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Heterogeneity of spray deposit and efficacy within a single swath applied by aircraft over forest infested with spruce budworm, *Choristoneura fumiferana* (Clem.)

I.W. Varty and S.E. Holmes

Information Report M-X-168
Canadian Forestry Service - Maritimes

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HETEROGENEITY OF SPRAY DEPOSIT AND EFFICACY WITHIN A SINGLE SWATH APPLIED BY AIRCRAFT OVER FOREST INFESTED WITH SPRUCE BUDWORM, *CHORISTONEURA FUMIFERANA* (CLEM.)

by

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Fredericton, New Brunswick

Information Report M-X-168

Government of Canada
1988

Catalogue no. Fo46-19/168E
ISBN 0-662-16417-2
ISSN 0834-406X

Additional copies of this publication are available in limited quantities at no charge from:

Canadian Forestry Service-Maritimes
P.O. Box 4000
Fredericton, N.B. Canada E3B 5P7

(506) 452-3500

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ABSTRACT

This report describes the first season of a 3-year project to elucidate deposit/response relationships from the aerial application of fenitrothion insecticide against spruce budworm, *Choristoneura fumiferana* (Clem.), infesting spruce-fir forest in New Brunswick, Canada.

The heterogeneity of insecticide deposit distribution over a 100 m transect of forest within a multi-swath target block is detailed as statistics of tracer dye mass and droplet density on foliage of fir and spruce. Deposit is analysed by plot location downwind, by crown level, by crown aspect, and by single trees, based on measurements of 1152 twig samples of each species. Gradients of density downwind and through crown contributed to distribution frequencies peaking at low levels (ca 1µg fenitrothion/shoot) but skewed as far as 20 µg/shoot. Droplet density averaged 0.4 droplets/needle on fir, but with broad deviation from the mean. In effect, although the average deposit was satisfactory, many shoots received too little deposit and some too much. Spruce and fir had similar deposit patterns.

The spruce budworm larva is generally too well concealed under silk or in the bud mine to be vulnerable to direct impact by droplets. Therefore, the target is the foliage of the outer microhabitat, where the larvae may move into contact with residues. Hypotheses are developed to explain vulnerability to sprays in relation to silking behavior and weather.

The criterion of spray efficacy was reduction in density of larvae per tree within 6 days of treatment. Mortality was measured by count of larvae falling to drop trays. Efficacy varied widely from plot to plot and tree to tree; it was twice as high on fir as on spruce, indicating host-specific differences in larval behavior. The drop tray technique is a promising way to assess direct efficacy.

RÉSUMÉ

Ce rapport porte sur la première saison d'une étude de 3 ans sur les relations dépôt-effet des pulvérisations aériennes de fénitrothion contre les infestations de la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* (Clem.)) dans la forêt d'épinettes et de sapins du Nouveau-Brunswick, au Canada.

L'hétérogénéité de la distribution du dépôt de l'insecticide sur un transect de 100 m dans un bloc-cible où il y avait plusieurs bandes d'aspersion est expliquée à partir des données sur la masse d'un traceur coloré et la densité des gouttelettes sur le feuillage des sapins et des épinettes. Le dépôt mesuré sur 1 152 échantillons de rameaux de chaque espèce est analysé en fonction de l'emplacement de la placette sous le vent, du niveau de la cible, du faciès de la cime et des arbres individuels. Les gradients de la densité sous le vent et dans la cime ont contribué au fait que les fréquences de distribution atteignent un sommet à des concentrations faibles (autour de 1 µg de fénitrothion par pousse mais s'étalent jusqu'à 20 µg/pousse. La densité des gouttelettes était en moyenne de 0,4 gouttelette/aiguille sur le sapin, mais la déviation par rapport à la moyenne était élevée. En effet, même si le dépôt moyen était satisfaisant, beaucoup de pousses ont reçu trop peu de gouttelettes, tandis que certaines en ont reçu beaucoup trop. Les caractéristiques du dépôt sur l'épinette et le sapin étaient similaires.

La larve de la tordeuse des bourgeons de l'épinette est généralement trop bien protégée à l'intérieur des fils de soie qu'elle tisse ou des bourgeons qu'elle mine pour être affectée directement par les gouttelettes. Par conséquent, la cible est le feuillage du microhabitat extérieur où les larves peuvent venir en contact avec les résidus. Des hypothèses sont formulées pour expliquer la vulnérabilité aux arrosages en fonction du comportement de production de fils de soie et en fonction des conditions météorologiques.

