5021

UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

STUDIES OF THE BIOLOGY, HABITS AND CONTROL OF THE BLACK-HEADED BUDWORM IN ALASKA

Season of 1953

S
Control
Insects Blackheaded
Budworm

by

W. F. McCambridge

Pacific Northwest Forest and Range Experiment Station
R. W. Cowlin, Director
Portland, Oregon

In cooperation with
The Alaska Forest Research Center
R. F. Taylor, Forester-in-charge
Juneau, Alaska
May - 1954

TABLE OF CONTENTS

ACKNOWLEDGMENT

The conduct and completion of the planned program of studies described in this paper were made possible through the kind cooperation of Region 10 personnel of the Tongass National Forest. The facilities furnished by the Alaska Forest Research Center and the Admiralty Division office were most necessary for the completion of these studies.

Special mention should be made of the field assistants who conducted the work described herein. Their names and period of employment are given below.

Correll, J. Lee	May 6 to June 30
Hutchison, Frank T.	April 6 to October 8
Janssen, George E.	May 6 to September 30

STUDIES OF THE BIOLOGY, HABITS AND CONTROL OF THE BLACK-HEADED BUDWORM IN ALASKA

Season - 1953

by

W. F McCambridge

SUMMARY

The current outbreak of the black-headed budworm Acleris variana, Fern. in the hemlock forests of the Tongass National Forest in southeastern Alaska developed about 1948. By 1952, approximately 11,000,000 gross land acres were within the boundaries of the infested area. Although the budworm had been studied in eastern and western Canada, and had been observed in northeastern and northwestern United States, adequate published material was unavailable and no work had been done in Alaska. Therefore, in 1953 studies were initiated to determine the biology, habits and control of the insect.

The following information was obtained and is reported on in this paper:

(1) The black-headed budworm goes through one generation per year. Eggs are laid in September and October and the winter is passed in that stage. The eggs hatch in May and June as buds open and the larvae feed, preferably on new foliage, for about six weeks. Pupation occurs on the tree, the pupal period lasting for about three weeks. Normally moths begin to emerge in August.

(2) There are five larval instars. The head of the budworm is black during the first four, tan to orange in the fifth.

(3) Defoliation resulting from egg concentrations of .1 egg per twig-inch of needles is not serious. Defoliation resulting from egg concentrations of .27 eggs per twig-inch is quite noticeable, causing general browning of foliage in the upper crowns of open grown reproduction.

(4) Under very heavy infestations, current needle growth of Sitka spruce will be killed and light defoliation will occur on the last few year's needle growth.

(5) The budworm showed no significant preference for egg deposition between cardinal directions within the upper third of the crowns of open grown hemlock of reproduction size.

(6) Egg deposits were much greater in the upper third of the crowns of open grown hemlock reproduction than at either the middle or lower third levels. Deposits decreased directly with descending levels of the crown.

(7) Young open grown hemlock trees appear more suitable for budworm oviposition than trees of similar size growing under the protection of the mature forest canopy. This statement could not be statistically proven in tests conducted and reported on in this paper.

(8) Undetermined disease organisms and the fungus Empusa grylli (Fres) Nowak were very effective in reducing budworm populations. These agents killed approximately 50 percent of all pupae collected in Juneau. In some areas these agents exterminated the budworm populations.

(9) Two parasites, Itoplectis quadricingulatus Cush. and Phaeogenes articus Cush. were recovered from 98 percent of the budworm pupae parasitized. These parasites were found in 14 percent of all pupae collected in Juneau.

(10) Nicotine sulphate shows promise in killing budworm eggs.

(11) Hand methods of application using water emulsions of DDT at concentrations of 6.25 percent and 1.90 percent gave excellent control of budworm larvae in the third instar.

(12) Hand methods of application using DDT oil solutions at concentrations of 6.25 percent applied at a volume of approximately one gallon per acre (.52 pounds of DDT per acre) gave very good control of third and fourth instar larvae. A 1.90 percent solution at the same volume of application but containing only .16 pounds of DDT per acre gave uncertain results.

INTRODUCTION

In 1948 black-headed budworm infestations developed in a few western hemlock stands scattered throughout the southern portion of the Tongass National Forest. In the years that followed, the infestation centers expanded and coalesced and by 1952, the outbreak extended throughout eleven million gross land acres of the Tongass, eight million acres of which contained areas suffering very heavy defoliation. Such was the situation in the fall of 1952 when the author was assigned to conduct a survey of the budworm outbreak and appraise the situation.

When the survey was concluded in October of 1952, it was apparent that the spread of the outbreak was tremendous, that western hemlock over extensive areas was suffering considerable top kill as a result of repeated defoliation, and that in many areas defoliation would continue. This information was far from adequate with which to appraise the situation. From miscellaneous reports and conversations it was learned that the budworm had been observed from time to time over the Tongass National Forest; however, these reports indicated no such widespread destruction as currently existed. A review of the literature indicated that extensive outbreaks in the Pacific Northwest had not inflected serious damage, nor was budworm damage in British Columbia severe enough to cause tree mortality. While such past histories of budworm activity were reassuring, they did not guarantee that a similar pattern would be repeated in Alaska. Futhermore, because of the repeated histories which excluded the budworm from the role of a primary forest killer, serious shortages of published material existed on some detailed aspects of the biology, habits and control of the insect. To correct this situation, certain fundamental studies were initiated as outlined below.

PURPOSE

The initial studies undertaken in 1953 were exploratory in nature, and designed to supply a wide range of general information with which to improve surveys, develop control measures and plan future detailed studies. The immediate objectives were:

(1) To determine the life history of the budworm in Alaska.

(2) To strengthen the survey technique by determining the habits of the budworm with reference to: (a) the amount of defoliation resulting from known insect populations, (b) the egg laying habits of the budworm on small trees.

(3) To determine some of the factors causing budworm mortality and to measure the amount of such mortality.

(4) To test the effectiveness of various insecticides on budworm eggs and larvae.

