THE BIOLOGY AND CONTROL OF NANTUCKET PINE TIP MOTH, RHYACIONIA FRUSTRANA (COMSTOCK) IN KANSAS.

by

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TABLE OF CONTENTS

INTRODUCTION

Importance

The Nantucket pine tip moth, Rhyacionia frustrana (Comst.), has damaged pine trees in eastern United States since before the turn of the century. Reports of R. frustrana (Comst.) infestations have been received from Quebec to the Gulf of Mexico and west to the Rockies (Underhill, 1943).

In areas of the United States where tip moth is endemic, it attacks two- and three-needled pines (Pirone, Dodge and Rickett, 1960). Injury to a tree usually is killing and subsequent distorting of leaders, which results in the tree's loss for ornamental or timber purposes (Donley, 1960) and loss in height (Foil, Hansbrough and Merrifield, 1962) and (Warren, 1964).

The first official report of R. frustrana's presence in Kansas was made in the Cooperative Survey Insect Report, Oct. 21, 1960. It was reported in Sedgwick and southeastern counties. Personal correspondence of Dell E. Gates, Extension Specialist in Entomology, Kansas State University, indicated the presence of tip moth as early as 1949-50 in Decatur County.

The tip moth has become a problem recently as the number of pine tree plantations increased. Economic losses from tip moth damage have caused some growers to consider discontinuing the planting of pine trees.

The accepted common name for R. frustrana (Comst.) is Nantucket pine tip moth (Committee on Common Names of Insects, 1965). In this thesis it will be referred to as "tip moth."

Literature Review

R. frustrana (Comst.) overwinters in the pupal stage, but Comstock

(1879) found one full-grown larva in early February, which would indicate possible larval hibernation.

In the southern part of the United States adults may appear as early as January, but further north they will not appear until two or three months later (Yates, 1960). Oviposition takes place in the evening about two days following emergence (Mortimer, 1941). Scudder was of the opinion that eggs are laid between the scales of the bursting bud (Packard, 1890). Underhill (1943) found that caged tip moths laid eggs on the bud, on the needles, and on the stem; but the majority were laid in the axils of the leaves. Upon emergence, the larvae burrow into the bud and from there down the shoot for a distance of 1 to 1½ inches. When fully grown, the larva pupates somewhere within the burrow (Packard, 1890).

The number of generations per year varies from 2 in Pennsylvania (Mortimer, 1941) to as many as 5 or 6 in the extreme South (Yates, 1960).

The moth was first observed on Nantucket Island in 1876 and described by Mr. S. H. Scudder (Packard, 1890) and given the name Retinia frustrana Scudder, but this report was not published. In the Report of the Commissioner of Agriculture in 1879, Mr. J. H. Comstock reported an infestation near Washington, D. C. and used Scudder's description. As a result Comstock has been given credit for describing the species. In 1903, Fernald reclassified it as Evetria frustrana (Dyar, 1903). Heinrich revised the classification of the subfamily Eucosminae of the family Olethreutidae in 1923 and placed the moth in the genus Rhyacionia where it remains to the present (Heinrich, 1923).

There are ten species in this genus known to exist in the United States. Generally their habit is to burrow into buds and young stems of various pines (Yates, 1960).

Scudder thought the only means of control for the tip moth was clipping every infested tip from every tree, thus depriving the larvae of their food source. He also recommended building bonfires at dusk to attract egg-laden moths (Packard, 1890).

Treat (1891) also thought that clipping tips was a means of control; furthermore, he found that tip moths would not lay eggs on twigs dusted with pyrethrum powder following a rain.

Mortimer (1941) performed an experiment using lime-sulfur, Bordeaux mixture, fish oil emulsion, Pestroy (active ingredients unknown), summer oil emulsion, kerosene emulsion, arsenate of lead and nicotine sulfate. He found fish oil emulsion gave the most satisfactory control (88.7 percent) of the insect.

In an experiment using 50% DDT wettable powder at 0.48% and .118% conc., summer oil and nicotine sulfate, .48% DDT proved the most effective. Emergence of moths was used to time sprays (Fenton and Afanasiev, 1946).

An experiment in Delaware was done on red pines using nicotine sulfate and Grasselli Spreader Sticker, summer oil and lead arsenate, benzene hexachloride, parathion, and DDT. These insecticides were applied in June and July to control the European pine shoot moth, R. buoliana (Schiff.). When the effectiveness of the sprays was investigated, records were also kept of tip moth larvae present, and these showed that DDT and parathion sprays substantially reduced the number (Stearn, 1953).

Neel (1957) found that one 0.5% DDT spray applied at peak emergence was just as effective for controlling the first generation as two applications. However, the second generation seemed to be controlled better with two applications.

In another test Neel (1959) used a mist blower from the ground and a conventional airplane to apply DDT, Malathion and Guthion. These were applied at 2.0, 1.5, and 0.5 lbs. actual in 3 gallons of water per acre. The insecticides were applied when 75-90% of the adults had emerged. There was no significant difference between treatments from the April and June applications. July insecticide applications gave significantly better control. Differences in results may be attributed to two factors: (1) April and June applications were followed by heavy rains and (2) the July application was made a little later after peak emergence.

A recent experiment was conducted in Louisiana studying the effectiveness of systemic insecticides for controlling tip moth infestations. Results indicated that an insect infestation could be effectively controlled on 1- and 2-year loblolly pine using 10% phorate granules. 10.5 g/plant gave effective seasonal control but 42 and 84 g/plant gave additional control into the second season. Bidrin[R] was applied as a foliar spray at the rate of 0.25 lb./100 gal. and this gave appreciable control for one generation of the insect (Barras, Clower and Merrifield, 1967).

The first parasites on R. frustrana (Comst.) were found by Scudder in 1876 (Packard, 1890). He found a species of Bracon proper and a minute Perilampus, both apparently undescribed and in insufficient numbers to control the tip moth effectively.

Possibly the best example of effective parasitism was reported from the Nebraska National Forest where pines, especially yellow pine (species not given), were so severely injured by the tip moth that it seemed advisable to discontinue planting that species. Parasites from Virginia were released in Nebraska during June and July of 1925. Only one of the species, Campoplex frustranae, was recovered, but it was so effective that in the neighborhood of its original release as high as 80% of the tip moth larvae were parasitized, and planting of the yellow pine was continued. Four years after the parasites were introduced, infestation of terminal shoots was reduced from 90% to 15% (Wadley, 1932).

