A SUMMARY OF CURRENT TECHNIQUES USED FOR SAMPLING SPRUCE BUDWORM POPULATIONS AND ESTIMATING DEFOLIATION IN EASTERN CANADA

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ABSTRACT

Methods currently used by the Canadian Forestry Service and provincial agencies in Ontario, Quebec, the Maritime provinces and Newfoundland are described for estimating population densities of eggs, overwintering second-instar larvae, "large larvae", pupae and adults, and for estimating defoliation. Information is included on the derivation of the techniques and precautions are given regarding their use.

RÉSUMÉ

L'auteur décrit les méthodes couramment employées par le Service canadien des forêts et par les organismes provinciaux de l'Ontario, du Québec, des Maritimes et de la Terre-Neuve pour évaluer les densités de population des oeufs, des larves hibernantes du second stade, des "grosses larves", des pupes et des adultes, et pour évaluer la défoliation. Il inclut des informations sur la dérivation des techniques et indique les précautions quant à leur utilisation.

TABLE OF CONTENTS

(continued)

TABLE OF CONTENTS (concluded)

1. INTRODUCTION

This report describes the methods currently in use in eastern Canada for sampling populations of the eastern spruce budworm (*Choristoneura fumiferana* [Clem.]). The purpose is not to establish standard methods throughout eastern Canada, but to provide the reader with the information necessary for evaluating data from different areas and for making comparisons between areas. For those who are new to the field, the report may also be of use in helping them to decide which techniques might be appropriate to their own needs.

The reader may wonder why such differences in methods exist, since most of the sampling is being carried out by the same agency, the Canadian Forestry Service. However, it must be remembered that forest management in Canada, including forest protection, is a provincial responsibility. Different provinces have developed different strategies for dealing with the spruce budworm; consequently, information needs are different. Much of the current sampling is aimed at providing information to provincial forest management agencies, and the methods used have evolved to suit the circumstances.

This should not be considered a definitive report on how sampling for the spruce budworm is carried out in eastern Canada. Methods are being modified continually as new information and techniques become available and as needs change. The information in this report represents the state of the art in 1977.

Two other documents concerned with sampling of spruce budworm populations have been produced recently. Both were compiled by Louis Dorais, as chairman of the Committee for the Standardization of Survey and Assessment Techniques, convened by the Eastern Spruce Budworm Council. (This council consists of representatives of the six eastern Canadian provinces and the state of Maine.) The first document, entitled, "Sampling techniques used operationally in New Brunswick, Quebec, Newfoundland and Maine regarding population dynamics, damage evaluations and risk rating mapping during spruce budworm large scale spraying operations" and dated February 1978, is a compendium of the procedures used in those jurisdictions. Much of the information in this compendium inevitably overlaps that contained in the present report. However, where the Dorais report is intended as an operational guide to procedures in use, the present report is designed to provide the reader with an overview of the various techniques available and in use, so that he can select the technique appropriate to his purposes. The second report of the Eastern Spruce Budworm Council is entitled "Report of the activities for 1977 and recommendations of the Committee for Standardization of Survey and Assessment Techniques" and is dated March 1978. This report is essentially a summary of the February 1978 report, but also contains discussions of the state of the art for each type of survey, and includes a series of recommendations related to the future use and standardization of procedures.

Ideally the two reports of the Eastern Spruce Budworm Council and the present report should be integrated to produce a single definitive document. However, such things take time, and meanwhile, in order to obtain a complete understanding of how budworm surveys and sampling are carried out in eastern Canada, the reader is advised to read all three reports.

The present report originated with a series of meetings, held in 1974, 1976 and 1977 and attended by representatives from all agencies involved in sampling populations of spruce budworm in eastern Canada. Essentially, then, this report is a condensation of the work of many people.

In some instances individuals have contributed complete sections, and in these cases their names are included. It is impossible to acknowledge here the names of all who have had some involvement in this report; they are listed in the Appendix.

The following abbreviations are used throughout the report for the names of government agencies involved in sampling budworm populations:

CFS	- Canadian Forestry Service
USFS	- United States Forestry Service
GLFRC	- Great Lakes Forest Research Centre
LFRC	- Laurentian Forest Research Centre
MFRC	- Maritimes Forest Research Centre
Nfld. FRC	- Newfoundland Forest Research Centre
PFRC	- Pacific Forest Research Centre
CCRI	- Chemical Control Research Institute
IPRI	- Insect Pathology Research Institute
FPMI	- Forest Pest Management Institute (amalgamation of CCRI and IPRI)
QLF	- Quebec Ministry of Lands and Forests

The various sampling methods are grouped according to the stage of the insect's life cycle that is being sampled: egg, second instar larva, large larva, pupa or adult. The descriptions of the sampling methods are followed by a section on the assessment of defoliation. Since most of the techniques originally employed English units, measurements are given in English units when these techniques are described.

The report ends with a body of information that is recommended for inclusion in all reports on control operations or experimental trials of control techniques. Those attending the last of the three meetings agreed that this information is necessary for a full understanding and evaluation of any such operation or trial.

2. EGG SAMPLING

2.1 Sample Unit

One whole branch is used as the sample unit throughout eastern Canada. The rationale for the choice of this unit is discussed in Morris (1954 and 1955).

The data are expressed as numbers of egg masses per 10 m^2 of foliage (originally per 100 ft^2). Different methods of determining the area of foliage have evolved in different parts of Canada. These are as follows:

i) Length of branch from tip to last living branch nearest tree bole (= L) x width (= W) at 1/2 L.

ii) L x W at 1/2 L adjusted for defoliation by measuring L and W of foliated branch only.

iii) L x $W/_2$ where W is the widest dimension of the branch, usually at its base.

iv) L x $W/_2$ adjusted for defoliation as in ii).

v) The rectangular method, used in Quebec, where branches are cut up into small pieces, then loosely arranged into a rectangle; the lengths of the sides are then multiplied to give the area.

The results of measuring branches by methods iii) and v) are compared in Section 2.9.

Although there has been some attempt at standardization since 1976, several of these methods are still in use. For general purposes such as categorizing egg densities into high, medium or low, the differences among the various methods are not likely to be significant. However, for more accurate assessments the method used to compute the branch surface area should be noted.

2.2 Distribution in Tree

Intertree variance is higher than intratree variance. Therefore, a single mid-crown branch is adequate to establish infestation classes for extensive surveys.

For intensive studies (e.g., of population dynamics) intratree variance among crown zones is important, and branches should be taken from each crown zone (Morris 1955).

2.3 Number of Samples

Data on intra- and intertree variance of egg-mass density/10 ft^2 on balsam fir (*Abies balsamea* [L.] Mill.) in New Brunswick are contained in Morris (1955). From these data the number of samples for a required precision can be calculated (see also Miller et al. (1972) and Webb et al. (1956) for additional information for New Brunswick, and Fettes (1950) for information for Ontario).

2.4 Sequential Sampling

Classification of infestations, on the basis of sequential egg sampling carried out on a single mid-crown branch, as light (<25 egg masses per 10 m^2), moderate (50-100 egg masses) or severe (>200 egg masses) is described by Morris (1954) for balsam fir. The same classification is also currently being used for white spruce (*Picea glauca* [Moench] Voss), on the assumption that the statistics derived for balsam fir can be applied to white spruce as well. This assumption needs checking. For extensive egg surveys the maximum number of branches sampled at each sample plot is five in Quebec, three in New Brunswick, and six in Ontario.

When such data are used to express population density, averages are determined by summating egg counts per sample plot, then dividing the total branch surface examined. The number per unit area for each branch is not calculated first.

A simpler version involving only two categories is shown in Table 1 (from Prebble [1975]).