LOCATION

During the summers of 1951 and 1952, budworm feeding in the Juneau area was so light as to be scarcely perceptible. In the fall of 1952, a tremendous moth flight was observed at Juneau and the resulting egg deposit was heavy. Indications pointed to considerable defoliation in 1953, similar to that which was so prevalent throughout the Southern half of the Tongass Forest. With such an accurate history of the progress of the budworm outbreak and with damage about to be noticeable, Juneau then became an ideal location for the initiation of studies of this insect.

BIOLOGY

Classification and Description

The black-headed budworm, Acleris variana Fernald, belongs to the large family Tortricidae of the order Lepidoptera.

Budworm moths are predominantly grey, occasionally brown and with a wide variety of wing designs from mottled white, to red or yellow longitudinal lines. The moth is about one centimeter long and three-quarters of a centimeter wide. Eggs are yellow and oval to round and slightly flattened on top. They are approximately one-half to three quarters of a millimeter in diameter. Larvae are predominantly yellow to yellow-green with a shiny black head until the last instar, during which time the head is tan to orange. When full grown the larvae are about two and a half centimeters in length. Pupae are brown to green-brown and characteristic of the order. They are about one to one and one-half centimeters long.

Distribution and Hosts

The black-headed budworm can be found throughout the northern part of the United States, Canada and coastal Alaska where suitable host trees are found. In the northeastern United States and eastern Canada the budworm appears in epidemic numbers only where mature true fir forms a high percentage of the stand. White, red and black spruce and occasionally larch are also defoliated. In the northwest, western hemlock and Pacific silver fir are the preferred hosts, but Douglas-fir, grand fir, alpine fir, Sitka spruce, Engelmann spruce and mountain hemlock are also attacked (1, p 106 (2).

Life History

The life history of the budworm has been described by Canadian entomologists during previous studies on the Pacific Coast (2) (3). The following account based on work done in Juneau in 1953 is in accord with this earlier work.

The black-headed budworm in Alaska goes through one generation per year. Eggs are laid singly on the underside of western hemlock and Sitka spruce needles in September and early October and the winter is passed in that stage. As buds begin to expand in the spring during late May and early June, the eggs hatch and the tiny larvae mine inside the new buds. Often the bud is destroyed by this mining before it can completely open and put out new growth. When this happens, the larva will move to another bud. As needle growth continues, the larva webs a few needles together and feeds while inside this protective covering. The larval stage lasts for approximately six to seven weeks on western hemlock, but seems to be somewhat faster on Sitka spruce. About mid-July to early August, pupae are formed. The pupal stage lasts for approximately three weeks, during which time the pupae are most often found within the webbed needles formed by the larvae prior to pupation. Moths begin to emerge in late August, mate and lay eggs thus completing the life cycle. The moths die after this egg laying period.

The exact dates of development of the various budworm stages at Juneau in 1953 were as follows: Eggs began to hatch on May 29; pupation began on July 11; moths began emerging on July 31, but eggs were not deposited until September 1.

The rate of development of the budworm appears more rapid on spruce than on hemlock and on June 22, larval collections were made in order to check these field observations. It was found that on the above date, thirty-five percent of the larvae on Sitka spruce had reached the last instar, whereas only one percent of the larvae on a nearby hemlock had reached that stage of development. It is not known whether the more open foliage of spruce presents a warmer environment, whether there is more nourishment in spruce needles than in hemlock, or whether the budworm feeds faster on spruce than on hemlock.

Larval Instar Determinations and Rate of Development

To determine the number of larval instars of the budworm and also to obtain information on the rate of larval development, two hundred larvae were collected at weekly intervals, head capsules measured, and a histogram constructed (see page 24). In measuring the width of the head capsules, the larvae were first killed in alcohol, placed ventrally on a watch glass which was then inserted under a Leupold and Stevens core measuring machine equipped with a binocular microscope.

The histogram indicates five larval instars with a total range of head width from 191 microns to 1729 microns. Mean head capsule width and range for each instar are presented in Table I.

Table I.--Head capsule width and range for each instar of the black-headed budworm.

Larval Stage	Head capsule width in microns (Arithmetic mean)	Probable Range 1/	Number of measurements	Head color
First instar	244	191-316	115	shiny black
Second instar	429	317-516	371	shiny black
Third instar	715	542-866	209	shiny black
Fourth instar	994	867-1142	180	shiny black
Fifth instar	1447	1067-1729	223	tan to orange

1/ Exact overlap in the ranges of the first four instars not possible to determine from the data as collected and shown in Figure I.

The weekly collections of larvae for head capsule measurements also indicated the rate of larval development on western hemlock found at approximately 50 feet above sea level. This development is shown below in Table II.

Table II.--Rate of black-headed budworm larval development in Juneau, Alaska, 1953

	Budworm stage shown in percent						
Date	Eggs	First instar	Second instar	Third instar	Fourth instar	Fifth instar	Pupae
May 26	100.0	--	--	--	--	--	--
June 3	20.0	70.0	10.0	--	--	--	--
June 10	--	.6	98.0	1.4	--	--	--
June 17	--	--	83.5	16.5	--	--	--
June 24	--	--	2.0	79.0	16.0	3.0	--
July 1	--	--	--	8.5	71.5	20.0	--
July 8	--	--	--	--	3.5	96.5	--