Underhill (1943) working in Virginia stated that for the years 1930-33 inclusive, parasitism of the first brood averaged 32.4%, 27.2%, 28.2%, and 31.0% respectively. Several families of Chalcidoidea were reared, and some Dipterous parasites were also noted. Peak emergence for parasites came a week to twelve days after that of the moths.

The purpose of this study was to

- determine the number of generations per year and approximate time of moths' flight in Kansas
- determine the most appropriate time to apply insecticides during the insects' developmental period and evaluate insecticides as potential control agents
- determine the species of parasites and predators present
- determine length of egg, larval, pupal and adult stages and related biological information

MATERIALS AND METHODS

Study Area

Wheeler's Pine Tree Farm, six miles west of Manhattan, was the site where most research was done. All insecticide applications and light trap collections were made there. Most infected tips were collected at Wheeler's, but some were collected from the Kansas State University Ashland horticulture farm and from a planting at Zeandale, Kansas.

The planting at Wheeler's consists of 40 acres of Scotch pine, 10 acres of Austrian pine and 1-2 acres of white pine. Research on chemical control was done on 6-year-old Scotch pines which were about 4 feet tall.

Biological Study

Moth Flights Per Year. Starting April 10, a black light trap was run whenever moth emergence was expected to determine moth flights and peak emergence. Light trap data was supplemented by collection of infested tips to observe larval development and increase in number of pupae. These observations and daily field checks for adults aided in predicting a tip moth flight.

Adult. Adults were obtained by rearing field collected larvae or pupae as described in their respective sections. These adults were anesthesized with CO_2 and placed in plastic boxes[1] (measuring 1 1/2" x 1 1/4" x 2 7/8") attached to freshly clipped pine tips. The cut end of the pine tip was placed in a glass jar containing distilled water. The apparatus was placed in a growth chamber having an 8 hr. - 16 hr. dark-light cycle, 80° F: temperature and 65-75% relative humidity. Daily records were kept on commencement of egg laying and longevity.

Male-female pairs or individual males and females were also placed in the plastic boxes not attached to pine tips. Records of egg laying and longevity were also kept for these.

Egg. Eggs were acquired from females caged on pine tips. Data was gathered on location of egg deposit and emergence of first larvae from eggs laid on pine tips.

Measurements were made with the aid of an ocular micrometer in a Spencer binocular microscope. The ocular had a 15x magnification and the objectives were powered 10x, 15x, 20x, 30x and 40x. Micrometer units were converted to millimeters.

Field checks for eggs proved unsuccessful.

Larva. Field observations were made to study larval habits. Laboratory tests to determine length of larval stage proved unsuccessful.

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[1]Althor Products, 2260 Benson Avenue, Brooklyn, N.Y., No. H-12.

Pupa. Late instar larvae were removed from infested tips collected in the field and placed in jelly cups[1] containing a diet described below. These jelly cups were kept in a rearing room having an 8 hr. - 16 hr. dark-light cycle, temperature of 80° F., and humidity of 70-80%.

Larvae that developed into pupae were used to determine the length of the pupal stage by keeping daily records of emergence. Pupae were also collected from the field to determine which parasites or predators occur on them. This is discussed further in the section on natural control.

Modification of Wheatgerm Diet by Vanderzant

1. Steep 100 grams of freshly cut pine tips in 500 ml. of acetone for 30 minutes at room temperature.
2. Decant acetone and dry needles under a gentle stream of air and then chop in a food blender.
3. Add 10 grams of chopped needles to 500 ml. of distilled water and bring to gentle boil.
4. Material is then filtered and resulting amber colored liquid is added to the following:

a. Wheat germ	3.2 grams
b. Sucrose	3.0 grams
c. Casein, Vit. free	3.8 grams
d. Wessen's salt	1.1 grams
e. Alphacel	1.0 grams
f. B-vit. mixture	1.1 grams
g. Ascorbic Acid	0.4 grams
h. Corn oil	1.0 ml.
i. Distilled water	90 ml.
j. Methyl parahydroxybenzoate (in 95% alcohol)	1.5 ml.
k. Agar	8 grams

Control

Biological. Experiments were set up to determine the parasites and predators attacking larvae and pupae. Infested tips were clipped from trees in the field and brought to the laboratory where larvae and pupae were removed. Several larval parasites were found feeding on tip moth larvae. Since these parasites were in the larval stage, it was necessary to rear them to

[1]Premium Plastics Co., 2440 S. Indiana Ave., Chic., Ill., No. 6916.

adulthood for identification. Rearing was done by autoclaving sand for 20 minutes, permitting it to cool to room temperature and then half filling a jelly cup with it. Distilled water was added to the sand, but only enough to moisten it to provide a humid environment for the organism. Using sterilized sand and distilled water reduced the possibility of fungal growth on the parasite. Only one larva without its host was placed in a jelly cup and then covered. Small holes were pierced into the cover with a dissecting needle to permit exchange of gases.

Tip moth pupae found in infested tips were placed in empty jelly cups, and daily observations were made to see if parasites emerged from them. Jelly cups containing larvae and pupae were placed in the rearing room mentioned earlier.

Reared adults and larvae were sent to the U.S.D.A. Insect Identification and Parasite Introduction Research Branch at Beltsville, Maryland, for identification.

Chemical. Insecticides were applied to coincide with moth emergence as determined by light trap data. Applications were made to units consisting of seven plots. Six plots were treated with insecticides and the seventh was used as a control. The plots set up during the first part of the season contained fifteen trees, but later ones included twenty trees. Insecticides applied were Bidrin, DDT, Diazinon, Guthion, Meta-systox R, and Sevin. They were all applied at 1 lb. actual per 100 gal. except Guthion which was applied at .85 lbs.

Accepting the standard application of 100 gallons of water per acre and assuming that there were 1200 trees per acre in a 6' X 6' planting, the amounts mentioned above were reduced proportionately to the plot size.

A three gallon Oakes compressed-air garden sprayer was used to make all applications.

