SEQUENTIAL SAMPLING OF THE FOREST TENT CATERPILLAR

by

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INTERIM REPORT

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Introduction

At the beginning of this investigation statistically reliable techniques for measurement of the forest tent caterpillar were not available. Some arbitrary methods were in use but the accuracy of such surveys were unknown. As this is one of the major pests of the aspen forests of Canada and U.S.A. it is necessary to develop some fast reliable method to follow the variations of the populations from year to year and place to place. A basis for predicting defoliation for control purposes is necessary.

The data necessary to set up a sequential sampling system for this insect was collected by the Forest Insect Survey. This report is the first synthesis of this material and the sequential system proposed is to be tested and revised as more information becomes available.

Distribution of Shoots and Egg Masses

Before the sampling system was selected it was necessary to know the distribution of egg masses and laying sites over the tree. Sixteen trees were sampled at each of five locations in the Elk Point area of Alberta where a light population was present. The crowns were split into three levels and the data for each branch within each level were tabulated separately. Crowns were divided by measuring the total length of the live crown and dividing it into three equal parts. The data tallied included the length of each branch, the length of each twig over six inches, and the number of egg massed for each twig. The DBH, total height and crown length were recorded for each tree.

Analysis of this data showed that egg masses were not distributed evenly over the crown. As can be seen in Table I the egg masses are concentrated in the upper crown. This unequal distribution over the tree was further illustrated by summing the masses on the terminals, the first branches below the terminals, the second branches below the terminals, etc. The totals for the eighty trees were; terminal 57, first below the terminals 21, second below the terminals 17, third below the terminals 14, and fourth below the terminals 13. A Chi-square test was made of the distribution of egg masses found in the top four branches exclusive of the terminal. No significant difference was found, although a larger sample may detect some difference.

TABLE I

Distribution of Egg Masses and Laying Sites (Shoots over 6") on Eighty Trees

Crown Level	No. Egg Masses per Level per Tree	No. of Shoots over 6" per Level per Tree	No. of Egg Masses per 1000 Shoots
Upper	1.03	13.9	7.4
Middle	1.04	38.8	2.7
Lower	.40	52.4	0.8
Total	2.47	105.1	2.3

The laying site of the tent caterpillar is a shoot or twig. The distribution of these is also shown in Table I. About half of these possible sites occur in the lower crown and half in the middle and upper crowns combined. These laying sites are not the same however, some are longer and thicker than others. The mean length of the last internode of the shoots in the upper crown was 13.9, those in the middle crown 7.2, and those of the lower was 2.8. In comparison to this, the mean length of the last internode of shoots in the upper crown which were bearing egg masses was 17.3. This is a significant difference between all the lengths in the upper crown and those selected by the moth for laying sites.

Previous sampling methods frequently involved cutting down the trees and checking all branches for egg masses. Much time was lost in checking all the branches, and also, because of the destructive process, the system has limited value. A later method (Connola et al. 1957) involved cutting ten branches randomly from the whole crown of the tree, and sampling trees on a sequential basis until a decision could be made as to whether the population was going to be heavy enough to cause noticeable defoliation (from aircraft) or not. This system, although not destructive, has some disadvantages. Because the branches are selected from the whole crown, a large number of zero's will be obtained, adding to the number of samples that must be taken before a decision can be reached. If the samplers do not select the branches from different crown levels in the same proportion as they were selected in the basic study used to develop the sampling system, a bias will result. The use of only two defoliation classes reduces its usefulness.

It was proposed that by limiting the sample to the upper branches many of the above difficulties could be overcome. To determine the most efficient number of branches to sample per tree the data for the top four main branches exclusive of the terminal was extracted for the above mentioned 80 trees. The variance between branches (within trees) was 0.24271 and that between trees was 0.16073. These figures were used to calculate the most efficient number of branches to be taken from each tree following the formula of Morris (1955) using a standard error of 10% of the mean. The results appear in Table II.

TABLE II.

Combinations of number of branches per tree (N_B) and number of trees (N_T) necessary to give equal degrees of precision at different mean number of egg masses per branch.