Table 1. Sequential sampling of spruce budworm eggs. Sample unit is one mid-crown branch per tree from balsam fir.

No. of sample units	Balsam fir	
	Population category	
	Low	High
	(Cumulative egg-masses per 100 ft^2 (ca 10 m^2))	
1	-	313 or more
2	138 or less	469
3	293	624
4	448	779

2.5 Parasitism

Population estimates should include only non-parasitized egg masses. Parasitized eggs turn black. Egg masses with more than 50% of the eggs

black are classified as parasitized; those with fewer than 50% black are classified as non-parasitized. Information on rates of parasitism may be included in the presentation of data, but care must be taken to ensure that there is no confusion about the number of non-parasitized egg masses.

2.6 Sampling Period

Samples may be collected and examined at any time after oviposition is complete until the following spring. Estimates of the number of egg masses lost during the fall and winter vary between 25% and 75%. Sampling should therefore be carried out as soon as possible following the end of oviposition, i.e., during the latter half of August and September.

2.7 Technique

The foliage is examined visually for all egg masses; egg-bearing needles are removed and counted and a sample is kept for estimation of the number of eggs per egg mass.

During the first half of August both hatched and unhatched masses will be encountered. After August all egg masses should have hatched. Up to 25% of the old egg masses remain on the foliage until the following August or September. These are dirtier and more opaque than emerged egg masses of the current year and can be reliably distinguished with experience. A proportion of the egg masses is almost invariably missed during the first examination and it is recommended that at least a partial check be conducted by a different worker.

Various techniques have been developed for assisting in the counting of eggs and egg masses. Eidt and Cameron (1970) found that "poaching" egg masses made it easier to count the number of eggs in an egg mass. Retnakaran and French (1971) describe a technique for separating individual eggs. Simmons (unpubl.) found that complete egg masses could be removed from the needles intact by soaking the foliage in baking soda dissolved in boiling water. He has also explored the use of stains for making egg masses more visible. Egg masses, including those that have hatched, fluoresce under UV light, but care must be taken to avoid wavelengths harmful to human eyes.

Of these techniques, UV light is the only one of value in the detection of hatched egg masses. However, the stomatal bands on balsam fir also fluoresce, and care must be taken to distinguish these from egg masses. For best results, observations should be made in the dark, and most Canadian workers who have tried the technique feel it is more trouble than it is worth.[1]

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[1] With development of an automated counter by the USFS in Maine a reassessment of this technique may be necessary.

2.8 Examination Time

Balsam fir 60 min/br (should be repeated by second observer)

Spruce 120 min/br (repeated)

2.9 Comparison of Two Different Techniques for Measuring Branch Surface for Egg Density

The following comparisons were made in Quebec by P. Benoit (LFRC) who provided the information for inclusion in this report. The comparisons were made on 700 branch samples using the following methods:

A. Rectangular (LFRC): rearrangement of branch foliage to form a loose rectangle of foliage. Surface = length x width.

B. Triangular (QLF/1976, 1977): length of branch measured from the first green branchlets at the base as far as the tip of the branch; width taken at its widest dimension, usually at the base of the branch. The surface is obtained as follows: $\frac{\text{length x width}}{2}$

This method assumes that balsam fir branches are generally triangular. Occasionally, some very oddly shaped branches have to be reshaped.

Mathematically, both methods should yield similar results; however, with the LFRC method there is a danger of expanding or compressing the branch surface through manipulation.

The results (Table 2) show that the rectangular method used by LFRC increases the estimate of the branch surface by some 13%, thereby underestimating the egg population density.

Table 2. Estimates of branch surface area made by the "triangular" method expressed as a percent of the measurement by the "rectangular" method, and determined by nine different technicians (Benoit unpubl.).

Technician	Number of branches	$\frac{\text{triangular} \times 100}{\text{rectangular}}$
A	52	89.2 ± 13.9
B	64	89.6 ± 14.3
C	44	81.0 ± 9.8
D	98	96.2 ± 11.3
E	87	85.4 ± 15.6
F	34	95.5 ± 15.8
G	94	95.5 ± 18.1
H	170	72.3 ± 15.3
I	59	103.4 ± 22.1

3. SECOND INSTAR LARVAE

3.1 Sample Unit

One whole branch is the sample unit used everywhere except in Quebec, where a 45 cm branch tip is the sample unit.

Miller (1958) showed that an insignificant number of eastern spruce budworm larvae overwinter on the tree trunk; hence the branch is an acceptable sample unit.

3.2 Distribution in Tree

Intertree variance is higher than intratree variance (Miller et al. 1971). For extensive surveys to establish infestation classes a single mid-crown branch per tree is adequate.

For detailed studies (e.g., of population dynamics) a branch should be taken from each of the four crown zones. Distribution of overwintering larvae differs from that of eggs or feeding larvae (Miller and Kettela 1972).

3.3 Number of Samples

Some data on distribution of larvae on balsam fir are contained in Miller et al. (1971). Additional data (Miller, unpubl.) are given in Table 3.

Table 3. Tentative estimates of variance-mean relationships for overwintering second-instar larvae on mid-crown branches of balsam fir, and required sample size for 20% precision.

Mean	Variance	Required number of branches
2	2.3	14
4	5.4	8
6	10.5	7
8	17.1	7
10	25.0	6
>10		5

3.4 Sampling Period

Overwintering mortality is low (Miller 1958); hence the collection of sampling units for second-instar larvae can be carried out any time larvae are in hibernacula, from September through April. However, forcing is not practical until larval diapause requirements have been satisfied. In Quebec forcing starts in mid-February; elsewhere it starts in mid-March. Washing of larvae from foliage can be carried out any time from September through April.

The emergence period of the larvae during forcing is related to the length of the cold period spent in hibernacula. The longer the cold period the more rapid and concentrated the emergence period. Since all these techniques require considerable space, the time required for emergence may be a serious consideration.

3.5 Techniques

A. Washing foliage with hot NaOH (Miller and McDougall 1968, Miller et al. 1971). The following description of the current technique used in New Brunswick was provided by C. Miller and E. Kettela for this report.

(i) Foliage Collections: Sample foliage (mid-crown branches) can be collected in the late fall, throughout the winter, and in the early spring. Branches are measured (length x width), clipped, and put into paper bags, which should be tagged with plot, tree, and branch number. If prolonged storage is necessary the foliage should be kept at 0°C.

(ii) Washing the Samples: Equipment: 10 litre plastic pails; 400 ml collecting jars.

The samples to be washed on one day are left in a warm room overnight to thaw. Make two sets of tags showing plot, tree, and branch number, and tag washing pail and collecting jar. Transfer branch measurements to data recording sheet. Add 90 g of sodium hydroxide per pail and fill to the 9 litre mark with hot water (50°C) to make a 1% solution. Put foliage in pail, usually one branch per pail; do not pack tightly, and keep foliage completely submerged with a weighted screen top. The foliage should remain in the pails for 5 hours. Stir every hour.

(iii) Processing the Foliage: Equipment: large sink or 90 x 150 x 9 cm deep tray, preferably with a corrugated bottom, fitted to sewer outlet; two interlocking sieves (soil sieves)--top sieve should be about 0.8 mm mesh, bottom sieve 0.25 mm mesh; wire basket made of hardware cloth, 5 mm mesh, with a 'false' bottom (wire basket should fit inside a 40 cm x 20 cm tub or container).

Pour the liquid content of the pail through the two sieves. Place wire basket in tub. Pour the remaining contents of the pail into the wire basket. Rinse the pail and pour the rinse through the sieves. With a flexible hose, wash the foliage thoroughly in the wire basket inside the tub and discard. (Branches should be completely bare: they should contain no needles or bark scales.) Pour the contents of the tub through the sieves, being careful not to overflow the sieves. Rinse the tub and pour through the sieves. Wash the contents of the coarse sieve into the fine sieve. Wash the contents of the fine sieve into the tagged collecting jar.

