
Field Sparrow	31	Brown Thrasher	3
Robin	25	Bob-O-Link	1
Catbird	6	Unidentified Warblers	11
Starling	5	Unidentified Birds	7

Of these only a few of the robins were actually observed feeding on the shoot moth larvae.

Obviously this number of birds will consume a very large amount of food during the spring feeding period of the shoot moth larvae. But what portion of their food consists of the shoot moth larvae is not known.

Height on Tree	0-18"	18"-3'	3'-6'	Total to 6'	6'-9'	Total For Trees Over 6'
Av. No. of Tips per Tree	31.6	28.4	22.4	82.4	24.5	106.9
Av. No. of Live Buds per Tip	1.89	1.59	1.88	1.79	2.64	1.91
Av. No. of Live Buds per Tree	59.6	45.2	42.2	147	64.7	211.7
Av. No. of Buds Infested Previously	10.3	14.5	19.1	43.9	21	64.9
Av. No. of Buds Infested in 1946-7	27.8	38.8	39.2	105.8	59.5	165.3
Standard Error of Av. No. Buds Inf. in 1946-7	1.33	1.86	3.16	-	3.54	-
% of Live Buds Infested in 1946-7	46.7%	85.8 %	92.8 %	71.9 %	92 %	78.2 %
Av. No. of Live Larvae per Bud	0.68	0.88	0.92	-	1.23	-
Standard Error of Av. No. Live Larvae per Bud*	0.011	0.009	0.055	-	0.041	-
Av. No. of Winter Killed Larvae per Bud	0.0841	0.137	0.311	-	0.409	-
St. Error of Av. No. of Winter Killed Larv. per Bud*	0.007	0.017	0.022	-	0.031	-
Av. No. of Live Larvae per Tree	18.9	34.2	36.2	89.3	73.2	162.5
Av. No. of Winter Killed Larvae per Tree	2.34	5.31	12.18	19.83	24.3	44.13
Av. No. of Larvae per Tree Entering Winter Alive	21.24	39.51	48.38	109.13	97.5	206.63
% of Winter Mortality	11 %	13.45 %	25.2 %	18.1 %	24.9 %	21.35 %
% of Parasitism		-	-	9.45%	-	9.45 %
Av. No. of Larvae Parasitized per Tree	1.79	3.23	3.42	8.42	6.92	15.35
Av. No. of Larvae Surviving Winter and Parasitization/Tree	17.11	30.97	32.78	80.88	66.28	147.15
Av. No. of Trees per Acre		1064	827	237		
Av. No. of Larvae per Acre Entering Winter Alive		139,400				
Av. No. of Larvae per Acre Surviving Winter and Parasit.		100,800				

Table II. Status of Infestation in Compartments 30 & 32.

*Standard erros calculated for 2:1 probability and may be plus or minus.

During the course of this study no predatory insects were seen taking the shoot moth larvae, but a large number of Coccinellid beetles were seen on the stems of the trees. Whether they were interested solely in the Aphids occurring there, or were taking other available food could not be determined.

With all of the known losses plus some whose magnitude we do not know, we would expect at least 70 moths to emerge from the average tree in this stand.

There were a small number of larvae of another species of tip moth found during the censusing. These larvae were white with black heads, and were of about the same size as the larvae of the European Pine Shoot Moth. All attempts to rear these larvae to adults for identification failed. The number of this unknown species occurring in the stand at present is so small that it is insignificant.

Compartments 29 and 31

The stand in these two compartments has been damaged more severely by the European Pine Shoot Moth than any other in the Stinchfield area. The stand in general in these two compartments is very short, and apparently will make no further height growth until receiving some relief from the activities of the shoot moth. Trees of the club topped variety predominate in this stand.

Table III shows that the average tree in these compartments contained 119 living buds in the Fall of 1942. Of these about 83 or approximately 70% were destroyed during the fall or spring feeding periods of the shoot moth. A breakdown of these figures given in Table III again demonstrates the decided preference of the pest for the tree tops. Below 18 inches there were an average of 38.3 buds of which 59.8% were infested, and averaging 1.04 larvae per bud. Between 18 inches and 3 feet there were an average of 49 buds of which 65% were infested, and containing 1.13 larvae per bud. Between 3 and 6 feet there were 31.6 buds with 90.7% infested and containing 1.55 larvae per bud. Again 100% of the leading shoots were infested.

The standard errors of these averages figures are given in Table III.

Table III also shows the occurrance of 104.3 live larvae per tree in the Spring of 1947. Of this number 23.8 were below 18 inches, 36 between 18 inches and 3 feet, and 44.5 between 3 and 6 feet.