Applications for the first moth flight were made April 20 to 420 trees. This application consisted of plots containing 15 trees and four replicates. Two of these replicates were sprayed again during the second flight on July 2 for a comparison of the effectiveness of one treatment per year as opposed to two.

Applications for the second flight were made June 21 and 26, July 3 and 12 to a total of 1,050 trees. All treatments consisted of two replicates and twenty trees per plot, except the June 21 spraying which consisted of fifteen trees per plot. Each treatment mentioned was applied to trees previously not sprayed.

Treatments for the third flight were made August 12, 22, and 28 to a total of 1,260 trees. Three replicates were made instead of two as earlier with all plots composed of twenty trees. These applications were also made to trees that had not been sprayed earlier.

A test was conducted on 420 trees to determine the effectiveness of two applications per flight as opposed to one. An application consisting of three replicates and twenty trees per plot was made on August 14. The same plots were sprayed again on August 26 to give additional control.

Data was collected from three trees on fifteen-tree plots and four trees on twenty-tree plots. Trees not immediately adjacent to a neighboring plot were selected for making counts. The number of infested tips per tree were inserted into Abbott's (1925) formula for determining the percent control. The formula reads as follows:

$$\% \text{ control} = \frac{\text{number living on control} - \text{number living on treatment} \times 100}{\text{number living on control}}$$

Data from treatments was converted to the square root of X + 1 and an analysis of variance was made at the Department of Statistics and Computer Science Kansas State University.

Counts were made for all applications of a moth flight when reinfestation was evident. They were made approximately a month following the first application for a given flight.

RESULTS AND DISCUSSION

Life History

Generations Per Year. There were three periods of adult tip moth activity (Plate I) which is based on numbers of adults collected per evening. The first light trap collection was made April 10 when 25 adults were obtained. Were it not for the April 11 collection when only 1 moth was collected due to windy conditions, the numbers of subsequent collections would have plotted a straight line on the graph indicating a decrease in adult population. The April 26 and May 1 collections yielded 4 and 3 respectively. Thus it was concluded that the first flight came to an end the last part of April. The April 10 collection yielding the highest number would seem to indicate that peak emergence occurred on or before this date.

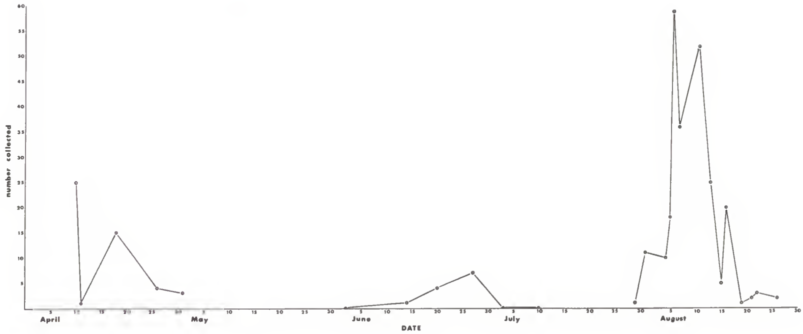
Moths were not seen again until June 14 when the first adult of the second flight was collected. Numbers collected during June were low, probably due to cool, windy conditions during evenings when collections were made. Moths were not collected at the pine tree farm after June 27 even though the trap was run on July 4 and 10. Adults were observed at the Ashland Horticulture Farm several miles away as late as July 5. From this information it is concluded that the second flight was about three weeks long with peak emergence on or about June 27.

The third flight began July 29, peaked August 6, and ended August 26 (Plate I). This was the last date the light trap was put out until mid-

Explanation of Plate I

Periods of moth activity during the summer of 1968.

Plate I



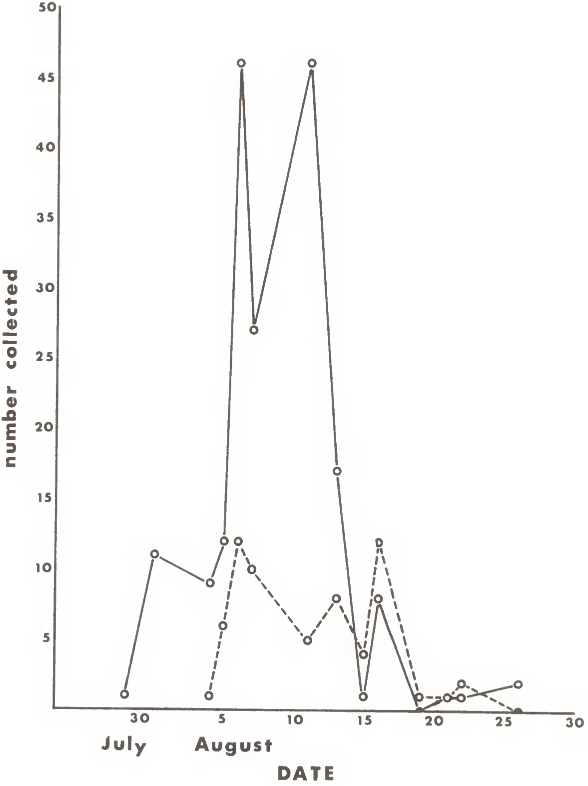
Explanation of Plate II

Number of males and females collected during the third moth flight.

- - - - - females

________ males

Plate II


50
45
40
35
30
25
20
15
10
5
number collected
30
5
10
15
20
25
30
July
August
DATE

Explanation of Plate III

Fig. 1. Exposed larva in infested tip.

Fig. 2. Exposed pupa in infested tip in burrow created by larva.

Fig. 3. Adult tip moth about 67 times natural size.

Plate III

Fig. 1

Fig. 2

Fig. 3

September when no adults were collected. Since numbers were low August 26, it was concluded the flight ended during this time. E. A. Heinrichs (Unpublished research) collected adults during late July and August of 1964 and found the flight to begin July 29 and peak on August 10. No moths were collected after August 18, but it is not known if collections were discontinued at this time or if adult activity ceased.

Using numbers collected in 1968 to plot points produced a graph with a jagged appearance (Plate I). Due to windy conditions the numbers of August 15 and 19 were lower than expected. However, the cause for the low numbers of August 4 and 7 is not known. According to the numbers collected, the third flight was the longest and continued strongly at least four weeks.