Spruce foliage tends to yield very little debris. Balsam fir, however, tends to have a good deal of debris, especially branches from mature trees, and there is a danger of plugging the fine sieve, overflowing both sieves, and losing larvae. This has to be checked carefully and it may be necessary to transfer the debris from a 'dirty' sample to the collecting jar on a step by step basis.

(iv) Separating Larvae from Debris: Equipment: 5000 ml separating funnel.

Pour the contents of the collecting jar into the separating funnel. Rinse jar to remove larvae that may stick to the sides. Add hexane to the separating funnel to create a 3 mm layer on top of the aqueous solution. Shake the water-hexane mixture vigorously to obtain a thorough mixing and allow 5 min. to settle. About 70 to 90 percent of the plant debris settles to the bottom of the funnel and 99 percent of the larvae collect at the oil-water interface. Draw off the plant debris that has settled at the bottom of the funnel and discard. Draw

off the oil-water fraction into 400 ml beakers to be vacuum filtered. Too much plant debris hinders the separation process; therefore only 100 ml of debris should be processed at one time.

(v) Vacuum Filtering: Equipment: 15 cm Buchner funnel; filtering flask, 5000 ml; Filtervac (rubber diaphgram); filter pump; gridded filter paper; microscope.

Fit the Buchner funnel to the 5000 ml filtering flask using a molded rubber diaphragm (Filtervac) and connect the filter pump. Pour debris onto the wetted filter paper. It is important not to overload the filter paper because small larvae could be missed when one is checking under the microscope. It is also helpful to have the filter paper gridded to a size that is visible under the microscope. The 'washed' budworm larvae have black head capsules and very light colored bodies.

NOTE: Careless handling of foliage samples can result in large counting errors with this technique.

Examination time for the Miller and Kettela method includes 5 hours for soaking and 30 min per branch for preparation and examination.

Miller et al. (1971) estimated the *cost* of washing larvae to be higher than that of beating for large larvae but only one-third that of counting egg masses.

B. Forcing "Enclosed Box" (see Miller 1958).

Diapause must be satisfied before larvae will emerge from hibernacula. This can be achieved by chilling clipped branches in the laboratory, or by delaying sampling until diapause is completed in the field (early March). Any sealed container with a transparent collecting vial attached is adequate as an emergence cage. The emergence cages are loosely filled with the foliage samples or bark samples and the covers are sealed with masking tape. They are then placed on their sides in a holding rack with the vials uppermost, and are pointed toward a bank of lights that serve as a light source. The lights are in operation approximately 10 hours per day. The larvae, attracted into the vials by the light, are collected and counted periodically during the emergence period.

A modification of this method is currently used in Quebec to check pre-spray budworm populations in April. It involves placing the sample unit (a 45 cm branch tip) in a small polystyrene ice bucket with the top closed. The bucket is painted black on the outside to reduce

light transmission, and a transparent plastic vial is fitted into the bottom of the bucket at the centre. All buckets are placed horizontally on a wire fence with the vials facing the light. (The buckets are protected from direct sunlight, however.) Emerging larvae are attracted to the light, enter the vial, and are counted daily with a minimum of manipulation. About 50% leave the bucket within a few days. The branch is kept in the bucket for a total of 10 days, after which it is examined visually. At that time, the larvae have grown to third or fourth instar and are easily recovered. Alternatively, the branches can be left in the boxes until the larvae have developed into the third (and fourth) instars, when they can be removed by beating the branches in a drum as in large larval sampling (see page 16).

(i) Examination Time: Time is not a serious factor with this technique since it requires only a few minutes to set up each sample and a few minutes to check each day for emerged larvae. The provision of suitable space and lighting is a consideration since the cages have to be left for several weeks.

C. Forcing - Paper Cone Method.

As in the "enclosed box" method, diapause must be satisfied. Since the branches are suspended in open bags they should be freshly cut to avoid the loss of needles; therefore, this method is suitable only when diapause has been completed under field conditions.

The technique was first devised in the 1950s at the Forest Insect Laboratory in Sault Ste. Marie. Samples are collected in April or early May, before emergence has begun. Branches are wrapped with paper towelling or brown wrapping paper to make a cone-shaped covering with the open apex at the butt end of the branches. The wrapped sample is then suspended under a strong light. The larvae are collected as they crawl on the paper; those that drop are caught on a sheet of paper placed beneath the sample ringed with tanglefoot. The suspension string is also ringed with tanglefoot. The samples are sprayed periodically with water during the emergence period.

(i) Examination Time: Examination time is similar to that required for the enclosed box method. However, because tanglefoot is used, this method is

somewhat messier than the enclosed box method; it also requires slightly more time for examination and more space.

3.6 Correlation with Subsequent Life Stages

Overwintering larvae are sampled frequently to provide a check on population densities prior to spraying and to help delineate spray boundaries. It is therefore essential to have some idea of the relationship between the counts of second instar larvae and the subsequent numbers of third and fourth instar larvae and/or the amount of subsequent defoliation.

Information on these relationships can be found in Miller et al. (1971) and Miller and Kettela (1972). Further information (as yet unpublished) is available from G.M. Howse (GLFRC), Y. Hardy (Laval University), E. Kettela (MFRC), and A.P. Randall (FPMI).

4. LARGE LARVAE (THIRD - SIXTH INSTAR)

4.1 Sample Unit

1. Extensive surveys: 45 cm (18 in.) branch tip

2. Intensive sampling: whole branch

The "18 in." tip was introduced as a sampling unit by Atwood (1944). The rationale for use of the whole branch has been exhaustively studied for balsam fir by Morris (1955).

In extensive surveys no consideration is normally given to the number of buds (expanding shoots) per branch. However, since density is affected by the number of feeding sites, the number of buds should be recorded whenever possible.

4.2 Distribution in Tree

For intensive sampling programs (e.g., preparation of life tables) branches should be taken from each crown zone of dominant and codominant trees. This is quite feasible in moderate or high density populations where the number of samples required for a given precision is not too great. However, at low population densities the required number becomes so large that obtaining samples from each crown zone is impractical. In order to maximize the amount of information obtained with limited manpower, Miller (1964) proposed the use of a single branch from the B-crown zone of each sample tree. (Mid-crown branches serve the same purpose.)

If sampling is being carried out to assess the effects of a spray application, account should be taken of the fact that deposit

(and presumably larval mortality) will be greater on the upwind side of the tree (J.A. Armstrong, pers. comm.).

4.3 Number of Samples

Data on intra- and intertree variance/10 ft^2 for whole branches for the four crown zones of balsam fir in moderate to high densities are contained in Morris (1955); from these, the number of samples for a required accuracy can be calculated.

Miller (1964) presented equivalent data for low density populations on balsam fir. For this report, more recent information on the relationship between larval density and the required sample size for balsam fir has been provided by C. Miller as follows: for whole mid-crown branches in Table 4, for 45 cm tips in Table 5, and for unit area (square metres) in Table 6.

Table 4. Tentative estimates of variance-mean relationships for third/fourth instar larvae per whole mid-crown balsam fir branch. (Miller, unpubl.)

Mean	Variance	Required number of branches
1	1.7	42
2	4.5	23
4	13	20
6	25	16
8	36	14
10	50	12
20	140	9
30	250	7
40	400	6
50	530	5
>50		

Table 5. Tentative estimates of variance-mean relationships for third/fourth instar larvae per 45 cm balsam fir branch tip (one mid-crown branch per tree). (Miller, unpubl.)