HABITS

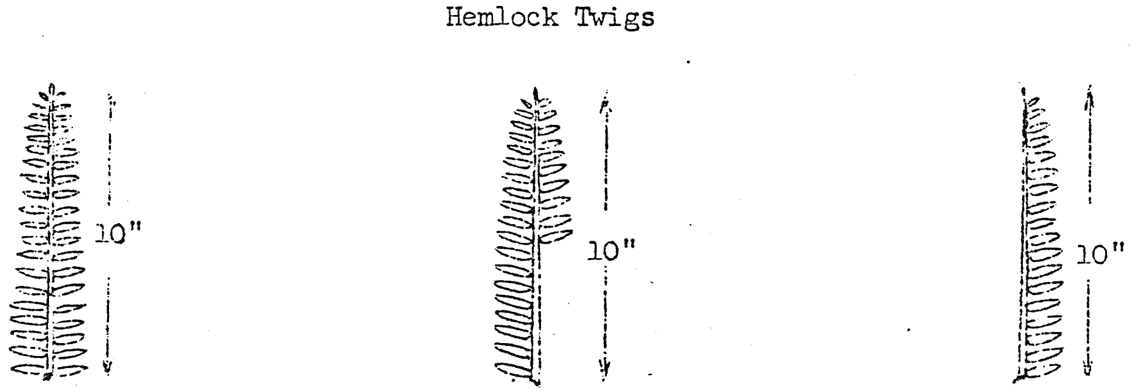
The initial studies of the habits of the budworm were designed principally to obtain information with which to strengthen the survey techniques. Studies initiated to determine the degree of defoliation resulting from known insect populations were needed in order to evaluate survey data. Information on the egg laying habits of the budworm on small trees was needed to determine the sampling location where budworm eggs would most likely be found and which could be practically sampled from the ground. Additional information was obtained in the course of the studies.

Defoliation resulting from known egg populations

For determining the degree of defoliation resulting from known budworm populations, two courses of study were pursued. In the first, (called study b-1) egg counts and foliage measurements were made on specified portions of suppressed trees on seven plots. Upon the completion of larval feeding, a similar sample of foliage was obtained from the trees previously sampled and all foliage not devoured was measured. In the second study,(called study b-2) egg counts were made on specified portions of suppressed trees on five plots. Upon completion of larval feeding, visual estimates were made of the amount and location of defoliation on dominant trees. This second study is a long-term study to follow the feeding habits of the budworm and study the deterioration of hemlock stands.

Study b-1 - Seven four-acre plots in mature hemlock stands were laid out. Within each plot twenty suppressed hemlock trees were tagged. From each of these twenty trees, eight ten-inch twigs were cut from the ends of branches within the upper third of the crown. On each ten-inch twig a field count was made of the eggs. In addition, the twig length bearing normal needle growth or the equivalent of normal growth was measured on each ten-inch twig. This measurement is called twig-inches of needles throughout this paper. Perhaps the definition of twig-inches of needles can be more easily understood by referring to the following illustrations.

Figure 2 - Illustration of twig-inches of needles or equivalent



10 twig-inches of needles

7.5 twig-inches of needles

5 twig inches of needles

When all egg counts and measurements of twig-inches of needles had been made the average of eggs per twig-inch of needles was calculated for each plot. Upon completion of larval feeding, eight more ten-inch twigs were cut from the ends of lateral branches in the upper third of each of the twenty trees initially sampled. On these twigs were measured the twig-inches of normal needles or equivalent, the twig-inches of normal needles or equivalent devoured by the budworm, and the number of bud clusters killed by budworm feeding. The results of this study are given in Table III.

Table III.--Hemlock defoliation caused by light concentrations of black-headed budworm eggs.

Plot	1952 Eggs per twig-inch of needles	1953 Defoliation on terminal ten-inch twigs in percent	Bud clusters killed per twig
Lemon Creek #1	.04	16	12
Lemon Creek #2	.06	22	14
Lemon Creek #3	.06	25	15
Lemon Creek #4	.07	21	10
Montana #1	.05	16	17
Montana #3	.06	20	20
Douglas #3	.09	23	14

Further information of a more general nature is available with respect to the degree of defoliation which results from known budworm populations. From a study of host exposure preference (outlined on page 19), egg populations were determined on twenty trees in each of four plots and the resulting defoliation observed. From these plots the following information was obtained.

(1) A mean egg deposit of .11 eggs per twig-inch of hemlock needles caused light general browning of hemlock needles in the upper crowns of the largest trees, and scattered tip defoliation on the lateral branches.

(2) A mean egg deposit of 1.19 eggs per twig-inch of hemlock needles produced 100 percent defoliation throughout the upper half of the tallest and most open crowned hemlock. Defoliation on the smaller trees was scattered, both between trees and between branches on any given tree. Sitka spruce lost almost all of its 1953 needle growth in the upper half of the crowns.

(3) A deposit of 2.27 eggs per twig-inch of hemlock needles resulted in 100 percent defoliation throughout the upper half of the crowns of the taller trees and complete, or scattered complete defoliation within the upper third of the crowns of the intermediate trees. Sitka spruce reproduction in the immediate area suffered the loss of 100 percent of the 1953 foliage throughout the upper half of the crowns. Older spruce foliage was not damaged.

Considering the above discussion it is seen that deposits of .11 or more eggs per twig-inch of hemlock needles are associated with some browning of hemlock and spruce. On the other hand, deposits of .09 or less eggs per twig-inch of hemlock needles did not cause browning of foliage other than a few scattered brown bud clusters. Therefore, until more information can be obtained, .11 eggs per twig inch of hemlock needles is provisionally selected as the minimum egg deposit which will cause noticeable browning of foliage for which artificial control would be desirable on ornamental trees. Egg parasitism and other natural control pressures will affect this minimum deposit.

It will be noted in the discussions on page 8, that even with the heaviest of egg populations defoliation of Sitka spruce was confined to the current needle growth. This was not in every case correct. Under the most severe infestations, those in which adjacent hemlock were stripped of up to 95 percent of their total foliage, budworm feeding on spruce extended back in a spotty fashion to the 1952 and 1951 needle growth. The current growth turned brown as a result of partial chewing of needles by the larvae and also as a result of chewing of the cortex which killed the entire length of new growth. Needle growth produced during 1952 and 1951 did not turn brown, nor was the cortex damaged by larval feeding.

During the course of these investigations just described, information was obtained on the feeding habits of young larvae. It had been observed that young larvae upon mining into the expanding buds would or would not kill the bud. In those cases where the bud cluster was killed, the lack of larval remains within the cluster led to the belief that the young larvae moved from bud to bud. An examination of 2911 buds produced only 2257 larvae. This point was observed by Prebble and Graham in 1944, (2) who described the feeding in these terms. "Feeding at this time (May and early June - author's note) occurs in perfect concealment at the base of the immature needles in the bud cluster, and injured needles wilt and turn brown. Upon exhausting the food supply in one opening bud, the larva crawls to another, and may thus kill a succession of newly opening buds or young shoots in the early stages of larval development."