The second flight began at least six weeks after the first one, but the third flight began about three or four weeks after the second. This decrease in time was due to the faster development of the immature stages because of warmer temperatures.

Overlap of generations was observed during the third flight. Collections of infested tips contained late instar larvae and pupae from the second generation as well as early instar larvae from the third. This overlap in generations indicates a lengthened period of moth flight.

Ratio of males to females. During the second and third flights, checks were made on the number of males and females collected each night. Numbers from the second flight were too small to draw any conclusions. However, the third flight yielded a total of 244 adults of which 183 were males and 61 were females. Plate II shows that a proportionately larger number of males were collected than females.

Records were also kept of the number of males and females emerging from larvae and pupae collected in the field. Prior to the second flight 25 larvae and 178 pupae were collected from which 66 males and 104 females emerged in the laboratory. For the third flight 60 larvae and 153 pupae were collected from which 65 males and 65 females emerged.

Thus theoretically, the proportion of male and female moths collected in the light trap may not be an accurate sample of the actual sex ratio of a moth population. On the basis of laboratory data the total number of females equals the total number of males or even surpasses them. Underhill (1943) found the second brood to have a slightly higher percent of females.

Emergence of males in relation to females. Mortimer (1941) and Underhill (1943) state that males emerge several days before females, and Mortimer (1941) goes on to say that females compose the largest percentage of population during the termination of the flight. Collections made during the third flight shown on Plate II indicate that the first female was collected six days after the first male. August 15 was the first night that females collected were more numerous than males. Between August 15 and 26, 20 females were collected and 13 males. When discussing ratio of males to females, it was mentioned that light trap collections were a poor indicator of the number of females in a moth population. Thus it seems likely that the number of males was greater than the number of females before August 15 and that the females composed a larger percent of the population after this date than the graph indicates.

Adult

In January of 1968 four pupae and three adults were sent to the U.S.D.A. Insect Identification and Parasite Introduction Research Branch to make certain that the insect in question was *R. frustrana* (Comst.). All specimens sent were identified as belonging to the species mentioned.

Table 1. Number of days required from adult emergence to oviposition.

Stage collected	No. collected	Days	
		Range	Average
Larvae	11	1 - 6	2.45
Pupae	8	1 - 5	3.12
Total	19	1 - 6	2.73

Table 2. Number of eggs laid by caged tip moths in the growth chamber.

Stage collected	No. collected	Days	
		Range	Average
Larvae	18	2 - 54	21.66
Pupae	9	14 - 62	33.11
Total	27	2 - 62	25.48

Table 3. Location of egg on cut pine shoots enclosed in plastic boxes.

Female No.	Number laid		
	Needle	Bud	Plastic box
1	28		
2	22		
3	27		
4	14		
5	11	1	9
6	14	15	3
7	10		3
8	9	13	12
9	22	14	
10	28	14	12
11	9	5	2
12	29	1	1
13	33		9
Total	256	63	51
Percent	69.19%	17.02%	13.78%

Table 4. Longevity of adults caged in plastic boxes with and without pine tips.

	Number	Days	
		Range	Average
Females with pine tips	22	6 - 12	8.66
Males with pine tips	20	1 - 12	6.94
Total	42	1 - 12	7.93
Females without pine tips	5	6 - 11	8.40
Males without pine tips	9	3 - 8	6.44
Total	14	3 - 11	7.14

Table 5. Length of pupal stage.

Sex	Number	Days	
		Range	Average
Females	39	7 - 13	10.07
Males	45	7 - 15	10.22
Totals	84	7 - 15	10.22

Habits. During the daytime moths were found hiding among the fasicles where they were camouflaged because of similar coloration. Jarring the branches on which they were resting caused them to fly up, but they soon came to rest. In the evenings, moths were found flying from tree to tree or sitting on the tips of needles. Attempts to observe mating were unsuccessful.

Oviposition. Eggs were not found in the field, but several needles were found with the chorion of the egg still present. They were found on the inner side of the needle and 1" - 1½" from the base.

Eggs laid by moths caged on pine tips kept in the growth chamber were deposited singly or at times in twos or threes.

Nineteen females were studied to determine the length of time passing between emergence and oviposition. Table 1 shows that 2.73 days passed on the average in the tests conducted. Mortimer (1941) says about two days after emergence oviposition occurs.

The average number of eggs per female was 25.48 as is shown on table 2.

Females definitely showed a preference for needles as a site for egg deposit as is shown by table 3.

Longevity. Caged adults were reared in plastic boxes on pine tips or in plastic boxes without pine tips. Table 4 shows a slight difference in life span for the moths grown under these conditions. Males and females grown on pine tips had an average life span of 7.93 days whereas those reared without pine tips lived an average of 7.14 days. Females were found to live from 1.5-2 days longer than males. Females reared on pine tips lived 8.66 days and males 6.94. Those reared without pine tips, the females lived 8.40 days and males 6.44 days.

Egg

Tip moth eggs have a yellowish color. Measurements of six fertilized and 13 unfertilized eggs were made. On the average fertilized eggs were .7 mm wide and 1.0 mm long. Unfertilized eggs were slightly smaller - .6 mm wide and .9 mm long.

Under laboratory conditions the egg stage was slightly over a week long. Three male-female sets placed on separate pine tips produced fertile eggs. In one set the first larvae emerged 7 days after the first eggs were laid, and in the other two sets the first larvae emerged 8 days after the first eggs were laid.

Larva

Two needles infested with larvae were collected in the field and examined under a microscope. The burrow created by the larva in the needle was opened, and in both cases a head capsule was found in the burrow. This observation indicates that larvae emerging from eggs laid on needles spend at least the first instar in the needle. Upon reaching the needle's base, the larva tunnels out, spins a web around itself, feeds on needle bases for a short while and moves into the bud.

Pine tree damage occurs only during the larval stage. The first sign of larval infestation is indicated by the yellowing of the lower 1" - 1½" of the needles on the tips of branches. This yellowing is due to the burrowing activity of the larvae in the needles. Next occurs the formation of a web spun between the needles and the bud. As the larva burrows into the bud and on into the stem, the entire tip is killed causing all the needles to turn yellow and finally brown.