Mean	Variance	Required number of branches
1	1.8	45
2	5	31
4	14	22
6	25	17
8	40	16
10	54	14
15	100	11
20	150	9
30	280	8
40	400	6
50	600	6
>50		

Table 6. Tentative estimates of variance-mean relationships for third/fourth instar larvae per square metre of balsam fir branch surface. (Miller, unpubl.)

Mean	Variance	Required number of branches
4	15.5	24
6	24.0	17
8	36.0	14
10	42.0	10
20	150	9
40	375	6
>50		

More information is required on the number of crown zones from which sampling units should be collected for sampling low density (endemic) populations.

A simple classification into low or high population density by sequential sampling is shown in Table 7 (from Prebble [1975]).

Table 7. Sequential sampling of spruce budworm larvae developed for New Brunswick. Sample unit is one 45 cm tip per tree from fir, and one from spruce.

No. of sample units	Balsam fir		Red spruce	
	Population category		Population category	
	Low	High	Low	High
	(Cumulative larvae)		(Cumulative larvae)	
1	-	28 or more	-	34 or more
2	-	36	-	47
3	2 or less	43	3 or less	60
4	9	50	7	74
5	16	58	11	87

4.4 Sampling Period

Sampling can be carried out any time after larvae are established in the buds or new shoots, with the following provisos:

1. Mortality during the large larval stage is high; therefore, it is imperative that budworm phenology and the date be recorded.

2. Comparison of densities from year to year can be made only if budworm phenology at time of sampling is identical or if appropriate adjustments have been made.

3. As larvae mature the probability of their dropping when disturbed increases. Therefore, basket attachments on pole pruners should be used for sampling fifth and sixth instars (see Section 4.6 below).

4.5 Techniques

Foliage is examined visually for the presence of larvae, or else larvae are extracted by mechanical aids (see Section 4.7) and then counted.

On freshly gathered branches third and fourth instar larvae are found only in buds or staminate flowers. However, on branches that have been stored or carried in bags for any length of time, fifth or sixth instar larvae may be anywhere on the foliage or in the bags, and a complete search will therefore be necessary.

4.6 Baskets

DeBoo (1974) has shown that, up to the fourth instar, losses occurring when larvae that have been disturbed drop from branches are less than 6%. However, losses can rise to 30% for sixth instar larvae. Therefore, basket attachments on pole pruners should always be used when larvae are in fifth or sixth instar.

4.7 Drums

The drum technique evolved from earlier attempts to speed up larval counting by extracting larvae from samples by various mechanical and chemical techniques (DeBoo et al. 1973).

The equipment now used in many parts of eastern Canada consists essentially of the following six parts (Martineau and Benoit 1973):

(1) a galvanized steel drum, 60 cm (24 in.) deep and 48 cm (18.) in diameter

(2) a perforated cap (for 16 oz (ca 500 ml) screw top widemouth glass jar) welded close to the bottom end to fit a 5 cm (2 in.) hole, and a handle fixed near the point of balance on the opposite side of the drum

(3) a removable rectangular iron screen tray 59 x 45 cm (23.2 x 18 in.), made of mesh 1.25 cm (0.5 in.) framed with a welded steel rod .63 cm (0.25 in.) in diameter

(4) a 16 oz (ca 500 ml) collecting jar

(5) a paint brush (7 cm wide)

(6) a folding wooden stand built so as to keep the drum at the required angle and height when in operation, and fitting inside the drum during transportation.

The separation of the insect material from the foliage by the drum technique is done in three steps: (1) beating of the branch sample vigorously against the screen table and the side of the drum (30 strokes in all), (2) brushing down the screen and the inside of the drum to direct larvae into the jar, and (3) removing the jar for examination of contents.

4.8 Beating

For rapid, extensive surveys to provide indices of population density the beating technique has been used commonly throughout Canada. A standard technique for budworm sampling has been agreed upon for eastern Canada. At each sampling location two samples are taken, one

from each side of the tree, from 10 trees. Each sample consists of the number of larvae falling onto a cloth tray 3 ft x 3 ft (ca 1 m^2) when the foliage in a volume of 1 yd^3 (ca 1 m^3) above the tray is jarred.

Beating is most suitable for pre-outbreak surveys of large larval populations. Although tree beating samples are used primarily for quantitative studies, Miller et al. (1968) were able to show that, when they are taken over wide areas, they provide a population index that compares favorably with other, more intensive methods of sampling.

Number of beating samples: Table 8 presents data (provided by C. Miller for this report) on the required number of samples for balsam fir in New Brunswick.

Table 8. The required number of sample units (3 ft x 3 ft (ca 1 m x 1 m) tray) to measure budworm abundance at a set precision of 20% of the mean.

Mean larval density per tray	Observed variance	No. of trays
0.5	.45	45
1	1.2	29
2	2.8	18
3	4.8	13
5	9.5	10
7	15.	8
10	24.	6
15	40.	4
20	60.	4

There is evidence (Miller, unpubl.) that at densities above 5.0 larvae per tray, variance between trees is greater than variance within trees.

If this assumption is correct then Table 8 suggests the following sampling scheme:

Mean larvae per tray	No. of trees	No. of tray samples per tree
Fewer than 1.0	10 (minimum)	2
1.0 to 5.0	10	2
5.0 to 10.0	10	1
10.0 +	5	1

At densities below 1.0 larva per tray, zero counts begin to create a problem. For example, at a density of 1.0 larva per tray, field data show that 50% of the tray samples will have zero counts. Consequently, when larvae are very scarce, serious consideration should be give to the recommendation to sample at least 10 trees (20 trays) and, if no larvae are found, to continue sampling until one larva is found.

5. PUPAE

5.1 Sample Unit

1. Extensive surveys: 45 cm (18 in.) branch tip

2. Intensive sampling: whole branch

5.2 General

The techniques are similar to those used in large larvae sampling, and data on distribution at moderate to high densities are to be found in Morris (1955).

A simple two-way classification into low or high density populations by sequential sampling is given in Table 9 (from Prebble [1975]).

Table 9. Sequential sampling of spruce budworm pupae developed in New Brunswick. Sample unit is two 45 cm tips per tree from balsam fir, and four from red spruce (*Picea rubens* Sarg.).

No. of sample units	Balsam fir		Red spruce	
	Population category		Population category	
	Low	High	Low	High
	(Cumulative pupae)		(Cumulative pupae)	
1	-	33 or more	-	9 or more
2	1 or less	50	1 or less	12
3	5	66	4	15
4	10	83	8	19
5	14	100	11	23

Since larvae may pupate anywhere on the branch (often moving away from their feeding site to nearer the bole) all foliage must be examined.

Pupae are not dislodged as easily as larvae during the collection of samples, but sufficient are dislodged to warrant the use of

baskets. More information is required on the incidence of larvae dropping to pupate on or near the ground.

The drum technique is considered adequate for extracting pupae for extensive population estimates in Quebec. However, because of damage to the insects it is not suitable if the insects are required for rearing.

Pupal cases remain on the foliage following adult emergence, the time depending upon the severity of the weather. Therefore, allowing for the weather, sampling may be conducted for some time following adult emergence.

6. ADULTS

6.1 Light Traps

Light traps have been used as follows:

a) as an indication of population trends when operated for a number of years in the same location

b) as an indication of moth invasions by the incidence of unusually high catches on particular nights during a single season.

Miller et al. (1979) have shown that catches of female spruce budworm in light traps suspended in the forest canopy, coupled with the density of resident females (determined by pupae sampling), can be used as a crude predictor of egg-mass densities over a fairly wide range of population densities; this sampling method represents a considerable saving in time over conventional egg-mass sampling.