On a per acre basis, compartment 29, having 910 trees per acre with an average of 119.56 larvae per tree entering winter alive, contained 108,800 larvae in the Fall of 1946. Of these 94.44 per tree or 85,800 survived winter mortality and parasitization.

Compartment 31, having 705 red pines per acre with the same per tree figures, had 84,000 larvae in the Fall, of which 66,500 survived winter and parasitization. An additional undetermined number were present on the while and corsican pines in this compartment.

Winter mortality in these compartments also varied with the height on the trees. Table III lists 7.96% below 18 inches, 12.82% between 18 inches and 3 feet, and 15.09% above 3 feet, with an average of 12.77% for the entire tree.

The standard errors for the winter mortality averages are also given in Table III.

The percentage of parasitism is figured at the same amount in these compartments as in compartments 30 and 32. Predation by birds and other insects is again an unknown quantity.

Compartments 20 and 21

Of the 80 trees in these compartments that were examined, the leaders of 78 were infested with the European Pine Shoot Moth. This is approximately 97% of the leaders. Also about 84% of the buds in the top 6 feet of these 80 trees were infested. The tops of most of these trees are badly deformed, and the leaders of a few of them have been killed completely for the top 2 or 3 feet. The damage to these stands, although perhaps not as severe as the damage to compartments 29 to 32, represents much greater economic loss because the trees were considerably older and larger when damaged.

Compartment 3 of Block II

The leaders of 30 trees out of 80, or 36.3% were infested in this stand. The majority of the trees in this stand are approaching the height of 40 feet, which is 10 feet above the height reported by Friend, 1931 to be the maximum height to which the shoot moth will go. No examination was made in this stand of numbers of buds infested except for the leading shoots.

Height on Tree	0-18"	18"-3'	3'-6'	Tree Total
No. Tips per Tree	32	39	22.3	93.3
No. Live Buds per Tip	1.2	1.26	1.42	1.28
No. Live Buds per Tree	38.3	49	31.6	118.9
No. Buds Inf. Previously	13	18.7	17.3	49
No. Buds. Inf. 1946-47-Av.	22.9	31.8	28.7	83.4
Standard Error of Av.*	1.52	1.97	2.5	-
% of Living Buds Inf. 1946-47	59.8 %	65 %	90.7 %	70.2 %
No. of Live Larvae per Bud-Av.	1.04	1.13	1.55	-
Standard Error of Av.*	0.0109	0.0161	0.041	-
No. Winter Killed Larv./Bud-Av.	0.0875	0.166	0.276	-
Standard Error of Av.*	0.0057	0.0094	0.0194	-
No. Live Larvae per Tree	23.8	36.0	44.5	104.3
No. Winter Killed Larv./Tree	2.06	5.3	7.9	15.26
No. Larv. Entering Winter Alive	25.86	41.3	52.4	119.56
% of Winter Mortality	7.96 %	12.82 %	15.09 %	12.77 %
% of Parasitism	-	-	-	9.45 %
No. Larv. Parasitized per Tree	2.25	3.41	4.2	9.86
No. Larv. Surv. Winter & Paras.	21.55	32.59	40.3	94.44

Table III. Infestation per tree in compartments 29 and 31. Averaged from 60 sample trees.
*Plus or minus with 2:1 probability.

Compartment	29	31
No. of Trees per Acre	910	705
No. Larvae Per Acre Entering Winter Alive	108,800	84,200
No. Larvae Per Acre Surviving Winter and Parasit.	85,800	66,500

Table IV. Infestation per acre considering red pine only in compartments 29 and 31.

INSECT DEVELOPMENT IN FIELD

Beginning on April 3 a few larvae were extracted from buds at frequent intervals for preserving to allow size comparison for the growing season. These larvae were measured for breadth across dorsal surface of head, total length, and diameter at largest point of abdomen. Ten larvae were measured for each date, and these ten measurements averaged to give the average larval size for that date.

Date	Breadth of Head			Length			Body Diameter		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
Apr. 3	0.7	0.5	0.54	6.7	4.1	5.32	1.2	1.0	1.05
Apr.17	0.6	0.5	0.53	6.6	4.8	5.77	1.2	1.0	1.1
Apr.23	0.7	0.6	0.67	6.8	5.9	6.55	1.3	1.0	1.15
May 3	1.0	0.7	0.8	7.7	6.5	7.08	1.5	1.1	1.43
May 10	1.0	0.8	0.94	8.5	6.7	7.76	1.8	1.5	1.68
May 21	1.4	1.1	1.2	13.9	11.4	12.7	3.0	2.4	2.58
May 30	1.3	1.2	1.27	13.4	12.1	12.6	3.8	2.2	2.53
June 7	1.3	1.2	1.24	13.5	11.7	12.6	2.8	2.2	2.52

Table V. Average size of larvae at different periods prior to and during the Spring feeding period in millimeters.