New growth will branch out profusely from live tissue below the damaged area the following year. If the infested tip was a leader, as frequently is the case, the symmetry of the tree is spoiled because of multiple leaders.

It was hoped to rear larvae from the first instar to pupation on an artificial diet, but early instar larvae did not feed on the diet. A good number of late instar larvae fed and pupated, but even these may not have been properly nourished. Table 2 shows that field-collected larvae placed on a diet and reared to adulthood did not lay as many eggs as field-collected pupae that completed larval development on growing pines. Thus because of an inadequate diet, no knowledge was gained about the length of the larval stage.

Pupa

Length of the pupal stage as determined in the laboratory was 10.12 days. Table 5 shows females spent 10.07 days in the pupal stage and males spent 10.22 days so a slight difference exists between males and females in this test.

The overwintering site was determined by first examining debris under pine trees in February and later by examining damaged tips. Using a golf course hole cutter 4 inches in diameter, holes 1 inch deep were punched into the ground. A total of 76 samples were checked, and none revealed any of the tip moth stages.

Infested pine tips were examined in March and April. Pupae were found in the tips; some were viable but many no longer were. On April 10, additional tips were checked, and empty pupal skins thought to have been left by emerging adults were found lodged in the emergence holes of the bud.

These observations indicated strongly that overwintering in Kansas occurs as pupae in the infested tip.

Fifty pupae were measured and found to have an average width of 1.8 mm and length of 6.2 mm.

Biological Control

All of the natural enemies found were parasites except one unidentified spider. This spider was found preying on an adult tip moth that had emerged from infested tips placed in an ice cream container. All the parasites were found either on larvae or pupae.

During June, 223 pupae and larvae were studied for percent parasitization. In June, 19.25% were found to be parasitized. In August, a similar study was made on 145 pupae and larvae. Only 8.96% were parasitized, showing a marked decline from June.

The parasites with notes are listed below.

Diptera

Tachinidae - Identified by C. W. Sabrosky

Lixophaga plumbea Ald. Two of these were collected, one on July 30, 1968, at the pine tree farm and the other at the Apel planting on August 5, 1968. One was found in the pupal stage and the second in the larval stage in an infested tip near a dead tip moth larva. Cushman (1927a) reported the full grown larva emerged from the host larva and pupated in the burrow.

Lixophaga sp. Two were collected at the Ashland Horticulture Farm. Both specimens were in the larval stage and taken from infested pine tips. Each tip contained tip moth larva in addition to the parasites.

Erynnia tortricis (Coq.) Three were collected during the summer at the pine tree farm. All of them were in pupal cases of tip moths, and in two instances it was observed that the abdominal section of the host was drawn inward. Nothing has been found in the literature about the host range of this species, but from the above evidence, it is assumed to be a pupal parasite of the tip moth.

Hymenoptera

Chalcididae - Identified by B. D. Burks

Haltichella rhyacioniae Gahan This species has been reported to parasitize several members of the genus Rhyacionia. Two of these were collected at the pine tree farm in August in tip moth pupae from which they later emerged. They have been reported earlier to pupate in tip moth pupae (Cushman, 1927a).

Eurytomidae - Identified by B. D. Burks

Eurytoma pini Bugbee A total of 10 specimens were collected during June and August. Six were in the larval stage near a dead tip moth larva. One was in a tip moth pupa from which it later emerged. One was found in the larval stage near an empty tip moth pupal case. Two were found as larvae in an infested tip without any tip moth remains present. This species has been reported earlier as a parasite by Bugbee (1958).

Ichneumonidae - Identified by L. M. Walkley

Exeristes comstockii (Cress.) This species has been reported as a parasite on tip moth and several other insects attacking pine trees (Muesebeck, Krombein, and Townes, 1951). Two specimens were collected - one being in the larval stage and the other in the pupal case of a tip moth.

Itoplectis conquisitor (Say) A wide host range is attacked by this parasite, many of them being moths. Twenty-four males and females were collected during June and all were in the pupal cases of tip moths. Cushman (1927a) reported that it is rare as a parasite of the tip moth because the latter is too small a host. However, out of forty-nine parasite specimens collected this summer, twenty-four were I. conquisitor.

Phaeogennes walshiae australis (Cush.) One female emerged from a tip moth pupa which was removed from a bud with evidence of tip moth infestation. The parasite was collected June 18 at the pine tree farm definitely known to be infested with tip moth. On the basis of this evidence, it is assumed P. walshiae australis (Cush.) in this instance parasitized R. frustrana (Comst.).

This Ichneumonidae has never before been reported to parasitize R. frustrana (Comst.). The only host listed for this species is Laspeyresia caryana (Fitch) (Muesebeck et al., 1951), commonly known as the hickory shuckworm that infests pecan nuts. Cushman (1933) reported that P. walshiae australis (earlier known as Proscus walshiae australis) emerged from pupae of L. caryana that had been isolated as larvae.

Temelucha sp. nr. epagoges (Cush.) One adult emerged from a tip moth pupa collected at the pine tree farm in June.

Table 6. Percent control from applications for all three flights.

Insecticide	Date applied										
	April 20	June 21	June 26	July 3	July 12	April 20 & July 2	August 12	August 22	August 28	August 14 & 26	Average
Bidrin	77.5	100.0	100.0	89.5	100.0	68.7	71.4	00.0	46.2	90.0	74.3
Diazinon	77.5	100.0	100.0	94.7	100.0	100.0	92.8	50.0	69.2	00.0	78.4
DDT	89.8	65.6	76.2	84.2	62.5	93.7	64.3	25.0	76.9	60.0	69.8
Guthion	100.0	100.0	90.5	100.0	100.0	81.3	85.7	100.0	100.0	90.0	94.7
Meta-systox-R	73.5	87.5	52.8	94.7	100.0	93.7	71.4	50.0	100.0	80.0	80.4
Sevin	87.7	90.6	100.0	100.0	100.0	75.0	35.7	00.0	76.9	90.0	75.6

Bidrin - liquid containing 9 lbs./gal. applied at 1 lb./100 gals.
Diazinon - emulsifiable concentrate containing 4 lbs./gal. applied at 1 lb./100 gals.
DDT - emulsifiable concentrate containing 2 lbs./gal. applied at 1 lb./100 gals.
Guthion - 25% wettable powder applied at .85 lbs./100 gals.
Meta-systox-R - emulsifiable concentrate containing 2 lbs./gal. applied at 1 lb./100 gals.
Sevin - 50% wettable powder applied at 1 lb./100 gals.