	$\bar{x}$ = 0.5 egg masses per branch		$\bar{x}$ = 1.0		$\bar{x}$ = 2.0	
N_B	N_T	$N_B\ N_T$	N_T	$N_B\ N_T$	N_T	$N_B\ N_T$
1	161	161	41	41	11	11
2	113	226	29	58	8	16
3	97	291	25	75	7	21
4	88	352	23	92	6	24

The branches usually would be cut with a pruning hook and the time taken to move from tree to tree is more than the time needed to cut and examine another branch. It was decided that two branches per tree would probably be the most efficient for, as in the case of the $\bar{x}$ - 2.0, it would be quicker to cut and examine five additional branches than to move to three additional trees as would be necessary with one branch per tree. On the other hand it probably would not be faster to cut and examine five additional branches if three branches were taken per tree than to move to one extra tree. Based upon these studies sampling the following year was based upon two branches per tree. Thirty useable plots were established with five to twenty trees per plot. These formed the initial sample from which the basic information necessary for a sequential sampling system was derived.

Basic Data Necessary for the Plan

The first step in preparing a sequential sampling system is to determine the type of frequency distribution into which the samples fall. This can be most readily done when one has a large number of random samples from a single location for one year. The frequency distribution is compared with theoretical distributions using a chi-square test. However, as in the present case, when a large number of small samples are available from scattered locations, a comparison has to be made between the mean and variance. In the present study there was a relationship between these two statistics which largely disappeared when transformed to a log (x + 1) basis. When the latter data was tested with Bartlett's test of homogeneity of variance it was found that a value as large as that found would be exceeded 90 percent of the time just through random errors. This indicated that the transformation was effective in reemoving the relationship between the mean and variance and that the distribution of samples approximates the negative bionomial.

The next step in setting up a system of sequential sampling is to define the classes to be used. In this case the system for estimating the defoliation as outlined by Duncan et al. (1956) and modified by C.E. Brown (per com.) was used.

Three classes were used:

Heavy: Aspen trees completely stripped and conspicuous feeding damage on other species including underbrush.

Moderate: Occasional aspen completely stripped, most aspen with tops thin; little feeding on underbrush.

Light: No trees showing complete defoliation. Feeding damage confined to top of aspen crowns; little or no feeding on other tree or brush species.

Estimates following this system were made in the same plots the year following the egg mass survey. These plots were separated by defoliation classes and the number of egg masses compared between classes to give some idea of where the boundaries should fall. Unfortunately only about thirty plots were available, most of which fell in the light class. This is a small sample upon which to make decisions of boundaries and those proposed should be considered only as first approximations which may be revised as more information becomes available. The boundary between the light and moderate defoliation was set at 1.2 egg masses per sample of two branches from the upper crown; this is equivalent to about 7.5 egg masses for the whole tree. The boundary between the moderate and heavy classes was set at 2.4 egg masses or the equivalent of about 15 per whole tree. These are somewhat heavier than the levels indicated by Hodson (1941). He indicates that for similar diameter classes (3-5 inches) complete defoliation occurs with 9-14 egg masses per tree. The class limits were then set as follows:

No. of egg masses per two branch sample	Defoliation Class
0.8 or less	Light
1.6 to 2.0	Moderate
2.8 or more	Heavy

Allowable errors were set at 0.10 for all cases. This sampling technique will probably be used to follow populations in the field rather than form the basis for control decisions. For this purpose changes in population densities at low levels are just as important as changes at high levels and the same allowable error was used for all lines of decision.

The Sequential Analysis Plan

The statistics necessary for calculating the plan are found in Table III.

TABLE III

Basic Data for C lculating Decision Lines

Statistic	Light vs. Moderate	Moderate vs Heavy
m_1	0.8	2.0
m_2	1.6	2.8
k	13.88118	13.88118
p_1	0.05763	0.14408
p_2	0.11526	0.20171
q_1	1.05763	1.14408
q_2	1.11526	1.20171