The first activity of the larvae observed in the field was on May 3. However, the above table shows that some growth and moulting occurred between the 17th and 23rd of April. The 20th of April will then be considered as the end of the period of hibernation. The weather during the last 10 days of April was very cool and damp, and this would explain the slowness of the larvae in creating enough disturbance to be noticed, even though they were feeding some within the buds in which they wintered.

The body of the larvae grows gradually as the feeding period progresses, but the head and prothoracic shield being covered by a hard chitinous shell can expand only at the time of moulting. The head measurements then should give the number of larval instars completed during the Spring if grouped by sizes and irrespective of the time of collection. Since all of the larvae do not moult at the same time, and because individuals will vary in size for a given moult, it is not possible to draw a line between instars with absolute certainty. However when the head measurements were plotted by sizes on cross section paper, they fell into four rather well defined size classes of more or less equal proportions.

Head diameters of larvae collected August 1, 1947, were all five to six tenths millimeter. This corresponds to the head size of the larvae collected during hibernation and early Spring feeding. This indicates that there are only five larval instars unless there is a moult within the first few days after hatching.

Size Class	Number in Class
0.5-0.6 mm.	16
0.7-0.8 mm.	21
0.9-1.1 mm.	19
1.2-1.4 mm.	24

Table VI. Size Classes of Larval Head Breadth.

Table VI indicates that there are four instars during the spring feeding period. The finding of cast skins under the great majority of extracted pupae indicates a fourth spring moult just before pupating.

When the feeding period is completed, most of the larvae work their way to the base of the bud where the stem is no longer succulent for pupation. When more than one larva occurs within a single bud they may pupate side by side at the base of the bud or one or more may pupate nearer the apex of the bud.

The first pupae were found in the field on June 6, and three days later a ratio of seven pupae to two larvae was observed in extracting the insects from sixty buds. Since field observations were being made only twice weekly, it is likely that the earliest pupation occurred nearer the first of June and was not discovered for several days. On June 16 no live larvae were found in the buds. The period of time over which pupation began was slightly over two weeks in duration, which was a much shorter time than was anticipated.

Moths reared from larvae taken into the laboratory earlier in the season had remained in the pupal stage from sixteen to twenty seven days. Therefore starting about two weeks after the first pupae were observed, checks were made in the field every other day to catch the first moth emergence promptly. The first moths were seen on June 25, only six being found on inspecting thirty trees. Two days later an average of seven moths per tree were counted on inspecting fifty trees. The peak in moth population came on July 3 and tapered off rapidly until July 15 when none could be found anywhere in the stands.