Chemical Control

First generation. A single application was made April 20, ten days after peak emergence, and observations on results were made June 7, forty-eight days after treatment. All treatments were significantly better than the control, but only Guthion, with 100% reduction in infested tips, gave satisfactory control as is shown in the first column of table 6.

Second generation. Applications were made June 21 six days before, June 26 one day before, July 3 six days after, and July 12 fifteen days after peak emergence. Observations were gathered July 23, thirty-two days after the first treatment. Less time was permitted to elapse between the first treatment and recording of observations than for the first flight because development of larvae was proceeding at a faster rate. As shown in the column dated June 21, Bidrin, Diazinon, and Guthion all gave 100% control when applied six days before peak emergence. Relatively satisfactory control was also given by Meta-systox-R and Sevin which achieved 87.5% and 90.6% reduction in population respectively. DDT proved unsatisfactory by achieving only 65.6% control.

Results from treatments one day before peak emergence shown in the column dated June 26 were similar except Meta-systox-R gave only 52.8% control. Sevin improved to 100% control and Guthion slipped to 90.5%.

Guthion and Sevin gave 100% control when applied six days after peak emergence as is shown in the column dated July 3. Diazinon and Meta-systox-R both gave satisfactory control - 94.7%. Bidrin and DDT gave 89.5% and 84.2% control respectively.

Percent control by DDT became successively better with each application and reached its peak in this one. This is the only insecticide which showed such a trend.

All insecticides, except DDT (62.5% control), gave 100% control when applied fifteen days after peak emergence (July 12). Results from this flight are the best overall results achieved on any of the second flight applications.

The column dated April 20 and July 2 shows the results of one application against each of two generations in contrast to the control obtained by applying insecticides against the second generation only. Diazinon gave 100% control, and DDT and Meta-systox-R also gave good reduction in number of infested tips (93.7%).

Two problems existed which made results of this treatment inaccurate. First, these trees were bigger since they were not sheared in 1968 as were those on plots sprayed during the second flight. Secondly, since these counts were made of infested, not damaged shoots, it was not possible to determine if the total number of damaged shoots was different.

Third generation. Control during the third flight was less effective than during the second flight due to a lengthened period of adult emergence. Applications were made August 12 six days after, August 22 sixteen days after, and August 28 twenty-two days after peak emergence. On September 18 forty-three days after the first treatment, results were collected.

When application was made six days after peak emergence, Diazinon gave satisfactory control, 92.8%, as shown in the column dated August 12. Guthion, with 85.7%, was approaching an acceptable standard, but all others performed poorly.

The column dated August 22 shows that most treatments made sixteen days after peak emergence were ineffective. Guthion gave 100% control, but all other insecticides were below 50%. The number of infested tips on control plots was low which may be a partial explanation for the unsatisfactory results.

Guthion and Meta-systox-R, both with 100% reduction in population, were the only insecticides giving satisfactory control in the treatment applied twenty-two days after peak emergence. However, this application was more effective than the August 12 and August 22 treatments except for Bidrin and Diazinon which performed better on the first application.

The insecticide showing a trend during this flight was Guthion. In the application six days after peak emergence, it gave 85.71% control and when applied sixteen days and twenty-two days after peak emergence, it gave 100% control.

Effectiveness of two applications per flight is shown in the column dated August 14 and 26. Bidrin and Sevin both gave 90% which was better than any of their single applications for this flight. DDT, Guthion and Meta-systox-R gave better control with a single application on August 28 than in this treatment.

Effectiveness of individual insecticides. A statistical analysis of the insecticides for each flight indicates that no one insecticide is significantly better than another. However, they all were significantly better than the control.

Percent control for all applications made during the three flights are shown in the last column of table 6. If calculation is made on a percent basis, Guthion has a much higher percent control than the other insecticides and can be said to be the best one.

Number of insecticide applications. In the discussion of the column dated April 20 and July 2 it was mentioned that all the single applications of the second flight performed better than one application against each of two flights, except DDT which gave better control with two applications. The problems involved in this treatment were also mentioned.

In the discussion of the column dated August 14 and 26 it was mentioned that Bidrin and Sevin performed better with two applications per flight than their single applications while DDT, Guthion, and Meta-systox-R performed better on a single application.

While it may be advantageous to make several applications of Bidrin, DDT, and Sevin per season or per flight, there are other insecticides which prove as effective with a single application. Thus, on the basis of this research, multiple applications do not seem advisable.

Timing of applications. In the discussion of the column dated July 3 it was noted that DDT performed best when applied six days after peak emergence. Guthion performed best when applied sixteen or twenty-two days after peak emergence as was mentioned in the discussion of the column dated August 22. These facts should be kept in mind if these two insecticides are used.

When discussing the column dated July 12, mention was made that during the second flight the application which followed peak emergence by fifteen days was the best. This is also true statistically.

On the basis of percent control, the application made twenty-two days after peak emergence during the third flight is better. However, a statistical analysis of third flight applications does not prove one treatment to be better than another.

The indications then are that treatment should follow peak emergence approximately fifteen days.

SUMMARY

The biology and control of Rhyacionia frustrana (Comst.) are discussed.

During the summer of 1968 three tip moth flights occurred - the first in April, the second in latter June and early July, and the third in August. Flights extended from three to four weeks. From laboratory data, the conclusion was made that females compose as large a percent of the population as

males or even larger, but females emerge later than males, and are more numerous during the terminal portion of the flight. The life span for males and females in the laboratory was almost eight days with females living 1½-2 days longer than males.

Adults hide among fasicles in the daytime and become active at night. Oviposition occurs most frequently on needles two to three days after emergence. Eggs are light yellow in color usually laid individually and hatch after seven or eight days.

Larvae spend the earliest portion of their life mining in pine tree needles and later move into the bud and shoot tip. Feeding in the bud and shoot causes them to die and leads to distortion of the tree.