Study b-2 - Determination of the degree of defoliation on dominant trees associated with known egg populations on suppressed trees.

At the outset of this study the oviposition and feeding preferentials of the budworm were not well understood. Since it is very impractical to sample the foliage of mature hemlock for budworm eggs and damage, it was hoped that some correlation could be found between egg counts on suppressed trees and defoliation on trees making up the forest canopy. This study, set up on a long term basis, would also attempt to follow the yearly feeding pattern on the overstory trees and the gradual deterioration of the stand, all tied in with the known quantity of eggs found on suppressed trees. With the hindsight of one field season of study, it appears now that suppressed trees carry too light an infestation level even during epidemics to form the base for any of the relationships mentioned above. Trees of size similar to suppressed trees but growing in the open may harbor budworm populations more closely related to those in the nearby forest overstory.

The method of procedure for this study was as follows. Five of the seven four-acre plots used in the previous study (b-1) were selected on the basis of having sufficient unevenness of crown canopy as to enable ten dominant crowns to be visible from the ground. The lack of time prevented the selection of ten dominant and ten intermediate trees as was originally planned. The ten dominant trees were tagged with metal bands. Stakes were driven in the ground at various measured distances from the trees, one stake for each tree. These stakes were placed at a location from which all, or almost all of the designated tree could be seen. It was originally planned to take abney readings to supply the following information: (1) Total height of the tree (2) Height to lowest live limb (3) Height on the stem above which no branches contain needles (4) Height on the stem above which the branches contain 50 percent or less foliage (visually estimated) (5) Height on the stem above which no branch contains current needle growth within its terminal three feet.

Unfortunately, defoliation was so light on all trees studied that most of the above readings could not be taken. Abney readings where then taken to those heights at which word descriptions could be given. These word descriptions revolved about three degrees of defoliation: (1) Light - defoliation visible (2) Moderate - defoliation 20 to 60 percent of the needles (3) Heavy - defoliation over 60 percent. Notes were made as to the location of these degrees of defoliation, and their nature; i.e. scattered or entire. These data were taken in May before 1953 growth and again in September so that the 1952 and 1953 defoliation could be observed. Silhouettes of all trees have now been plotted for the two years with appropriate symbols for the type and degree of defoliation suffered.

The study has not been in progress long enough to draw conclusions from the data. Some generalized observations have been made and are presented in Table IV.

Table IV. - Comparison of budworm egg populations on suppressed trees with defoliation occurring on dominant hemlock trees.

Plot	Eggs per twig-inch of needles on suppressed trees	Defoliation on dominant hemlock trees
Lemon #2	.06	Tips and tops light to moderate defoliation. Three trees with tip defoliation entire length of crown. One tree with no defoliation.
Lemon #4	.07	Tips and tops light defoliation. Four trees with no defoliation.
Montana #1	.05	Tips and tops moderate defoliation. One tree with tip defoliation entire length of crown. Three trees with no defoliation.
Montana #3	.06	Tips and tops moderate defoliation. One tree with tip defoliation entire length of crown.
Douglas #3	.09	Tips and tops moderate to heavy defoliation. Five trees with tip defoliation entire length of crown.

While collecting the data for this study the impression was gained that intermediate trees were the ones which most frequently suffered the heaviest defoliation.

Considerable work needs to be done to perfect this study and more fully understand the complicated host-budworm relationships.

Egg laying habits

Studies of the egg laying habits of the budworm on small hemlock trees were designed to obtain the following information:

(1) The fecundity of the budworm.

(2) The distribution of eggs on open grown trees.

(3) The egg laying preference between two groups of trees of similar size, one group composed of suppressed trees, the other of open grown reproduction.

Fecundity - For the study to determine the egg laying capacity of the budworm, the procedure was as follows: Pupae were collected from small hemlock trees and placed individually in gelatin capsules of 1/2-oz. capacity. As moths emerged their sex was determined, and one male and one female were placed in one of the capsules. During this work it was noted that male emergence far exceeded that of females during the early emergence period. This tendency was reversed toward the end of the period, indicating a fairly even sex ratio. This observation was under laboratory conditions only.

Twenty small hemlock trees were cleaned of all larvae and pupae and then caged in the field. These trees ranged in height from 2 to 4 feet. The cages were made of muslin with the exception of one side which was covered by standard window screening. The bottom of the cage was made of muslin which was drawn tightly around the stem of the tree. One pair of moths was then placed in each cage and the following results obtained as shown in Table V.

Table V. - Black-headed budworm egg production on small caged hemlock trees, Juneau, 1953

Cage No.	Date adults placed in cage	Date egg 1/ counts made	Number of normal appearing eggs per female
	July	September	
1	24	11	0
2	24	11	2
3	24	22	0
4	27	11	6
5	27	11	0

Table V. Continued

Cage No.	Date adults placed in cage	Date egg 1/ counts made	Number of normal appearing eggs per female
		September	
6	27	11	0
7	27	14	5
8	29	Cage destroyed	-
9	29	22	70
10	29	11	26
11	29	11	1
12	30	11	28
13	30	11	0
14	30	11	0
15	30	11	0
16	30	14	10
17	31	11	13
18	31	11	5
19	31	11	0
20	31	11	0

1/ Egg counts made when both moths in each cage had died.

All eggs found had been laid singly on the underside of the needle and were widely scattered throughout both old and new foliage.

Cage 6 was destroyed when it was opened before both moths had died. The cage was immediately repaired. However, the next day there were 8 moths in the cage. It was further observed that the moths seemed attracted to the cages as there were more moths on them than could be shaken from much larger trees in the immediate vicinity. Many of the moths found on the outside of the cages were copulating. This observation leads to the belief that better results can be obtained by placing these copulating pairs in the cages rather than hope for successful union by the caging method employed in 1953. There may also be some characteristic behavior of moths between emergence and oviposition which would be affected by placing the adults in capsules upon emergence. Daily observations of moth habits on a Sitka spruce showed that there was a period of one month and three days between the time moths began to emerge and the time the first eggs were seen.