These results have operational implications for choice of spray weather and tactics to reduce heterogeneity of deposit, and for timing to increase larval vulnerability, if validated.

Le critère utilisé pour établir l'efficacité des arrosages était la réduction de la densité des larves sur les arbres dans un délai de six jours après le traitement. La mortalité a été mesurée par dénombrement des larves tombant sur des plateaux. L'efficacité variait grandement d'une parcelle à l'autre et d'un arbre à l'autre, elle était deux fois plus élevée sur le sapin que sur l'épinette, indiquant des différences du comportement des larves en fonction de l'hôte. La technique de dénombrement sur des plateaux des larves tuées représente une méthode prometteuse pour l'évaluation de l'efficacité directe.

S'ils sont validés, ces résultats pourront influer sur les pratiques d'arrosage: choix de conditions météorologiques et de stratégies d'arrosage visant à réduire l'hétérogénéité du dépôt, et du moment propice des arrosages du point de vue de la vulnérabilité des larves.

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INTRODUCTION

The ultimate aim of spray efficacy research and development is to produce firm recommendations for improved aerial spray practice. Investigations in 1982 by the Canadian Forestry Service - Maritimes were aimed at documenting conventional aircraft delivery of fenitrothion emulsion formulations for spruce budworm larvae *(Choristoneura fumiferana* (Clem.)). However, the principles can be applied to other emission systems and other pests.

The specific objectives for 1982 were: (1) to document the heterogeneity of deposit on defined target surfaces following conventional aerial spray application of fenitrothion against spruce budworm by Grumman Avenger (TBM) spray aircraft; (2) to relate deposit to larval population reduction (fallout) on balsam fir and red spruce; and (3) to identify factors such as larval behavior by instar, post-spray weather, and host-tree phenology, which may influence larval vulnerability to the insecticide deposit.

These objectives arose from research in 1981 which identified some of the factors controlling aerial spray efficacy (Varty and Godin 1983); they had their roots in a problem analysis for aerial pesticide application technology by Ekblad *et al.* (1978).

Spray efficacy depends upon adequate deposit of insecticide on specified habitat foliage and high larval vulnerability. The probability of obtaining acceptable results from a spray operation employing fenitrothion against spruce budworm is generally high, but is subject to variability in natural factors: (a) spray delivery (variables are atmospheric stability, air temperature, turbulence; humidity, and wind speed above and within the canopy); (b) homogeneity of coverage (related to stand structure, crown density, non-target foliage filters, and terrain topography); and (c) spray timing (variables are larval development stage, host influence on larval development and behavior, weather influence on larval development and behavior, and weather influence on insecticide residue persistence). Success also depends on operational factors: aircraft type, emission spectrum, formulation, aircraft speed, navigation accuracy, aircraft height above the canopy, and vortex behavior.

A generalized model of spray efficacy for budworm (Fig. 1) outlines the sequence of factors which affect the outcome of spray applications. The essential linkage is droplet deposition and larval vulnerability, producing spray efficacy as a reduction in pest population, leading to stand response in rates of defoliation, growth and tree survival.

Since spray efficacy varies from stand to stand, branch to branch, and date to date, the first step in technical development is to explain the mechanisms of that variability.

An intimate understanding is needed of the biological interface between spray deposit pattern and impact on budworm population reduction. The spray target surfaces implicated in larval vulnerability and the mechanisms of budworm mortality must be characterized before recommendations can be made as to quantity and quality of emissions and their timing. Two sets of research skills are needed: physical studies on droplet impaction; and biological investigation of the interplay of host tree phenology, larval behavior, and weather, relative to insecticide distribution.

An experiment was conducted in 1981 to test sampling techniques needed to relate deposit and larval fallout (Varty and Godin, 1983). It produced hypotheses to partly explain variations in efficacy; particularly, that budworm vulnerability to deposits is primarily induced by dermal contact with residues outside the feeding mine and results from larval movement around buds and old foliage to spin silk; also, that such silking activity is increased by feeding on growing buds and shoots and by diurnal warmth.

In 1982, a multi-disciplinary, three-year project was initiated by the New Brunswick Spray Efficacy Research Group to investigate spray dispersion and biological parameters which influence operational efficacy against spruce budworm. The objectives of the biological studies were to:

1. Identify spray deposit in terms of:
   a. droplet size and density impacting on foliage,
   b. defined target surfaces, i.e. the larval microhabitat,
   c. host species (balsam fir and red/black spruce).