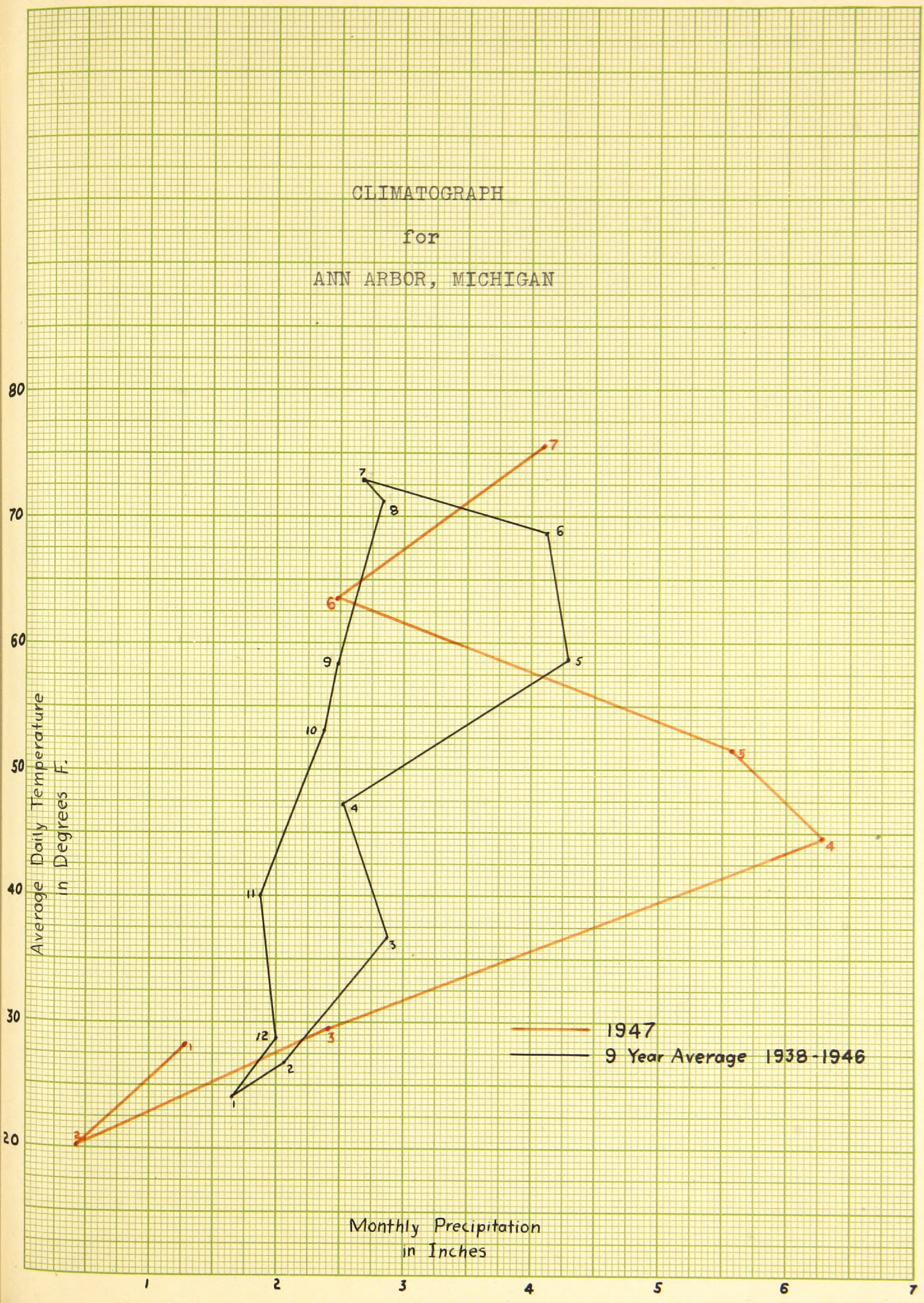
The period of emergence was seventeen to twenty days in duration; which is quite a contrast to the six week emergence period reported by Friend and West in Connecticut in 1934. It is possible that this short emergence period was due to the unusual weather conditions existing in the Spring of 1947.

	Average Daily Temperature in Degrees F.		Average Monthly Precipitation in inches	
	9 Yr. Av. 1938-1946	1947	9 Yr. Av. 1938-1946	1947
Jan.	24.0	28.4	1.65	1.28
Feb.	26.7	20.4	2.06	0.41
Mar.	36.6	29.6	2.87	2.43
Apr.	47.3	44.6	2.52	6.27
May	58.6	52.8	4.28	5.56
Jun.	68.6	64.0	4.11	2.49
Jul.	72.7	75.6	2.67	4.10
Aug.	71.0		2.81	
Sep.	58.2		2.47	
Oct.	53.2		2.36	
Nov.	40.2		1.86	
Dec.	28.8		2.00	

Table VII. Comparison of average daily temperature for 9 year av. 1938-1946 with 1947.

Table VIII. Comparison of average monthly precipitation for 9 yr. av. 1938-1946 with 1947.

Tables VII and VIII, prepared from the Ann Arbor weather station records, show for April, 1947 an average daily temperature 2.7 degrees cooler than the nine year average. For May, the temperature was 5.8 degrees cooler


CLIMATOGRAPH
for
ANN ARBOR, MICHIGAN
80
70
60
50
40
30
20
Average Daily Temperature
in Degrees F.
Monthly Precipitation
in Inches
1
2
3
4
5
6
7
1947
9 Year Average 1938-1946

and there was 1.28 inches more precipitation than for the nine year average.

What the tables do not bring out directly is that on a large percentage of the days in April, and more than five days out of six in May there was rainfall, and a general cloudy condition existed throughout the two months.

With such a large amount of rainfall and small amount of sunshine, the warmest temperature during the day is not usually much greater than the average temperature for the day. With this condition existing, quite obviously the beginning of activity for all dormant or hibernating organisms would be delayed longer than if the daily range in temperatures were greater, even though the average were the same.

The value given as the daily average temperature is computed by averaging the maximum and minimum temperatures recorded for each day, and therefore does not necessarily represent the true average temperature for a twenty four hour period.

The conditions required for the development of the shoot moth is not precisely known, however it seems reasonable that the minimum temperature for each successive stage might be somewhat greater. If this were true the farther advanced stages would be held up in development while the less mature individuals were still growing, and thereby closing the spread of time during which emergence later in the season would occur.