Before light-trap catches can be used as accurate estimators of population densities, however, much information is needed on the effects of the following factors:

a) different wavelengths and energy output of the light sources

b) different trap designs

c) different responses by the two sexes

d) trap location (within canopy, above canopy, in clearings, etc.)

e) mating and oviposition status and age on adult response

f) climate.

6.2 Malaise Traps

These are not in operational use, but their potential is being explored by A.W. Thomas at MFRC.

6.3 Sex Attractant Traps

These are not yet in operational use. Miller and McDougall (1973) demonstrated a correlation between catches of adult males in traps baited with virgin females and subsequent larval populations. Recently developed synthetic lures are more homogeneous than virgin females and should therefore give better correlations. Recommendations for an operational trap and lure have been made (Sanders 1978) and evaluation is now required.

7. HAZARD MAPPING

Areas within which trees require protection are delineated in both Quebec and New Brunswick by assessing the "hazard" to the trees for the coming year. However, the method of assessing hazard differs in the two areas.

7.1 New Brunswick

The method of assessing hazard in the Maritimes is described by Miller and Kettela in Prebble (1975). A summary of the method follows.

The assessment of hazard is based on four criteria: current defoliation, previous damage, recovery, and the prediction of further attack as indicated by egg-mass counts. Each of these four criteria is assigned a numerical value (Table 10).

In hazard evaluation the greatest reliance is placed on egg sampling, because egg-mass counts in August are reliable predictors of budworm abundance and level of defoliation in the following year, and these data are vital to control decisions. About 1000-1500 points are sampled annually throughout the province. Egg-mass counts are separated into five categories: nil, light (1 to 99 masses/100 ft^2 of foliage), moderate (100-239), severe (240-399) and extreme (400+), and are plotted on a 1:125,000 scale map to display 'predicted' budworm abundance by location in the following year.

Defoliation and tree vigor are assessed by ground and aerial surveys. The ground survey covers the 1000-1500 egg-sampling points. At each point the foliage-collection crew estimates current defoliation of balsam fir by the Fettes method (see Section 8), as well as previous damage, and any sign of recovery of previously damaged trees, but it makes no consistent attempt to assess defoliation of spruce. Defoliation is tallied in the field in a code ranging from T (trace), 1 (5 to

15%) through to 9 (85 to 95%), 10a (shoot axil and the following year's bud remaining), and 10b (shoot axil missing).

Aerial surveys are also conducted annually over most of the province during July, along predetermined flight lines which are set two to five miles (ca 3-8 km) apart and take advantage of obvious ground check points. The observer notes, at 30 sec intervals, current defoliation, previous damage (dead tops and/or the grey appearance of the trees), recovery (green shoots on sparsely foliated trees), and the predominant species in the stand. Current defoliation is recorded as light, moderate or severe. The aerial survey data are combined with the ground survey data and plotted on a 1:500,000 scale map using five categories: nil, light (up to 25%), moderate (26 to 65%), severe (66 to 95%), and extreme (all shoots missing).

Previous damage is also a critical factor in assessing hazard. It is recorded in all egg sampling points in four categories: nil (no apparent damage other than to shoots of the current year), light (defoliation evident on 1-year-old twigs), moderate (defoliation evident on 1- and 2-year-old twigs; general thinness of crown foliage and occasional short, bare tops), severe (marked defoliation on 1- and 2-year-old twigs, crown noticeably thin and greyish in appearance and 60 cm or more of bare top).

Trees weakened by budworm attack vary in their ability to produce a crop of new foliage, or to recover, and this is tallied in four categories: good (current foliage crop apparently normal and trees evidently capable of rapid recovery), fair (shoot production moderate, obviously affected by declining tree vigor, but showing fair evidence of ability to recover), poor (some growth capacity), and nil. Recovery is easily assessed owing to the distinctive appearance of clusters of healthy shoots at the ends of otherwise sparsely foliated branches. It is evident mainly in areas protected by spraying and is given negative hazard value (Table 10) for obvious reasons.

In preparing the hazard map, the first step is to calculate a composite hazard rating for each of the egg-sampling points in the province by adding the relevant values for defoliation, previous damage, recovery, and egg-mass density listed in Table 10. The hazard ratings are plotted on 1:500,000 scale maps and hazard is delineated in four categories: low (hazard values ranging from 0 to 7), moderate (8-10), severe (11-14), extreme (15 or higher). Once delineated, hazard areas are checked against two overlay maps, defoliation in the previous season, and current egg-mass density, to permit interpolation between sampling points and to avoid discrepancies. Additional ground checks of tree vigor are sometimes carried out at the request of owners. Hence, the final hazard map is a composite of all available data on the ability of trees to withstand the budworm attack predicted for the following year. In general, the severe and extreme

hazard represents conditions under which tree mortality is highly probable in the following year and much of the forest so classified is sprayed.

Hazard is most easily defined early in the outbreak because it is comparatively easy to determine attack history and tree vigor. However, as the outbreak progresses and control measures are applied to selected regions there arises a mosaic of forest conditions ranging from vigorous stands (in which there are good protective measures) to stands in very poor condition (in which there is no treatment) to stands yielding indifferent results. Within this mosaic it becomes increasingly difficult to isolate severe hazard from low hazard in blocks that can be treated from the air. Therefore, if tree mortality is to be avoided, it is sometimes necessary to treat stands in relatively fair condition in order to include 'patches' of severe hazard.

Table 10. Hazard values assigned to tree condition and budworm abundance, New Brunswick (from Prebble [1975]).

Category	Hazard value	Category	Hazard value
Current defoliation		Recovery	
Nil	0	Good	-3
Light	1	Fair	-2
Moderate	2	Poor	-1
Severe	3	Nil	0
Extreme			
Previous damage		Egg-mass density	
Nil	0	Nil	0
Light	3	Light	1
Moderate	6	Moderate	2
Severe	9	Severe	3
		Extreme	4

Composite hazard rating for a forest stand is obtained by adding the individual ratings corresponding to observed conditions in each of the four factors.

7.2 Quebec

In Quebec, a spruce budworm hazard map is prepared yearly from the data gathered by annual defoliation and egg-mass surveys. This

technique is described by Hardy and Dorais (1976) and the following description has been provided by L. Dorais for this report.

The technique consists of combining the defoliation surveyed over the last four years with the most recent egg-mass survey in order to reconstitute the history of the outbreak for the last four years and to predict conditions in the coming year. The vigor of balsam fir is then evaluated by assuming that heavy or moderate defoliation leads to complete loss of the photosynthetic capacity of the foliage produced during the year under consideration, while no loss is sustained when the defoliation is light. On the basis of Clark's (1961) study on the photosynthesis and respiration of balsam fir, the contribution of each of the last five years of foliage to the productivity of the tree is established as follows: 37, 27, 19, 11 and 6%, respectively, from the current year's foliage to the oldest. The summation of the losses in productivity observed over the last four years, added to the loss forecast for the coming year (based on the density of the egg populations), will yield the total loss predicted for a given area. The territories under observation are then classified into six classes of risk which indicate the ability of balsam fir to recuperate if the outbreak comes to an end or if protection is successful.

The productivity losses for each level of risk are as follows:

Level of risk	Productivity losses
none	0
minimal	1-48
low	49-62
moderate	63-73
high	74-89
extreme	90-100
mortality	100

The following examples illustrate different situations corresponding to the various levels of risk:

Example	History	Productivity losses		Level of risk
1	light defoliation (1974)	0	37	MINIMAL
	egg population severe (1974)	37		
2	heavy defoliation (1973)	19	56	LOW
	light defoliation (1974) (successful spray operation)	0		
	egg population severe (1974)	37		
3	heavy defoliation (1974)	27	64	MODERATE
	egg population severe (1974)	37		

Example	History	Productivity losses		Level of risk
4	heavy defoliation (1974)	19		
	heavy defoliation (1974)	27	83	HIGH
	egg population severe (1974)	37		
5	heavy defoliation (1972)	11		
	heavy defoliation (1973)	19	94	EXTREME
	egg population severe (1974)	37		

The hazard map (Fig. 1) that results from these operations is a visual representation of the forest conditions anticipated for the coming year.