Distribution - The distribution of eggs on open grown hemlock trees was studied in the following manner. Four branches were cut from each of 15 open grown trees. These branches were taken from the upper third of the crown, one branch cut from each cardinal direction. Four ten-inch twigs were then cut from the middle third of the crown and four from the lower third of the crown. Again, one twig was cut from each cardinal direction at each of the two crown levels. Egg counts and foliage measurements were then made for all twigs and branches. The counts and measurements on the branches were tallied by the whole branch and by the terminal ten inches on each branch. The results of this study are as follows:

(1) An analysis by paired comparisons between mean eggs per twig-inch on ten-inch twigs and whole branches showed no significant difference existed. It was found that 16.3 percent of the eggs were on the terminal ten-inch twig and 16.1 percent of the foliage was on this section of the branch. The above refers to the upper third of the crown only. Considerable variation should be expected in these percentages if the study were repeated.

(2) An analysis of variance showed no significant difference in mean eggs per twig-inch between cardinal points of samples in the upper third of the crown.

Analysis

	SS	DF	MS	F	
Treatment (direction)	2.20	3	.73	.41	(2.83 at 95%) (4.29 at 99%)
Trees	82.39	14	5.88	3.30	
Residual	74.75	42	1.78		
Total:	159.34	59			

(3) An analysis of variance showed that egg deposits varied considerably between various crown levels of open grown hemlock reproduction.

Analysis

	SS	DF	MS	F	
Crown level	42.01	2	21.01	35.61 **	(3.34 at 95%) (5.45 at 99%)
Trees	10.53	14	.75	1.27	
Residual	16.44	28	.59		
Total:	68.98	44			

Calculations of critical difference showed:

(a) A critical difference in the mean egg count between the upper third of the crown and the other two crown levels.

(b) No critical difference in the mean egg counts found at the middle and lower third crown levels.

The mean eggs per twig-inch at the three crown levels were:
upper crown - 2.29, middle crown - .52, lower crown - .05.

Another indication of the distribution of eggs and foliage on ten-inch twigs sampled at three crown levels is given in Table VI.

Table VI. - Distribution of budworm eggs and foliage on ten-inch twigs sampled at three crown levels of open grown hemlock reproduction.

Crown position	Eggs		Twig-inches of needles		No. of 10-inch twigs sampled
	Number	Percent	Number	Percent	
Upper third	2855	79.6	1210	26.6	60
Middle third	640	17.8	1431	31.4	60
Lower third	91	2.6	1919	42.0	60
Total:	3586	100.0	4560	100.0	180

Host exposure preference - The egg laying preference of the budworm between two groups of trees of similar size, one group composed of suppressed trees, the other of open grown reproduction was determined as follows.

In a previous study (page 6) it will be recalled that suppressed trees were sampled in seven plots by cutting eight ten-inch twigs from the upper third of the crown of each of twenty trees within each plot. Adjacent to each of four of these plots a similar sample was taken of eight ten-inch twigs cut from the upper third of the crown of each of twenty open grown trees of related size. The mean eggs per twig-inch for each of the eight plots - four with suppressed trees, four with open grown trees - was calculated, compared and the following results obtained.

Table VII. - A comparison of black-headed budworm egg deposits on suppressed and open grown trees of small diameter.

Location	Suppressed trees Eggs per twig inch	Open grown trees Eggs per twig inch
Lemon #1	.04	2.27
Montana #2	.05	1.20
Montana #3	.09	.27
Douglas #3	.06	.11

From analysis of variance tests combining treatment times plot interaction it could not be proved that mean egg counts on suppressed trees were significantly different from mean egg counts on open grown trees. Analyses of data by paired comparisons for each plot showed a highly significant difference in each case. The standard mean errors of the differences of the paired means varied from 38 percent in plot L1 to 89 percent in plot M3. It is felt that more plots in heavily infested areas would show significant differences and lower standard errors. Despite the inability to statistically prove significance, field experience indicates that crews will have the best chance of finding budworm eggs if they will sample open grown hemlock reproduction.

NATURAL CONTROL FACTORS

The numerous factors exerting natural control of the black-headed budworm were not given adequate study during the 1953 field season. Neverthless, it is apparent from limited tests and observations that natural factors are very effective in reducing budworm populations and preventing serious forest destruction.

Probably the most important natural control agents are diseases. Their influence on the outbreak is variable, but at times considerable. In one area examined on the southern tip of Douglas Island, not a living larva or pupa could be found within an area of about seven acres. On all sides of this area disease symptoms were not nearly so evident. The insects had been destroyed by an undetermined agent, probably a polyhedral virus and by a fungus disease, Empusa grylli (Fres.) Nowak. 1/ In other areas where pupal collections were made disease exerted considerable control as shown in Table VIII.

Table VIII.--Incidence of disease and parasites found in pupal collections,1953

Location	Pupae Collected	Pupae Diseased	Per-cent	Pupae Parasitized	Per-cent	Moths Emerged	Per-cent
Juneau	130	66	51	27	21	37	28
Juneau-Mile 7	67	33	49	12	18	22	33
Juneau-Lemon Cr.	383	170	44	37	10	176	46
Juneau-Montana Cr.	315	164	52	51	16	100	32
Petersburg	113	65	57	35	31	13	12

It should be pointed out that the outbreak was in its first year at all sampling locations with the exception of Petersburg.

Next in importance of the natural control factors are parasites. Canadian entomologists found about forty different species attacking eggs, larvae and pupae (3). A number of these parasites were found to exert strong control pressures on the budworm populations. During the 1953 field work in southeastern Alaska, attempts were made to recover parasites from eggs and pupae only. With reference to Table VIII, 90 percent were Itoplectis quadricingulatus Cush., 8 percent were Phaeogenes articus Cush. and 2 percent others yet to be identified. Parasites of eggs, Trichogramma minutum Riley,exhibited a wide range of control as shown in Table IX.

1/ Identification by P. L. Lentz, Division of Mycology and Disease Survey

Table IX.--Incidence of egg parasitism by Trichogramma at various localities in Southeast Alaska, 1953.