In the laboratory the pupal stage lasted 10 days. From studies made it was concluded that in Kansas _R. frustrana_ overwinters as a pupa in burrows created by larvae.

Biological control studies in the summer of 1968 revealed 19.25% of the pupae and larvae to be parasitized in June and 8.96% in August. Three species of dipterous parasites were collected: _Lixophaga plumbea_ Ald., _Lixophaga_ sp., and _Erynnia tortricis_ (Coq.). Six hymenopterous species were collected: _Haltichella rhyacionia_ Gahan, _Eurytoma pini_ Bugbee, _Exeristes comstockii_ (Cress.), _Itoplectis conquisitor_ (Say), _Phaeogennes walshiae australis_ (Cush.), and _Temelucha_ sp. nr. _epagoges_ (Cush.). _I. conquisitor_ was collected in greatest number.

Chemical control studies attempted to determine effectiveness of individual insecticides, effectiveness of multiple applications, and appropriate time for application.

The insecticides used were Bidrin, Diazinnon, DDT, Guthion, Metasystox-R, and Sevin. The insecticides all proved better than the control, but no one proved significantly better than another. However, Guthion deserves mention as giving satisfactory control almost consistently.

Some insecticides proved better with multiple applications, but since other insecticides proved effective with single applications, multiple treatments are not recommended on the basis of data gathered in this research.

Evidence seems to indicate that the most appropriate time for application is about fifteen days after peak emergence.

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Extension Forestry, managers of Wheeler's Pine Tree Farm owned by the Kansas State University Endowment Association, made available plots of pine trees where research on chemical control was conducted and specimen collections made.

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Mr. D. R. Davis of the United States Department of Agriculture Identification and Parasite Introduction Research Branch, Beltsville, Maryland, verified identification of pine tip moth adults and pupae.

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APPENDIX

Below are listed some of the parasites and predators known to attack *Rhyacionia frustrana* (Comst.). The names of parasites have been compiled from the following references: (Aldrich, 1925), (Bugbee, 1958), (Cushman, 1927a), (Cushman, 1927b), (Gahan, 1927), (Muesebeck, Krombein, and Townes, 1951), (Eikenbary, 1965). Predators' names have been compiled from (Eikenbary and Fox, 1968).

Parasites

Diptera

Tachinidae

Lixophaga mediocris Ald.
Lixophaga plumbea Ald.

Hymenoptera

Braconidae

Agathis pini (Mues.)
Microgaster epagoges Gah.
Phanerotoma rhyacioniae Cush.
Bracon gelechiae Ashm.
Bracon gemmaecola (Cush.)
Bracon mellitor Say
Bracon rhyacioniae (Mues.)

Ichneumonidae

Scambus hispae (Harr.)
Calliephialtes comstockii (Cress.)
Itoplectis conquisitor (Say)
Glypta varipes Cress.
Campoplex frustranae Cush.
Cremastus epagoges Cush.
Epicrus indagator (Cress.)

Trechogrammatidae

Trichogramma minutum Riley

Eulophidae

Tetrastichus marylandensis (Gir.)
Elachertus pini Gah.
Hyssopus rhyacioniae Gah.
Hyssopus thymus Gir.
Euderus subopacus (Gah.)
Secodella subopaca (Gah.)

Elasmidae

Elasmus setosiscutellatus Cwfd.

Eupelmidae

Eupelmus cyaniceps amicus (Gir.)

Perilampidae

Perilampus chrysopae Cwfd.
Perilampus fulvicornis fulvicornis Ashm.

Pteramalidae

Arthrolytus aeneoviridis (Gir.)
Habrocytus rhyridopterigis How.

Eurytomidae

Eurytoma tylodermatis Ashm.
Eurytoma pini Bugbee

Chalcididae

Haltichella rhyacioniae Gah.
Spilochalcis flavopicta (Cress.)

Bethylidae

Goniozus electus Fouts

Predators

Coleoptera

Cleridae

Phyllobaenus lecontei (Wolcott)
Phyllobaenus singularis (Wolcott)
Enoclerus sp.

Coccinellidae

Coccinella novemnotata Herbst
Hippodamia convergens Guerin-Meneville

Neuroptera

Chrysopidae

Chrysopa plorabunda (Fitch)

Hemiptera

Reduviidae

Sinea diadema (F.)
Apiomerus crassipes (F.)

Orthoptera

Mantidae (Unidentified)
Tettigoniidae (Unidentified)

Thysanoptera

Phlaeothripidae

Cryptothrips pini (Watson)

Hymenoptera

Formicidae

Formica schaufussi dolosa Wheeler
Formica integra Nylander
Pogonomyrmex badius (Latreille)

Araneida

Salticidae

Metaphidippus galathea (Walckenaer)

Thomisidae

Misumenops asperatus (Hentz)

Araneidae

Allepeira conferta (Hentz)
Argiope aurantia (Lucas)
Mangora gibberosa (Hentz)

Table 1. Data from plots sprayed April 20.

	Total number of infested tips on three trees				Percent control based on four reps.
	Replicate 1	Replicate 2	Replicate 3	Replicate 4	
Bidrin	0	3	3	4	77.55
Diazinon	2	4	1	4	77.55
DDT	1	5	0	0	89.8
Guthion	0	0	0	0	100.0
Meta-systox-R	4	8	1	0	73.5
Sevin	2	1	0	3	87.7
Check	15	0	30	4	—

Formulation of insecticides as shown in tables 1 - 10.

Bidrin - liquid containing 9 lbs./gal. applied at 1 lb./100 gals.
Diazinon - emulsifiable concentrate containing 4 lbs./gal. applied at 1 lb./100 gals.
DDT - emulsifiable concentrate containing 2 lbs./gal. applied at 1 lb./100 gals.
Guthion - 25% wettable powder applied at .85 lbs./100 gals.
Meta-systox-R - emulsifiable concentrate containing 2 lbs./gal. applied at 1 lb./100 gals.
Sevin - 50% wettable powder applied at 1 lb./100 gals.

Table 2. Data from plots sprayed June 21.

	Total number of infested tips on three trees		% control based on two reps.
	Replicate 1	Replicate 2	
Bidrin	0	0	100.0
Diazinon	0	0	100.0
DDT	4	7	65.6
Guthion	0	0	100.0
Meta-systox-R	2	2	87.5
Sevin	0	3	90.6
Check	17	15	——

Table 3. Data from plots sprayed June 26.