On the basis of this information, it is then possible to delineate the areas in need of protection. The appropriate decision pertaining to each level of risk would be as follows:

1) Generally speaking, the territories where the level of risk is MINIMAL do not require any treatment. The trees are in no danger of dying since practically no defoliation has occurred yet. The high density of the egg population for the coming year is the only indication that some heavy defoliation is expected.

2) When the level of risk is LOW or MODERATE, aerial spraying is recommended. Even though the damage so far has not been too drastic, these forests must be treated to maintain their present condition. Given a successful spray operation, or the end of the outbreak from natural causes, these forests could easily regain their initial vigor. On the other hand, these levels of risk correspond to conditions under which spraying has been most effective, largely because there is a fair amount of foliage left on the trees, and this foliage intercepts relatively large amounts of the insecticide.

3) Areas in which the level of risk is HIGH must also be included within the spray program since this will probably be the last opportunity to act in these areas before it is too late. In these conditions, another year of heavy defoliation would bring the forest to the point of no return. However, the success rates of spray operations under these conditions are not high, since a HIGH risk usually contains some areas in which the outbreak has been more intense and, as a result of back feeding, there is an equivalent of three years of heavy defoliation. Therefore, before a decision is made to spray a HIGH risk area, it is

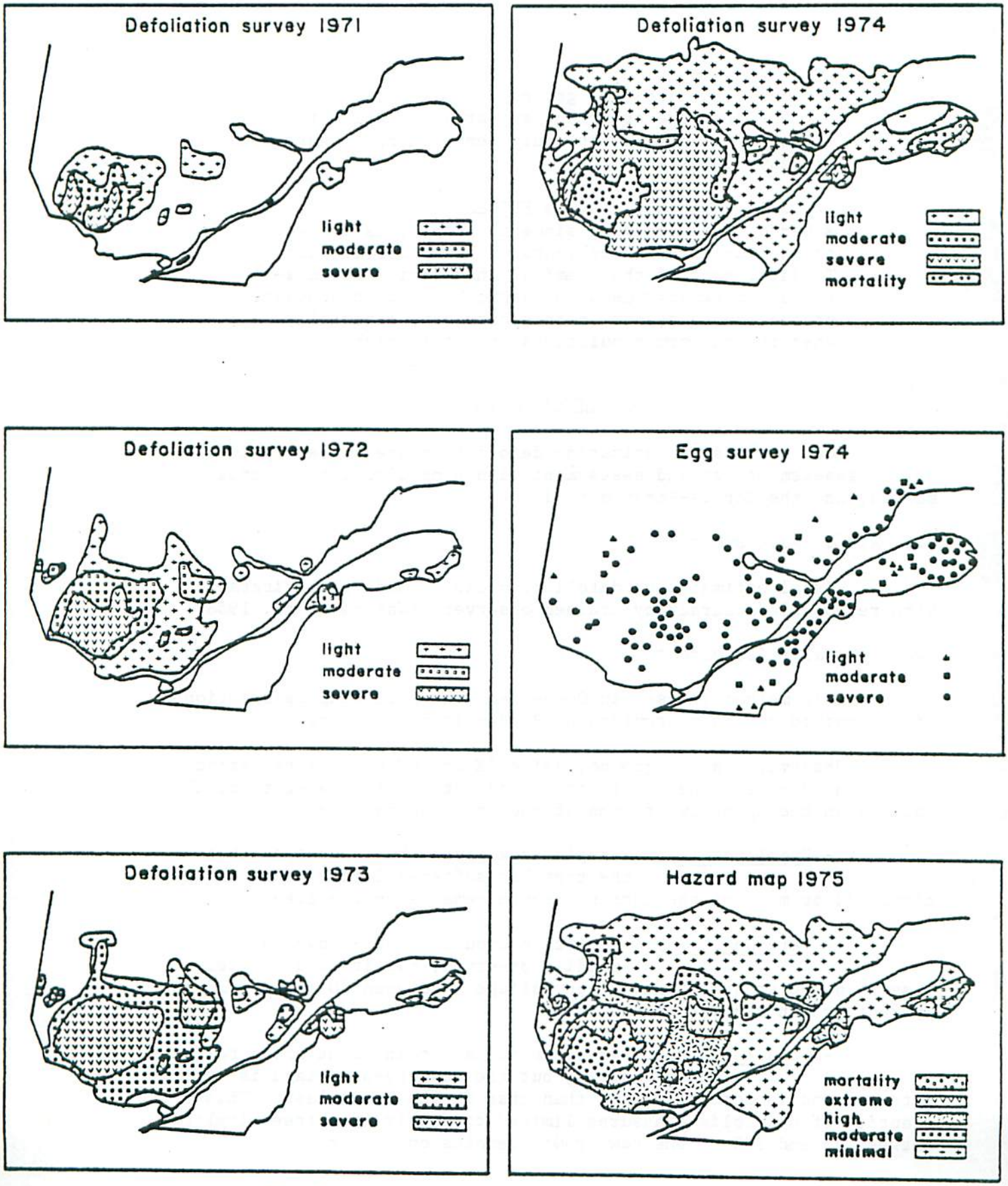

Fig. 1. The elaboration of a spruce budworm hazard map.

advisable to make some ground checks in order to exclude from the treatment any areas in which the trees have sustained an equivalent of three years of heavy defoliation.

4) Areas in which the risk is EXTREME are not considered worth spraying since the forest is unlikely to recover after three years of heavy defoliation. To date, none of the chemical insecticide formulations and timings used in Quebec have given adequate protection to stands in this category, especially when the budworm populations are still high.

8. DEFOLIATION

Four methods of estimating defoliation are currently in use: aerial assessment, ground assessment with binoculars, the Fettes method, and the Dorais-Hardy method.

8.1 Aerial Assessment

Visual estimates of defoliation can be made from aircraft with reasonable accuracy by trained observers (Waters et al. 1958).

8.2 Binocular Assessment

This method is used in Quebec and the following description of the method has been provided by P. Benoit for this report.

Observers on the ground, using 7X and 8X binoculars, stand less than 50 m from the sample tree, and categorize the state of the foliage on the upper two fifths of the crown as follows:

- Excellent (E): A rapid look gives the impression that the tree has suffered little or no defoliation; 75% or more of the current growth remains on the tree.

- Very Good (VG): A certain amount of red-brown foliage is readily observed, but it is definitely less than the amount of new green foliage. Between 50 and 75% of the current growth remains on the tree.

- Good (G): More red-brown foliage than light green foliage is visible, but the new green foliage is readily detected and is more plentiful than that in the Poor class. This quantity of new foliage assures limited to fairly good tree vitality. Between 25 and 50% of the new growth remains on the tree.

- Poor (P): Some new green foliage can be seen, but it is improbable that the tree could survive many years with so little new foliage added annually. A small quantity of new growth is still present, but it is less than in the Good class.

- Very Poor (VP): Only after a careful examination of the crown are any green shoots visible.

- Nil (N): Despite a careful examination of the crown, no new foliage can be seen. This represents total defoliation (100%) of the current year's growth.

8.3 Fettes Method

This method, first described by Fettes (1950), involves obtaining branches from the mid-crown of balsam fir and then visually estimating the percentage of needles removed from each current-year shoot on the branch (see Fig. 2). These are then averaged to provide a percent defoliation for the whole branch.