The possibility of unfavorable weather holding up an individuals development seems more likely to occur in delaying pupation than in delaying moulting between larval instars. However the possibility of either one should not be overlooked.

After the emergence of the moths began, it was siz days before any eggs were observed in the field. However, they are so difficult to locate when occurring in small numbers that it is quite likely that the first ones were overlooked. As discussed later in this section of the report, the females contain mature eggs within three days after emerging. This dates the first oviposition on or near June 27.

The last moths were seen on July 13; so the date of the last oviposition is considered as the 14th. The elapsed time between the first oviposition and the first larvae observed in the field was eighteen or nineteen days. The time required for incubation of the eggs may vary one or two days either way from these figures, but seems more likely to vary toward a greater length of time than toward the lesser. This is true because the newly hatched larvae are much easier to see than the eggs, and therefore were probably discovered more promptly. This dates the last hatching on or near August 2.

Newly hatched larvae were first observed on July 15. From all of this information on development Table IX was formed.

Life Stage	Beginning	End
Larval Hibernation	(Fall)	Apr. 20
Larval Spring Feeding	Apr. 20	June 15
Pupal	June 1	July 1
Adult	June 24	July 14
Egg	June 27	Aug. 2
Larval Summer and Fall Feeding Period.	July 15	(Fall)

Table IX. Periods for each life cycle stage of *Rhyacionia buoliana* for 1946-47 seasons.

To assist in determining the correct date for spraying, a large number of larvae in their tips were taken into the laboratory to hasten pupation and emergence. When these began emerging, each days hatch was caged and labeled, this was done at the same time each day, and this made each days hatch probably contain moths ranging in age from zero to twenty four hours. Females from these hatches were then removed and dissected at the appropriate times to have them in age groups of twenty four hours.

The dissection was done under a 30x binocular dissecting microscope with teasing needles. The abdomen was opened as carefully as possible to bare the ovary which consisted of a large number of follicles. These follicles were teased out one by one and the eggs in each counted and observed for maturity. Inevitably in this process a few eggs were ruptured before being counted, especially in those females having large numbers of eggs. No attempt was made to estimate the number of eggs ruptured, for they constituted such a small percentage of the total as to be insignificant.

The first day a few females in the zero to twenty four hour age class were dissected, and one of them contained eggs apparently ready for oviposition. All of the females contained eggs in a large variety of sizes, ranging from a mere clear swelling of the follicle to a yellowish mature or near mature egg. Twenty females in this first age class were dissected over a period of four days, and only one of them was ready for oviposition. Contrasted to this, twenty females in the forty eight to seventy two hour age class were dissected over a period of 4 days and every one of them contained mature eggs. This was accepted as sufficient evidence that all females are ready to start oviposition sometime before they are seventy two hours of age. Because of this, no older age classes were dissected. A total of sixty females were dissected.

Age Class	I	II	III
Age Range in Hours	0-24	24-48	48-72
No. Dissected	20	20	20
No. Containing Mature Eggs	1	14	20
% Containing Mature Eggs	5 %	70 %	100 %

Table X. Preoviposition Period of The European Pine Shoot Moth.

The total number of eggs present in each female dissected was recorded, and the results of these counts are given in Table XI.

Number of Females Dissected	60
Min. No. Eggs per Female	9
Max. No. Eggs per Female	226
Total No. Eggs	5702
Av. No. Eggs Per Female *	95

Table XI. Fecundity of the European Pine Shoot Moth.

*The standard error of this average is plus or minus 5.43 with 2:1 probability.

The figures in Table XI on the reproductive power of the females do not vary markedly except in average number per female from the figures given by Fiend, Plumb, and Hikock in 1938. They found the minimum number per female to be 11, the maximum number 203, and the average to be about 75. These workers also reported a heavy adult mortality before the females lay all her eggs. And they state that the presence of fifty to eighty living larvae per tree in the Fall or the Spring emergence of twenty five adults is sufficient population to cause significant damage to a stand.

A large number of the eggs are deposited on the needles, and on hatching the young larva seems to eat a small amount at the spot, as generally a slight flow of pitch from the needle occurs where a young larva is situated. However in one or two days the larva moves off to the nearest bud, and immediately tunnels into it. If the bud is a large one, the larva feeds in it for the rest of the Summer and Fall and hibernates in it over Winter. But if the first bud selected is small, the supply of food is soon depleted, and he is forced to search for another bud in which to eat and hibernate.

Numerous examples of this were observed during the censusing. A small bud would be completely hollowed out, but contain no larva; while often on the same tip a larger bud contained two or more larvae.

As previously brought out in this report, winter mortality accounted for the death of quite a high percentage of the hibernating shoot moth larvae at Stinchfield during the winter of 1946-47. This was not a particularly severe winter for this region.