	Total number of infested tips on four trees		% control based on two reps.
	Replicate 1	Replicate 2	
Bidrin	0	0	100.0
Diazinon	0	0	100.0
DDT	1	4	76.2
Guthion	0	2	90.5
Meta-systox-R	3	7	52.8
Sevin	0	0	100.0
Check	13	8	——

Table 4. Data from plots sprayed July 3.

	Total number of infested tips on four trees		% control based on two reps.
	Replicate 1	Replicate 2	
Bidrin	2	0	89.5
Diazinon	0	1	94.7
DDT	0	3	84.2
Guthion	0	0	100.0
Meta-systox-R	1	0	94.7
Sevin	0	0	100.0
Check	16	13	———

Table 5. Data from plots sprayed July 12.

	Total number of infested tips on four trees		% control based on two reps.
	Replicate 1	Replicate 2	
Bidrin	0	0	100.0
Diazinon	0	0	100.0
DDT	2	1	62.5
Guthion	0	0	100.0
Meta-systox-R	0	0	100.0
Sevin	0	0	100.0
Check	3	5	———

Table 6. Data from plots sprayed April 20 and July 2.

	Total number of infested tips on three trees		% control based on two reps.
	Replicate 1	Replicate 2	
Bidrin	4	1	68.7
Diazinon	0	0	100.0
DDT	1	0	93.7
Guthion	3	0	81.3
Meta-systox-R	1	0	93.7
Sevin	2	2	75.0
Check	4	12	———

Table 7. Data from plots sprayed August 12.

	Total number of infested tips on four trees			% control based on three reps.
	Rep. 1	Rep. 2	Rep. 3	
Bidrin	2	1	1	71.4
Diazinon	1	0	0	92.8
DDT	3	1	1	64.3
Guthion	1	0	1	85.7
Meta-systox-R	2	0	2	71.4
Sevin	6	0	3	35.7
Check	10	3	1	———

Table 8. Data from plots sprayed August 22.

	Total number of infested tips on four trees			% control based on three reps.
	Rep. 1	Rep. 2	Rep. 3	
Bidrin	0	4	0	00.0
Diazinon	0	2	0	50.0
DDT	1	2	0	25.0
Guthion	0	0	0	100.0
Meta-systox-R	1	0	1	50.0
Sevin	0	6	4	00.0
Check	1	3	0	———

Table 9. Data from plots sprayed August 28.

	Total number of infested tips on four trees			% control based on three reps.
	Rep. 1	Rep. 2	Rep. 3	
Bidrin	3	2	2	46.2
Diazinon	1	2	1	69.2
DDT	0	0	3	76.9
Guthion	0	0	0	100.0
Meta-systox-R	0	0	0	100.0
Sevin	2	0	2	76.9
Check	11	1	1	———

Table 10. Data from plots sprayed August 14 and 26.

	Total number of infested tips on four trees			% control based on three reps.
	Rep. 1	Rep. 2	Rep. 3	
Bidrin	1	0	0	90.0
Diazinon	10	0	3	00.0
DDT	3	1	0	60.0
Guthion	0	1	0	90.0
Meta-Systox-R	2	0	0	80.0
Sevin	0	1	0	90.0
Check	4	3	3	——

Vita

Willard C. Dick, son of Mr. and Mrs. Jacob L. Dick, was born November 23, 1938, at Bingham Lake, Minnesota. He attended elementary and secondary schools in Mountain Lake, Minnesota, graduating in 1956.

He received his B.A. degree in biology at Tabor College, Hillsboro, Kansas, in 1960.

He taught at Central Christian High School, Hutchinson, Kansas, for two years and then went to East Africa for a three-year term to teach in a secondary school for boys. Upon his return to the States, he was employed by the Menninger Foundation, Topeka, Kansas, to teach in their high school program for emotionally disturbed adolescents.

In 1967, he entered Kansas State University to study toward a Master's degree in the Department of Entomology. He was a Graduate Research Assistant under the supervision of Dr. Hugh E. Thompson.

He was united in marriage to Margaret Stucky, of McPherson, Kansas, on July 29, 1966. They are the parents of one son, Carl Willard, born July 30, 1968.

THE BIOLOGY AND CONTROL OF NANTUCKET PINE TIP MOTH, *RHYACIONIA FRUSTRANA* (COMSTOCK) IN KANSAS

by

WILLARD C. DICK

B.A., Tabor College, Hillsboro, Kansas, 1960

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During the summer of 1968, three flights of Nantucket pine tip moth, Rhyacicnia frustrana (Comst.), occurred. The first was in April, the second in late June and early July, and the third in August. Flights extended from three to four weeks.

Adults become active at night and lay eggs, light yellow in color, that hatch after seven or eight days.

Larvae spend their early life mining in pine tree needles. Later they move into the bud and shoot tip and feed, causing the bud and shoot tip to die. This leads to distortion of the tree.

The pupal stage lasted ten days in the laboratory. It was concluded that in Kansas it overwinters as a pupa in burrows created by the larva.

Parasitism of larvae and pupae during 1968 was 19.25% in June and 8.96% in August. Three species of dipterous parasites were collected: Erynnia tortricis (Coq.), Lixophaga sp., and Lixophaga plumbea Ald. Six hymenopterous species were collected: Haltichella rhyacionia Gahan, Eurytoma pini Bugbee, Exeristes comstockii (Cress.), Itoplectis conquisitor (Say), Phaeogennes walshiae australis (Cush.), and Temelucha sp. nr. epagoges (Cush.). I. conquisitor was collected in greatest number.

Chemical control studies were made on six-year-old Scotch pines. Tests attempted to determine effectiveness of individual insecticides, effectiveness of multiple applications, and appropriate time for applications.

The insecticides used were Bidrin®, Diazinon, DDT, Guthion, Meta-systox® and carbaryl. No one insecticide proved to be significantly better than another but Guthion gave satisfactory control almost consistently.

Some insecticides proved better with multiple applications, but others were effective with a single application.

The most appropriate time for application apparently is about fifteen days after peak emergence of adults.