8.4 Dorais-Hardy Method

This method described by Dorais and Hardy (1976) was devised for balsam fir in which high populations of budworm have prevented normal bud development. It therefore takes into account damage to buds as well as to foliage.

(i) Defoliation Before Spraying: This is recorded in the upper half of the form (Fig. 3). Only last year's three terminal shoots are considered (those circled by the dotted line in the illustration, Fig. 3).

a) Each shoot normally has three (or occasionally more) terminal buds. These are marked as present (1) or absent (0). Where there are more than three present a maximum of three are recorded. The number missing is then expressed as a percentage in the top box (% Brg_n), in this case three out of nine = 33%.

b) Each of the three last year's shoots is then assigned to one of the Fettes defoliation categories (1-12). The percent defoliation is then determined by averaging the figures for the midpoint of each category, in this case (85 + 25 + 55) ÷ 3 = 55%. This is entered in the lower box (% Def_{n-1}).

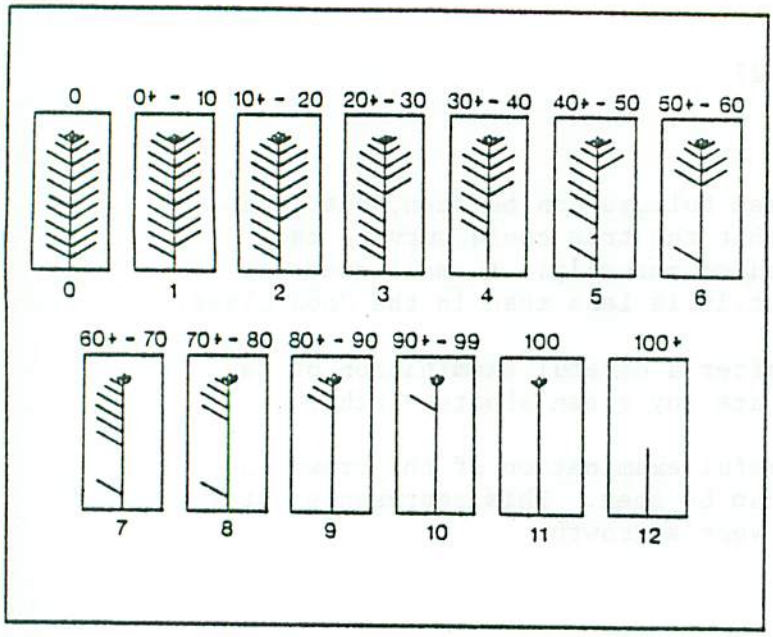

Fig. 2
Method of estimating defoliation after Fettes (1951). Top figures are percent defoliation, bottom are defoliation categories.

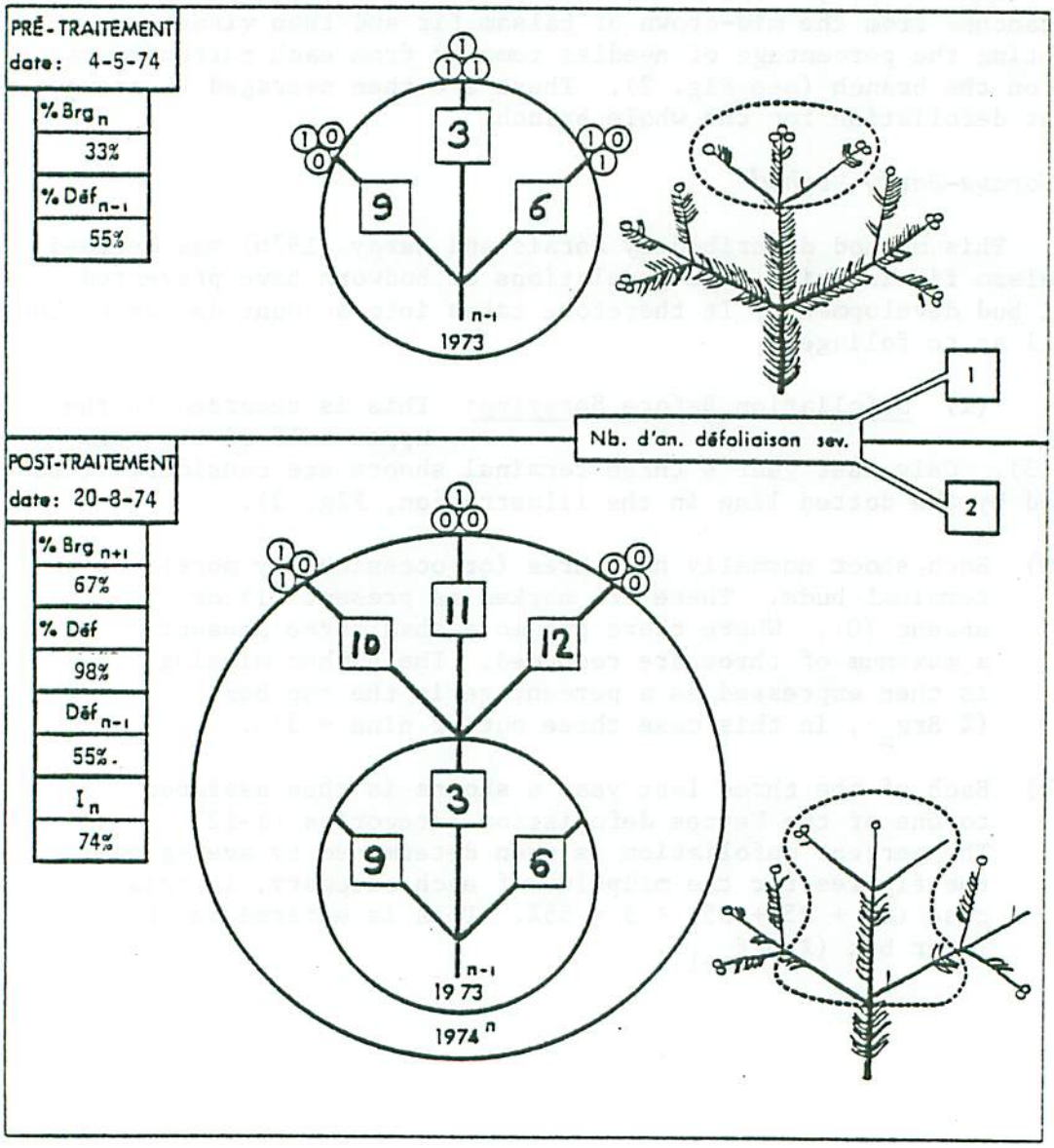

Fig. 3. Method of estimating defoliation after Dorais and Hardy (1976). See text for explanation.

(ii) Defoliation After Spraying: This is recorded in the lower half of the form, following the same procedure as above.

Because of the growth of the tree between pre- and post-spraying, there are now three categories as shown in Figure 3.

The % defoliation in year (n-1) can then be compared in the two samples to ensure that it is similar. An index of the tree's state of health is then calculated. In this calculation the presence of buds is weighted by a factor of 3 since the buds represent the potential for recovery in the following year. The index (I) is then

$$\frac{[3 \times \% \text{ BRG}_{(n+1)}] + \% \text{ Def}}{4} .$$

However, this method does not take into account the production of adventitious buds, which may be produced by heavily defoliated trees.

9. PRESENTATION OF DATA

During the meetings held in 1974, 1976 and 1977 at which the sampling techniques presented here were discussed, some thought was also given to what information should be collected and presented to allow adequate assessment of the success of control operations.