This resulted in the following decision lines for

Light vs Moderate

$$d_1 = 1.10050n - 3.43255$$

$$d_2 = 1.10050n + 3.43255$$

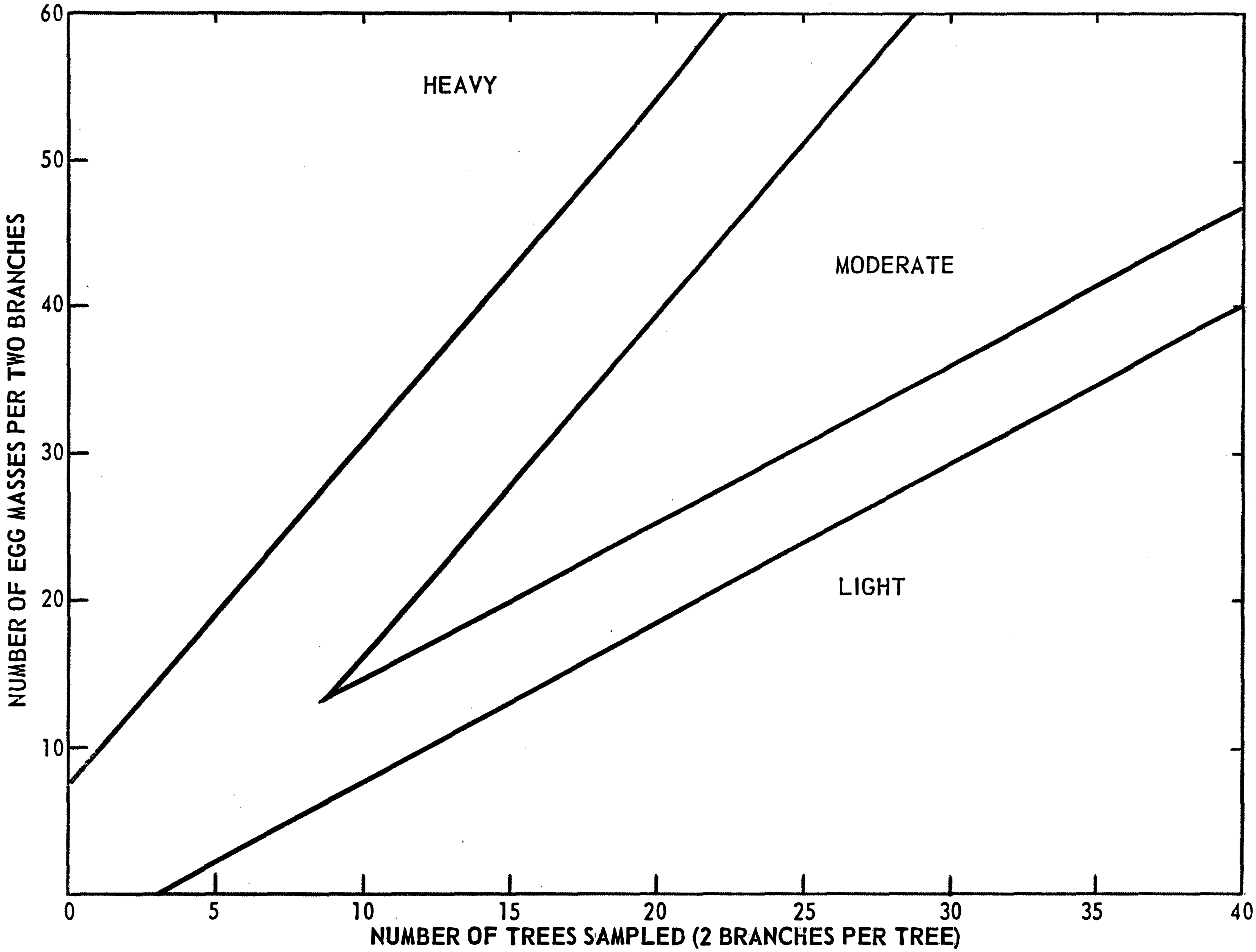
and the following for Moderate vs Heavy

$$d_1 = 2.38104n - 7.66651$$

$$d_2 = 2.38104n + 7.66651$$

The K was calculated after the method of Waters (1955) using the 30 above-mentioned plots. The sequential graph is illustrated in Fig. 1, and the sequential table for use by field personnel appears in Table IV. Because of the limited data, revisions to the table and the graph may be necessary as more data is accumulated. The operating characteristic and average sample curves were not calculated. These will be prepared when the sampling system is finalized.

Fig. 1. Sequential graph for the forest tent caterpillar showing the decision lines as related to the cumulative number of egg masses per two-branch tree samples.


HEAVY
MODERATE
LIGHT
NUMBER OF EGG MASSES PER TWO BRANCHES
NUMBER OF TREES SAMPLED (2 BRANCHES PER TREE)
0
5
10
15
20
25
30
35
40
50
60

Instruction for Field Application

Select a location and set up a sampling station filling one of the regular permanent collection plot forms (SE141). The stand to be sampled should be at least one acre in extent and if possible the trees three to five inches DBH. Move into the stand a distance at least equal to the height of the trees to eliminate edge affects and then randomly select trees for sampling; use pacing and a table of random numbers.