It was reported by Graham, 1939 that winter temperature as low as -18 degrees F. causes practically 100% winter mortality of the shoot moth larvae.

THE PARASITES

All early attempts to rear out the parasites found in some of the infested buds were failures. However, a limited number of them emerged from one of the infested tips kept in a petri dish late in the pupal season.

This parasite was one of the Chalsis-flies of the family Eurytomidae, but the species was undetermined.

Friend and Hikock, 1936, reported that the native parasites Calliephialtes comstocki, and Hyssopus thymus were active on the European Pine Shoot Moth in Connecticut. Mather and Olds, 1940, reported parasitization of R. buoliana in British Columbia by Calliephialtes comstockii, Ephialtes obesus, Eph. conquisitor, and Eph. evetriae.

The bureau of Entomology and Plant Quarantine has imported a number of European parasites of R. buoliana from Austria 1931-1935, England 1936, and Holland 1937. Twelve Hymenopterous and two dipterous parasites were introduced, of which three are known to have become established. These are Tetrastichus turionum, Cremastus interruptor, and Orgilus obscurator. (Dowden and Berry, 1938).

THE FOGGING OPERATION

As previously stated the insecticides were applied with a fog generator rather than a conventional sprayer.

To determine when to apply the fog, it was necessary to make counts of the adult moths after they began emerging. Further counts were necessary after the fogging to determine the effectiveness of the operation.

The censusing of moths was confined to compartments 30 and 32, which were identical in this study except for the insecticide applied. Sample plots 20 feet square were established at one-half chain intervals from the fire lanes in each compartment. Prior to the fogging no significant difference in moth numbers was found in the various sample plots, and they were all grouped together to calculate an average number of moths per tree for the entire stand. After the fogging each sample plot was considered separately.

On June 27 an average of seven moths per tree were counted on fifty trees. This population had built up so rapidly that arrangements were made to fog at the earliest possible date.

The fogging was done on June 30 under almost perfect conditions for the machine used. The machine was a "Beskill Fog Generator" supplied by the Michigan Orchard Supply Company.

This machine is a trailer type unit containing a water tank, an insecticide tank with agitator, a small gasoline engine for operating pumps and generating the heat necessary for the boiler, and the necessary pipe connections. The fog is expelled by the force of expansion created when the fluid is changed into steam, and consists of an equal mixture of water and the spray material. The insecticide solution or suspension is disseminated at the rate of thirty eight gallons per hour; therefore, the speed at which the unit is pulled must be varied to regulate the application of insecticide.

For this operation the boiler was operated at 300° C. The particle size produced by this temperature was not determined, but is probably less than ten microns, as at 700°C particles are approximately two microns in diameter, (Reported by Mr. R. L. Button who operated the unit).

For particles this small a rather still condition of the atmosphere is necessary. A light wind or the updrafts common during the hot part of the day would very likely prevent the particles from settling on the foliage of the trees. Therefore, the spraying was delayed until the temperature began to fall in the evening. Conditions existing at the time of fogging were as follows:

Time Fogging Began	8:10 p.m.
Highest Temp. For Day	84°F
Temp. at 8:10 p.m.	77°F
Wind	South -0-1 MPH
Time Fogging Completed	9:20 p.m.
Temp. at 9:20 p.m.	71°F

As the temperature was decreasing during the fogging operation, any vertical circulation of air was downward.

The two areas previously described as Spray areas I and II received different treatment.

Spray Area I

This area containing approximately six acres was fogged with a commercial spray known as "Gamtox" manufactured by the California Spray Chemical Corporation. This material contains 6% gamma isomer of benzene hexachloride, and 44% other isomers of the same chemical. It is used as a wettable spray dispersed in water. Hereafter this material is referred to as HCCH (Hexachlorocyclohexane). An additional three acres not a part of this study was fogged with HCCH also.

The dosage desired was one pound of the active ingredient per acre, meaning that eighteen pounds of the powder contains only 50% active ingredients.

This powder mixed with ten gallons of water made approximately twelve gallons of spray material. The distance to drive in disseminating the spray was twenty six chains. The time required for the machine to disseminate the material was twelve-thirty eighths of an hour or about nineteen minutes. To cover twenty six chains in nineteen minutes required a speed of fifty eight and one-half minutes per mile; or for all practical purposes, one MPH. The caterpillar used to pull the unit had no speedometer, but the speed was estimated very closely by the driver, and the fog generator ran out of material only a few feet short of the finish line.