Location	Number of eggs in sample	Normal eggs	Parasitized Eggs	Percent Parasitism
Ketchikan	1,000	777	223	22.3
Hollis	1,000	974	26	2.6
Petersburg	1,000	994	6	.6
Juneau				
Lemon Cr.	26,757	26,525	232	.9
Montana Cr. #1	4,015	4,002	13	.3
Montana Cr. #3	602	601	1	.2
Douglas #3	1,835	1,830	5	.3

In addition to egg and pupal parasitism and diseases in mature larvae and pupae, samples of half grown larvae collected at Ketchikan and Petersburg revealed mortalities of 27 percent from a combination of disease and parasites. Evidence of Eulophidae, perhaps Elachertus sp. was found during these examinations.

Other natural control factors of lesser importance are spiders, predacious insects and birds. These agents were not studied so an evaluation of their affect on the epidemic is not possible.

ARTIFICIAL CONTROL

Artificial control studies were directed along three lines: (1) To kill eggs, (2) to prevent oviposition, and (3) to kill larvae.

Tests against eggs

At the time tests were carried out on eggs of the budworm only two insecticides were available in Juneau; namely, "Black Leaf 40" and "Spradusto." 1/. In addition DN-289 (Dow Chemical Company, a 36 percent dinitro-sec-butylphenol Triethanolamine salt)was procured and tested. In all tests, three ten-inch egg-infested hemlock twigs were cut and placed in glass vials in the laboratory. Two twigs were used as checks in each test. All insecticides were applied with a hand sprayer in quantity to produce run-off. Results of these tests are tabulated below.

1/ "Spradusto," a dust containing: 1% Gamma isomer BHC, 5% DDT, 7% Forbam, 25% Sulphur, .1% Pyrethrins, .1% Rotenone and 59.9% inert ingredients.

Table X.--Relative efficiency of some insecticides tested in the laboratory for the control of black-headed budworm eggs.

Treatment	No. of twigs Sprayed	Date Sprayed	Date Examined	Percent egg hatch	Percent reduction
No. 1 - 1 part 40% nicotine sulphate 12 parts soap solution 250 parts water	3	5/20	6/2	33	67
Check	2	--	6/2	83	17
No. 2 - 1 part 40 % nicotine sulphate 1.2 parts soap solution 25 parts water	3	5/20	6/3	11	89
Check	2	--	6/3	78	22
No. 3 - 5 grams "Spradusto," water to make 472 ml.	3	5/21	6/2	87	13
Check	2	--	6/2	81	19
No. 4 - 15 grams "Spradusto" water to make 472 ml.	3	5/21	6/3	76	24
Check	2	--	6/3	86	14
No. 5 - 1 ml 36% DN-289 water to make 73 ml.	3	5/22	6/3	14	86
Check	2	--	6/3	53	47
No. 6 - 1 ml 36% DN-289 water to make 70 ml.	3	5/22	6/4	8	92
Check	2	--	6/4	61	39

The relatively low percent hatch obtained in check twigs for tests 5 and 6 is probably due to the close proximity of the check twigs to the treated twigs. It must also be mentioned that the temperature in the laboratory was often well in excess of 90 ° F. which may have had some affect on the percent hatch of the checks.

Hemlock foliage on twigs sprayed with formulations for tests 5 and 6 showed considerable burn after one day. No other formulations caused foliage burn. Buds were opening on all twigs when sprayed.

On September 29, 1953, five twigs were sprayed in the field with various formulations of nicotine sulphate, nicotine sulphate plus Dendrol, and with Dendrol alone. Results will be checked in May, 1954.

Tests to prevent oviposition

Water emulsions of DDT were applied to hemlock foliage in an attempt to determine if the insecticide showed promise in preventing oviposition by the budworm. A twelve percent emulsion of DDT was used throughout the tests. Five small hemlock trees were used for each treatment and five trees held as checks. The insecticide was directed to the underside of the needles until run-off occurred. The results of these tests were negative as shown in the table that follows:

Table XI.--Black-headed budworm egg deposits on hemlock foliage sprayed with a 12 percent emulsion of DDT prior to oviposition.

Tree No.	Treatment	Date of Spray	Twigs Collected	Twig inches of needles	Eggs	Eggs per twig inch
1	12 percent	7/29 & 8/18	9/22	100	1	.01
2	water	"	"	120	14	.17
3	emulsion	"	"	81	2	.02
4	of	"	"	70	3	.04
5	DDT	"	"	79	1	.01
6	12 percent	7/29	9/22	67	0	.00
7	water	"	"	172	0	.00
8	emulsion	"	"	142	1	.01
9	of	"	"	78	0	.00
10	DDT	"	"	114	0	.00
11	Check	-	9/22	169	10	.06
12		-	"	151	4	.03
13		-	"	153	0	.00
14		-	"	124	7	.06
15		-	"	76	2	.03

The egg deposits in the test area were too light to be able to draw conclusions from the data. The tests should be repeated at higher infestation levels.

Tests against larvae

DDT water emulsions and oil solutions were tested against larvae of the budworm under field conditions. Five small trees were sprayed with each insecticide using a portable hand tank sprayer for the emulsion tests, and a hand sprayer for the oil tests. The emulsion was applied until run-off occurred. The oil was applied as a fine mist at a roughly approximated dosage of one gallon per acre or equivalents of .52 and .16 pounds of DDT per acre. The volume dosage was estimated from the drop pattern which fell on spray droplet cards developed at the Beltsville, Maryland Forest Insect Laboratory. Pre-spray larval populations were estimaed from counts on five ten-inch twigs cut from the upper crown of each tree. Post-spray larval populations were estimated from counts on ten ten-inch twigs cut from the upper crown of each tree. The results of the DDT water emulsions tests are presented in the following two tables.

Table XII.--Effect of DDT emulsion sprays on black-headed budworm third instar larvae infesting western hemlock.