Most of those engaged in the biological assessment of experimental field trials or in control operations in eastern Canada were present at these meetings and agreed on the following list.

The information needed can be divided into two categories:

1. Population data (population densities before and after treatment, and the state of the population when treated).

2. Data which describe the treatment and its application.

9.1 Population Data

Location of plots
Stand description
Number of plots
Number of trees sampled per plot
Number of sampling units per tree
Host tree

Selection of sample trees (random, systematic, objective)
Sampling unit
Size of trees
Date of sampling
Budworm phenology
Population density estimate
Measure of variance of estimate

9.2 Summary of Control Method

Treatment:

Formulation, including additives
Aircraft used
Spray equipment
Active ingredient/volume/hectare emitted
Drops deposited/cm^2
% deposit is desirable, but not essential
Number of applications
Date
Budworm phenology
Weather parameters (during and after application)

*Plot description

Size of area

*Pre-treatment assessment

Date
Budworm phenology
Population density

*Post-treatment assessment

Date
Budworm phenology
Population density (Successive samples will be required for treatments involving delayed mortality†)
Population reduction (Abbott's Formula)

*Defoliation

% Defoliation (specifying method of estimation)
% Foliage saved

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* Both treatment(s) and check plots.
† For treatments involving delayed mortality, information should indicate whether data refer to living insects or the number surviving following laboratory rearings.

LITERATURE CITED

Atwood, C.E. 1944. The feeding habits of young spruce budworm larvae. Can. Ent. 76:64-66.

Clark, J. 1961. Photosynthesis and respiration in white spruce and balsam fir. N.Y. State Univ. Coll. For. Tech. Publ. 85.

DeBoo, R.F., Campbell, L.M. and Copeman, A.G. 1973. A sampling technique for estimating numerical trends in larval population of insect defoliation on conifers. I. Development and experimental evaluation of the technique. Phytoprotection 54:9-22.

DeBoo, R.F. 1974. Budworms and baskets: An appraisal of a basket attachment for pole pruners in sampling larval populations of the spruce budworm. Can. For. Serv., Ottawa, Ont. CCRI File Rep. No. 6.

Dorais, L.G. and Hardy, Y.J. 1976. Méthode d'évaluation de la protection accordée au sapin baumier par les pulvérisations aériennes contre la tordeuse des bourgeons de l'épinette. Can. J. For. Res. 6:86-92.

Eidt, D.C. and Cameron, M.D. 1970. Pretreatment of spruce budworm eggs for counting. Can. Dep. Fish For., Ottawa, Ont. Bi-mon. Res. Notes 26:46-47.

Fettes, J.J. 1950. Investigations of sampling techniques for population studies of the spruce budworm on balsam fir in Ontario. *In* Annu. Rep., For. Insect Lab., Sault Ste. Marie, Ont.

Hardy, Y.J. and Dorais, L.G. 1976. Cartographie du risque de retrouver de la mortalité dans les forêts de sapin baumier attaquées par la tordeuse des bourgeons de l'épinette. Can. J. For. Res. 6:262-267.

Martineau, R. and Benoit, P. 1973. A sampling technique for estimating numerical trends in larval populations of insect defoliation on conifers. II. Modification and operational use of the technique for extensive sampling of spruce budworm population in Québec. Phytoprotection 54:23-31.

Miller, C.A. 1958. The measurement of spruce budworm populations and mortality during the first and second larval instars. Can. J. Zool. 36:409-422.

Miller, C.A. 1964. A sampling plan for endemic populations of the spruce budworm. Can. For. Serv., Fredericton, N.B. Interim Res. Rep.

Miller, C.A. and McDougall, G.A. 1968. A new sampling technique for spruce budworm larvae. Can. Dep. For. Rur. Dev., Ottawa, Ont. Bi-mon. Res. Notes 24:30-31.

Miller, C.A. and Kettela, E.G. 1972. An additional note on sampling overwintering spruce budworm larvae. Can. For. Serv., Fredericton, N.B. Inf. Rep. M-X-34.

Miller, C.A. and McDougall, G.A. 1973. Spruce budworm moth trapping using virgin females. Can. J. Zool. 51:853-858.

Miller, C.A., Forbes, R.S., and Dobson, C.M. 1968. Studies of the spruce budworm in the Maritimes Region by the Forest Insect and Disease Survey. I. A comparison of larval surveys, 1957-1967 with two independent sources of population data. Can. Dep. For. Rur. Dev., Fredericton, N.B. Intern. Rep. M-34.

Miller, C.A., Kettela, E.G., and McDougall, G.A. 1971. A sampling technique for overwintering spruce budworm and its applicability to population surveys. Can. For. Serv., Fredericton, N.B. Inf. Rep. M-X-25.

Miller, C.A., Kettela, E.G., and McDougall, G.A. 1972. Sampling methods in spruce budworm surveys. Can. For. Serv., Ottawa, Ont. Bi-mon. Res. Notes 28(5):31.

Miller, C.A., Greenbank, D.O., and Kettela, E.G. 1979. Possible use of canopy light traps in predicting spruce budworm egg-mass counts. Can. For. Serv., Ottawa, Ont. Bi-mon. Res. Notes 35: 29-30.

Morris, R.F. 1954. A sequential sampling technique for spruce budworm egg surveys. Can. J. Zool. 32:302-313.

Morris, R.F. 1955. Development of sampling techniques for forest insect defoliators, with special reference to the spruce budworm. Can. J. Zool. 33:225-294.

Prebble, M.L. 1975. Aerial control of forest insects in Canada. Can. For. Serv., Ottawa, Ont. 330 p.

Retnakaran, A. and French, J. 1971. A method for separating and surface sterilizing the eggs of the spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae). Can. Ent. 103:712-716.

Sanders, C.J. 1978. Evaluation of sex attractant traps for monitoring spruce budworm populations (Lepidoptera: Tortricidae). Can. Ent. 110:43-50.

Waters, W.E., Heller, R.C., and Bean, J.L. 1958. Aerial appraisal of damage by the spruce budworm. J. For. 56:269-276.

Webb, F.E., Cameron, D.G., and MacDonald, D.R. 1956. Studies of aerial spraying against spruce budworm in New Brunswick. V. Techniques for large-scale egg and defoliation ground surveys. Div. For. Biol. Dep. Agric. Ottawa, Ont. Unpubl. Rep.

APPENDIX

List of participants at CFS Eastern Spruce Budworm Sampling workshop.

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G.M. Howse ≠ ϕ *
L.A. Lyons *
C.J. Sanders ϕ

LFRC

P. Benoit ≠ ϕ *
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MFRC

E.G. Kettela ≠ ϕ
C.A. Miller ≠ ϕ *
M.M. Neilson
T. Royama ϕ
A.W. Thomas ϕ

Nfld. FRC

D. Bryant ϕ
J. Hudak *
I. Otvos *

Forest Protection Ltd. N.B.

W.J.A. Volney ϕ *

PFRC

R.F. Shepherd ϕ

FPMI (CCRI)

J. Armstrong *
R. DeBoo ≠ ϕ
M. Hildebrand ≠
O.N. Morris ≠ *
P.C. Nigam *
A.P. Randall ≠ *

FPMI (IPRI)

J.C. Cunningham ≠ *
W. Kaupp ϕ *
A. Retnakaran ≠ *
G. Wilson ϕ *

QLF

M. Auger *
L. Dorais *

Univ. Laval

Y. Hardy ϕ *

Univ. Maine

M. Houseweart *
D. Leonard ϕ
G. Simmons ϕ

USFS

M. McKnight ϕ
B. Blum ϕ

≠ Attended 1974, meeting Ottawa
ϕ Attended 1976, meeting Toronto
* Attended 1977, meeting Sault Ste. Marie