Spray Area II

This area containing approximately sixteen acres was sprayed with DDT at the rate of one pound per acre. To prepare this spray material, sixteen pounds of DDT were first dissolved in two gallons of Triad, making a volume of three and three-fourths gallons of solution. This was mixed with twelve and one-fourth gallons of No. 10 Base Oil to make a total of sixteen gallons of spray material containing sixteen pounds of DDT.

There were eighty one chains of distance over which to drive to disseminate this sixteen gallons of spray. The time required was sixteen-thirty eighths of an hour or about twenty five minutes. For all practical purposes this meant a speed of one mile in twenty five minutes or 2.4 MPH. Once again the estimation of speed of the caterpillar was very good, and less than one-half gallon of material remained in the tank when the finish line was crossed.

With both of the insecticides a dense white fog was produced which clung to the ground and seeped into the low places, but which did not ascend slopes to any appreciable degree. In Spray Area I the trees for the first few feet away from the spray lanes were coated with a silvery glaze, and throughout this area for several days the very musty odor of the impurities in the HCCH could be detected.

No burning of the foliage could be detected anywhere in the area fogged with DDT in oil. Perhaps the small size of the particles produced by the fog generator minimized the burning effect of the oil.

SPRAY EFFECTIVENESS

After the moths began emerging, their numbers built up at a very rapid rate. The first moths were found on June 25.

Date	No. of Trees Inspected	Total No. of Moths	Av. No. Moths per Tree
June 25	30	6	0.5
June 27	50	349	7
June 29	50	1464	29
July 1 *	9	471	52

TABLE XII. Speed of Moth Population Increase

*This group of tree inspected the day following the fogging in an area not reached by the insecticide.

On the evening of the fogging, there was a very dense swarm of the moths flitting about every tree. The same trees, several minutes after the fog was applied, had no moths whatsoever flying around them. This was true in both the DDT and HCCH areas.

Table XII indicates that there was somewhere in the neighborhood of fifty moths per tree throughout the two compartments censused at the time of the fogging. Following the fogging, censusing was done in the sample plots at frequent intervals until no moths were found in the trees.

Distance From Spray Lane	½ch.	1ch.	1½	2	2½	3	Unsprayed Area
Av. No. Moths Per Tree							
July 1	0	0	0.1	0	0.2	4.0	52
July 3	0	0	1.4	0.6	4.5	7.3	58
July 7	0	0	0	3.5	4.4	6.8	49
July 9	0	0	2.7	2.9	0.9	3.4	27
July 11	0	0.4	4.1	2.3	1.2	3.3	9
July 13	0	0.7	0	0.6	0.7	0	1.4
July 15	0	0	0	0	0	0	0

Table XIII. HCCH Fog Effectiveness.

It is quite noteworthy that there was a portion of spray area II untouched by the DDT fog which had a very high moth population after the fogging, and that these moths did not disseminate into the surrounding unpopulated portions of the stand to any great extent. This may be partially due to some residual effect of the DDT, but is attributed largely to the habit of the moth of remaining throughout its life in one rather small circumscribed area. Friend, 1931, reported that the natural spread of the shoot moth is not great unless aided by winds, and that the moths tend to reinfest the same trees year after year.

Spray Area I is just slightly over six chains wide at the widest point, and it was sprayed from both sides. In this compartment the fog could be seen drifting over every portion of the area, and Table XIII indicates that the kill of moths was almost 100% for the entire stand, and that the subsequent population remained at a very low level.

The populations observed on the control plot leads one to believe that this low population following the fogging was due to the large percentage of the moths that had emerged prior to the fogging.

Distance From Spray Lane	½ch.	1ch.	1½	2	2½	3	3½*	Control
Av. No. Moths Per Tree								
July 1	0	0	1.4	2.3	1.8	2.9	17.3	52
July 3	0	0	0	0.3	0	5.9	22.2	58
July 7	0	0	0.8	0.7	1.6	5.1	22.0	49
July 9	0	0	1.3	0.7	1.1	2.9	7.1	27
July 11	0	0	0.7	0.6	0.3	2.8	3.2	9
July 13	0	0	0	0.4	0	0	1.1	1.4
July 15	0	0	0	0	0	0	0	0

Table XIV. DDT Fog Effectiveness and Subsequent Moth Population

*This plot was in such a location that the fog drifted to it very poorly.

Compartment 30 in Spray Area II is about seven and one-half chains wide at the widest point, and it also was fogged from both sides. The fog drifted over all portions of this compartment except one area on the peak of a hill and the north face of the slope away from it. The control sample plot was in this area, and the sample plot at three and one-half chains distance from the spray lane was at the lower end of this area where the fog drifted to it very poorly.

The figures from Table XIV for the three and one-half chain distance and the control plot show a very sharp drop in the moth population after July 7. The time elapsed between the sharp upsurge in the population after June 27 and this date, which is nine or ten days, very likely represents the average life span of the adult moth in the field.