Tree	Treatment	Larvae per ten-inch twig: Prespray counts Alive	Prespray counts Dead	Postspray counts Alive	Postspray counts Dead	Percent Reduction
1	6.25 percent	138	1	0	63	100
2	DDT emulsion	54	1	0	43	100
3	applied 6/22	67	3	0	50	100
4		78	1	0	68	100
5		109	0	0	51	100
6	1.90 percent	74	1	0	13	100
7	DDT emulsion	107	3	0	57	100
8	applied 6/22	61	0	0	33	100
9		59	0	0	23	100
10		59	0	0	34	100
11	check	137	0	155	3	
12	"	76	0	76	2	
13	"	136	4	174	1	

In order to check the pattern of larval mortality and provide a means of determining the date to collect post-spray samples, cloth trays were erected under three trèes in each test series. The larval drop data is tabulated below.

Table XIII.--Black-headed budworm larval drop counts following DDT emulsion sprays

Tree	Treatment	Days after spray: Number of dead larvae in trays: 1	%	2	%	3	%	4	%	5	%
1	6.25 percent	78	93	5	6	0	-	1	1	0	-
4	DDT	64	73	12	13	2	2	6	7	4	5
5	emulsion	179	86	20	10	5	3	3	1	0	-
8	1.90 percent	145	72	27	14	5	2	18	9	7	3
9	DDT	136	79	11	6	2	1	21	12	3	2
10	emulsion	330	83	32	8	14	4	13	3	10	2

The percentage figures shown above refer to only those larvae recorded in the drop trays and do not apply to any more definable population. Practically 100 percent of the hemlock sawfly larvae on the trees fell within the first 24 hours.

The larval drop counts indicate that while both concentrations gave excellent control, 1.9 percent DDT emulsion was the slower acting. During the course of the tests the weather was cloudless.

On June 22, similar DDT emulsion tests were carried out against fourth instar larvae on Sitka spruce. No budworms survived these tests.

Some very light damage to herbaceous plants was caused by the residue of DDT, solvent and emulsifier. This burn-like damage was later prevented by simply washing the plants with water while the emulsion was still present on the foliage.

On June 24 a series of tests were conducted against third instar larvae but using oil solutions of DDT. The results of these tests are given below.

Table XIV.--Effect of DDT - oil solution sprays on black-headed budworm third instar larvae infesting hemlock.

		Larvae per ten-inch twig				
		Prespray counts		Postspray counts		Percent
Tree	Treatment	Alive	Dead	Alive	Dead	Reduction
1	6.25 percent DDT-oil solution applied at approximately .52 lbs. per acre	88	0	0	5	100
2		66	0	0	1	100
3		31	0	0	4	100
5		60	0	0	10	100
6		34	0	0	1	100
4	1.90 percent DDT-oil solution applied at approximately .16 lbs. per acre	91	2	0	4	100
7		90	0	0	6	100
8		78	0	1	19	95
10		32	0	2	4	67
11		55	0	3	1	25
1	check	121	1	70	4	
2	"	202	1	87	0	
3	"	154	1	63	1	

Table XV.--Black-headed budworm larvae drop counts following DDT oil solution sprays

		Number of dead larvae in trays															
Tree	Treatment	Days After Spray: 1	%	2	%	3	%	4	%	5	%	6	%	7	%	8	%
5	6.25 percent DDT at .52 lbs. per acre	80	58	22	16	-	-	26	18	5	4	3	2	2	1	1	1
6		153	80	17	9	-	-	8	4	4	2	3	2	6	3	0	0
10	1.90 percent DDT at .16 lbs. per acre	107	42	83	33	-	-	52	20	7	3	2	1	2	1	1	0
11		285	71	49	12	-	-	31	8	14	3	13	3	9	2	3	1

Practically 100 percent of the hemlock sawfly larvae on the trees fell within the first 24 hours. On July 3, a series of tests similar to those described above were carried out against fourth instar larvae. The results of these tests are tabulated below.

Table XVI.--Effect of DDT-oil solution sprays on black-headed budworm fourth instar larvae infesting western hemlock

Tree	Treatment	Larvae per ten-inch twig: Prespray counts Alive	Prespray counts Dead	Postspray counts Alive	Postspray counts Dead	Percent Reduction
12	6.25 percent DDT-oil solution applied at approximately .52 lbs. per acre	28	2	0	3	100
13		23	7	0	4	100
14		53	1	1	6	86
15		26	3	0	3	100
16		47	4	0	7	100
17	1.90 percent DDT-oil solution applied at approximately .16 lbs. per acre	75	2	1	6	86
18		49	1	7	6	46
19		33	4	2	0	00
20		53	0	0	3	100
21		11	2	0	7	100
22	check	84	5	50	7	
23	"	63	4	57	2	
24	"	49	0	65	0	

Table XVII.--Black-headed budworm larval drop counts following DDT-oil solution sprays.

Tree	Treatment	Days after spray: Number of dead larvae in trays 1	%	2	%	3	%	4	%	5	%
12	6.25 percent DDT at .52 lbs. per acre	335	86	17	4	19	5	14	4	4	1
13		284	85	15	4	15	4	16	5	6	2
18	1.90 percent DDT at .16 lbs. per acre	572	67	153	18	43	5	55	6	32	4
20		191	72	36	13	18	7	17	6	5	2

Examinations of the data presented in Tables XII through XVII indicate the following:

(1) DDT emulsions appear to give better control than DDT oil solutions. This conclusion is not valid due to the uncontrollable variation in the quantity of insecticides sprayed on each tree. It is believed that oil solutions were too lightly applied.

(2) Both 6.25 percent and 1.90 percent DDT emulsions gave excellent control of budworm larvae. The 6.25 percent emulsion may give quicker knockdown. (Please refer to Tables XII and XIII).

(3) A 6.25 percent oil solution of DDT is more effective than 1.90 percent oil solution in killing budworm larvae when applied in approximately even volumes of finished insecticide (Table XIV).

(4) From the data available and considering the lack of control in dosage application, it cannot be concluded that 3rd instar larvae are more susceptible to DDT oil solutions than are 4th instar larvae (Table XIV vs. Table XVI).