Cut two branches from the top four branches of the tree exclusive of the terminal. These must be branches which extend to the top of the canopy. Count the number of egg masses in the outer 18 inches of the branch; this branch may be a single long branch such as you would get in a young tree or they may be a branch with many laterals. In either case measure back from the outermost tip for 18 inches and then count all of the egg clusters which occur from the 18 inch point outward whether they occur on the main branch or the laterals. Add the number of egg masses together, record it for the first tree, and check in the sequential table to see if another sample has to be taken. If so, select another tree, cut two branches from it, record the number of egg masses found, add it to the first sample and record the cumulative number of egg masses found on both trees. Check to see if more samples are necessary before a decision can be made. If more samples are necessary repeat the above process until the cumulative number of egg masses falls into one of the defoliation classes.

The following are examples illustrating the use of the table to determine the amount of sampling needed to predict the defoliation at a given site.

1. Two branches are cut from the first tree and one egg mass is found. Reference to the table opposite tree No. 1 shows no decision can be made. Two branches are cut from the second tree and no egg masses are found. The cumulative total is 1 for 2 trees and sampling must continue. No egg masses from a third tree gives a cumulative total of 1 for three trees and still no decision can be made. If from the fourth tree one egg mass is obtained there would be a cumulative total of 2 for 4 trees and reference to the table shows that we can stop and classify the infestation as light.

2. We cut two branches from the first tree and find 6 egg masses. Sampling must continue and we obtain 8 egg masses from the branches of the second tree. This gives 14 egg masses for 2 trees and reference to the table shows sampling can stop here and the infestation is classified as heavy.

3. If we collect samples as follows:

Tree No.	No. Egg Masses	Cumulative No. Egg Masses	Procedure
1	0	0	continue sampling
2	1	1	"
3	1	2	"
4	2	4	"
5	0	4	"
6	3	7	"
7	1	8	"
8	2	10	"
9	1	11	"
10	2	13	"
11	2	15	classify as moderate

The infestation would be called moderate upon the sampling of the eleventh tree. It should be noted that unless the population is heavy at least four trees have to be sampled before a decision can be made.

If by the end of 25 trees no decision has been reached stop sampling. The population probably falls in the boundary zone between the classes and should be so indicated.

Table IV

Forest Tent Caterpillar Sequential Sampling

Date............Plot No........Location.....................................

Name...............Ave. Height of Stand......Ave..D.B.H. Stand..........

Tree No.	HT.	D.B.H.	No. Egg Clusters	Tree No.	HT.	D. B.H.	No Egg Clusters

No Egg Clusters

Number of Trees	Light / Continue sampling	Continue sampling / Moderate	Moderate / Continue Sampling	Continue Sampling / Heavy
1	-	-	-	11
2	-	-	-	13
3	-	-	-	15
4	2	-	-	17
5	3	-	-	19
6	4	-	-	22
7	5	-	-	25
8	6	-	-	27
9	7	13	13	30
10	8	14	16	32
11	9	15	18	34
12	10	16	20	37
13	11	17	23	39
14	13	18	25	42
15	14	19	28	44
16	15	21	30	46
17	16	22	32	49
18	17	23	35	51
19	18	24	37	53
20	19	25	39	56
21	20	26	42	58
22	21	27	44	61
23	22	28	47	63
24	24	29	49	65
25	25	30	51	68

Discussion

It should be noted that the following features of the system are weak and additional information is needed.

1. Frequency Distribution: This is based upon indirect evidence of the relation between the mean and variance. One large sample of perhaps 500 samples (1000 branches) is needed from one moderately infested stand at one time. Failing this many more plots are needed to obtain a clearer understanding of the relation between the mean and variance, particularly at the moderate and high infestation levels.

2. Estimate of the Parameter K.
   Additional samples are needed to define this parameter more accurately.

3. Defoliation Levels: This is perhaps the weakest part of the system. Information is needed to define the size of the populations which results in light, moderate, and heavy defoliation.

In addition to these it should be noted that the following factors do not enter into the sequential sampling system and have to be considered in interpreting the results.

1. There is considerable variation in population density between adjacent stands and the stand sampled may not be representative of the general conditions of the district.
2. Changes in the number of eggs per egg mass throughout the history of an outbreak should be checked.

3. Changes in the amount of foliage produced between years as a result of defoliation may be important.

4. Variations in the survival of the insect between eggs in the autumn when the sample is made, and mature larvae the next summer when the damage is done.

References

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