The necessity for a second fogging operation ten days or two weeks following the first was anticipated, but as Tables XIII and XIV reveal, the moth population went down instead of back up. This made fogging unnecessary.

Just prior to the fogging, groups of papers were clipped to the foliage of the trees in the sample plots. These papers were collected the morning following fogging and later analyzed chemically for the amount of DDT deposited on them. The results of these analyses appear in Table XV.

Distance in Chains From Spray Lane	0-¼	½	1	2	3	3½
Total Top Surface Area of Papers -Sq.Ft.	3.25	3.25	3.25	3.25	3.25	3.25
Total DDT on Papers Milligrams	9.08	3.31	1.27	0.58	1.1	0.71
Milligrams of DDT per Sq. Ft. of Surface	2.8	1.02	0.39	0.18	0.34	0.22

Table XV. Deposit of DDT from Fog.

A previous fogging with DDT, using two types of fog generators for the control of another pest in these stands, had no effect on the larvae and pupae of the European Pine Shoot Moth.

Experiments carried out by Friend and West, 1934, and Friend and Plumb, 1938, indicate that sprays directed against the egg or early larval stages are most successful. Two percent summer oil is recommended as an ovicide, and lead arsenate as a larvicide. Good results were obtained in the 1938 experiments with a mixture of four pounds of ground derris root or cube' root with one pound of powdered skim milk in one hundred gallons of water. Numerous other sprays used with varying degrees of success in the 1938 experiments are discussed in the Journal of Economic Entomology 31: 176-183, 1938.

SUMMARY

1. The infestation of leading shoots in compartments 20, 21, 29, 30, 31, and 32 is between 95% and 100%; while the infestation of leading shoots in compartment 3, Block II is about 35%.

2. The shoot moth has a decided preference for the upper portion of the tree. This is a result of the oviposition habits of the adult, and not because of larval migration.

3. Some factor, probably weather, caused a severe constriction of the emergence period of the moths in 1947.

4. DDT fog has no effect on the larvae and pupae of the shoot moth as they are well protected by the buds or shoots which they occupy.

5. Both the DDT and HCCH gave excellent results in killing the moths; however, the moth population had built up to such an extent before the fogging that a fairly large number of eggs had already been deposited. The average female moth has a reproductive potential of ninety five eggs.

6. Winter mortality and parasites are both taking a rather heavy toll of the shoot moth in the Stinchfield area. Winter mortality accounted for the death of about 18%

of all the larvae in the four compartments studied intensively; although the lowest temperature recorded at the weather station was only -1.5 degrees F. The percentage of winter mortality is greater in the upper portion of the tree. Parasites killed approximately 10% of the larvae surviving Winter.

7. In the fogging operation, about three chains was the maximum distance good results were obtained, but the effective distance would undoubtedly be considerably greater if the terrain were such that the fog drifted downhill to all areas.

CONCLUSIONS

1. The European Pine Shoot Moth can be controlled in the adult stage by applying an insecticide such as DDT or HCCH, if atmospheric and other conditions permit the application at the proper time. Two or possibly three applications would be necessary if the emergence period were extended to four or six weeks.

2. A fog generator can be used quite successfully in control operations where it is possible to take the machine through at rather close intervals, and where it is not necessary for the fog to reach areas much above the point of origin.

3. This latitude is very near the possible northern limit of the insects range.

4. Although some birds do feed on the shoot moth larvae, the factor of bird predation alone can hardly be expected to ever control outbreaks of this insect, for the larva spends practically all of its life sheltered within a bud.

5. Compartment 3 in Block II, because of the height of the trees, should not sustain further damage from the shoot moth.

6. The trees in the six compartments of red pine in Block I have been distorted so severely already by the pest

that they will never produce good saw logs, even if released completely from further damage.

7. While the shoot moth population in 1948 will be rather low because of the control measures carried out in 1947, the population in 1949-50 might easily equal or exceed that of 1946-7.

8. It is quite possible that the parasite population, which is already significant in numbers, might increase to the point where it would check the shoot moth outbreak before it builds up again. It is not known what effects the fogging had on the parasites, but it may well have seriously decimated their numbers in the compartments fogged.

9. Although the European Pine Shoot Moth can be controlled by insecticidal sprays or fogs, it is economically unsound to rely on such measures for use over large forest areas. It will, however, be necessary to use direct control measures if young stands already infested are to escape ruination until they reach an immune height.

We should take advantage of the characteristic of this pest of having a slow rate of natural spread, and prevent infestation of new areas by careful inspection of planting stock.

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