(5) Hemlock sawfly larvae were readily killed by both forms and dosages of DDT used in these tests.

(6) Mortality determinations made on trees sprayed with DDT oil solutions on July 3 may have been premature by one day (Table XVII).

FURTHER RESEARCH NEEDS

Emphasis on research in the immediate future should be placed on the natural control factors, host-budworm relationships and artificial control.

The studies of natural control factors should be detailed and should strive to determine all of the factors causing control and their effectiveness in reducing the current budworm outbreak. Included in this phase of studies should be tests on the artificial dissemination of disease organisms.

Host-budworm relationships are not well understood and studies along these lines should strive to answer such important questions as:

(1) The relative susceptibility of hemlock stands to budworm attack as affected by (a) growth rate (b) stand composition (c) site (d) exposure (e) altitude.

(2) The relative susceptibility of hemlock trees to budworm attack according to (a) age (b) crown position (c) growth rate.

(3) The effect of budworm defoliation on hemlock growth, mortality and stand deterioration.

(4) The interrelationship of the budworm with other defoliators of hemlock and the effects of such combined defoliation on the stand.

Artificial control studies should continue along two lines of investigation; namely, tests of insecticide to prevent damage on ornamental trees, and small scale aerial tests to limit forest defoliation or produce satisfactory reductions in larval populations. This latter line of investigation is to develop a method of protecting limited forest stands of high value.

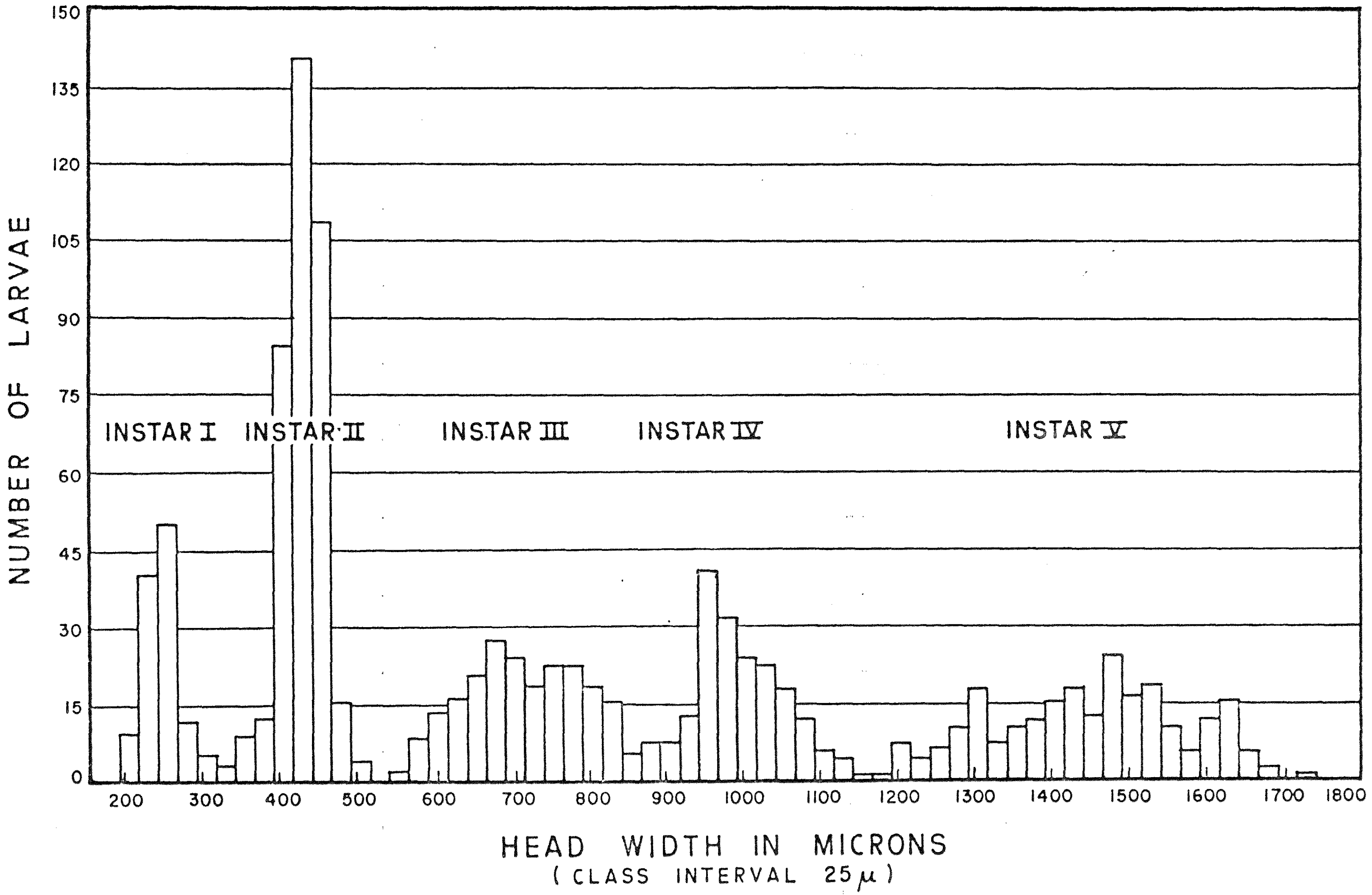


Figure No. 1 -- Histogram of Black-headed Budworm Larval Head Measurements
Juneau, Alaska, 1953

REFERENCES

(1) Keen, F. P.
Revised 1952, Issued 1938. Insect Enemies of Western Forests, U. S. Dept. of Agriculture, Misc. Publication No. 273.

(2) Prebble, M. L. and Graham, K.
1943 - The Outbreak of the Black-headed budworm in the Coastal District of British Columbia, a Preliminary Report, 1940-1943. Forest Insect Investigations, Dominion Dept. of Agriculture, Victoria, B. C., unpublished report.

(3) Prebble, M. L. and Graham, K.
1945 - the Current Outbreak of Defoliating Insects in Coast Hemlock Forests of British Columbia, Part I, Description of Outbreak and damage. British Columbia Lumberman, February, 1945.