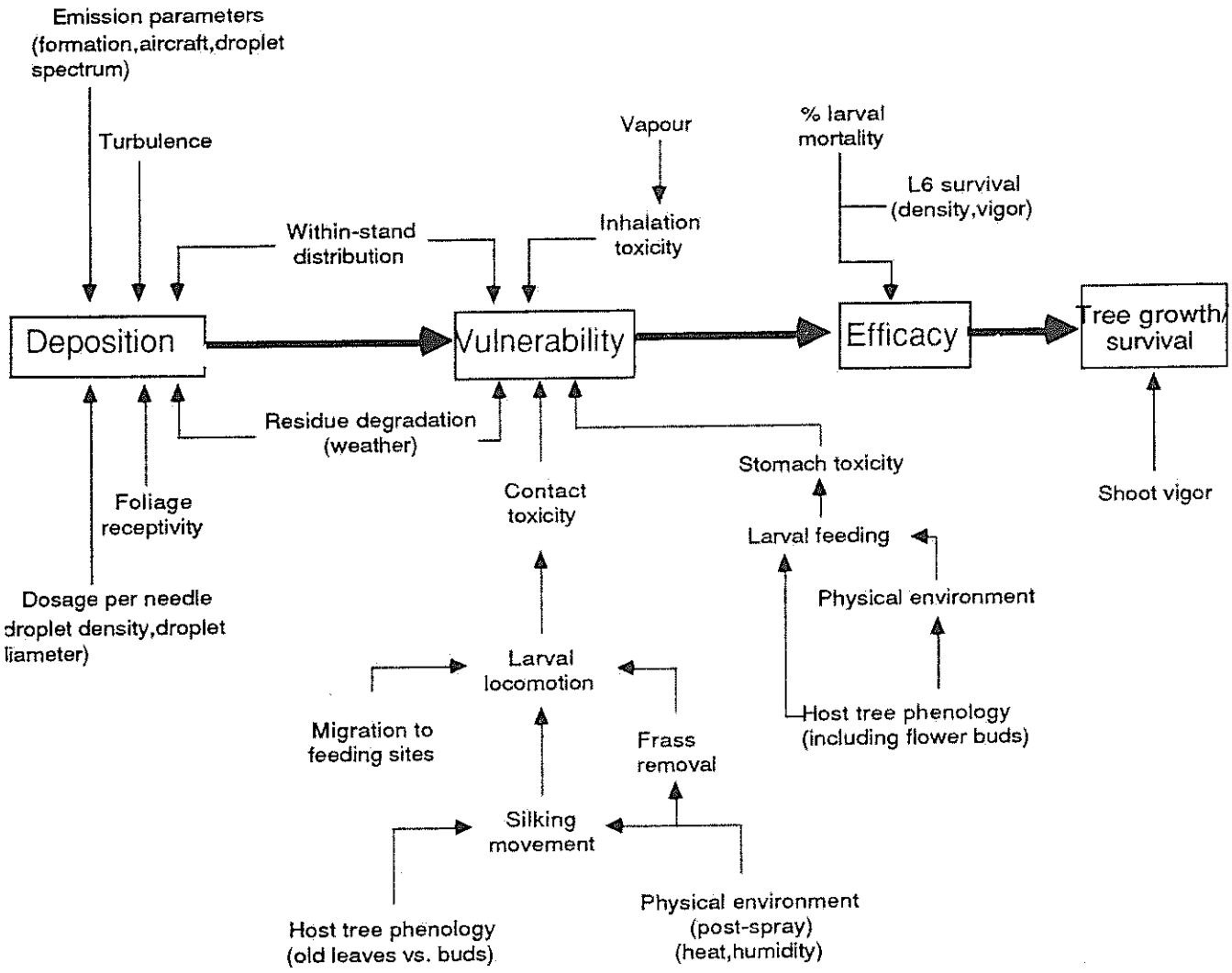

Fig.1 Factors influencing the efficacy of aerial spray against spruce budworm larvae.

2. Determine optimal and acceptable spray relative to budworm seasonal vulnerability and damage reduction.
3. Determine optimal post-spray weather to maximize behavioural exposure and insecticide efficacy.
4. Define efficacy variation across a swath.

Studies in 1982 are now reported.

METHODS

Study Area

The study area was located in southwestern New Brunswick, approximately 20 km south of Nackawic (Fig. 2). The area is a glaciated plain with deposits of well-drained gravel till and patches of imperfectly drained, peaty soils. The dominant trees were balsam fir (*Abies balsamea* L. (Mill.)) and red/black spruce, an intermediate introgression of

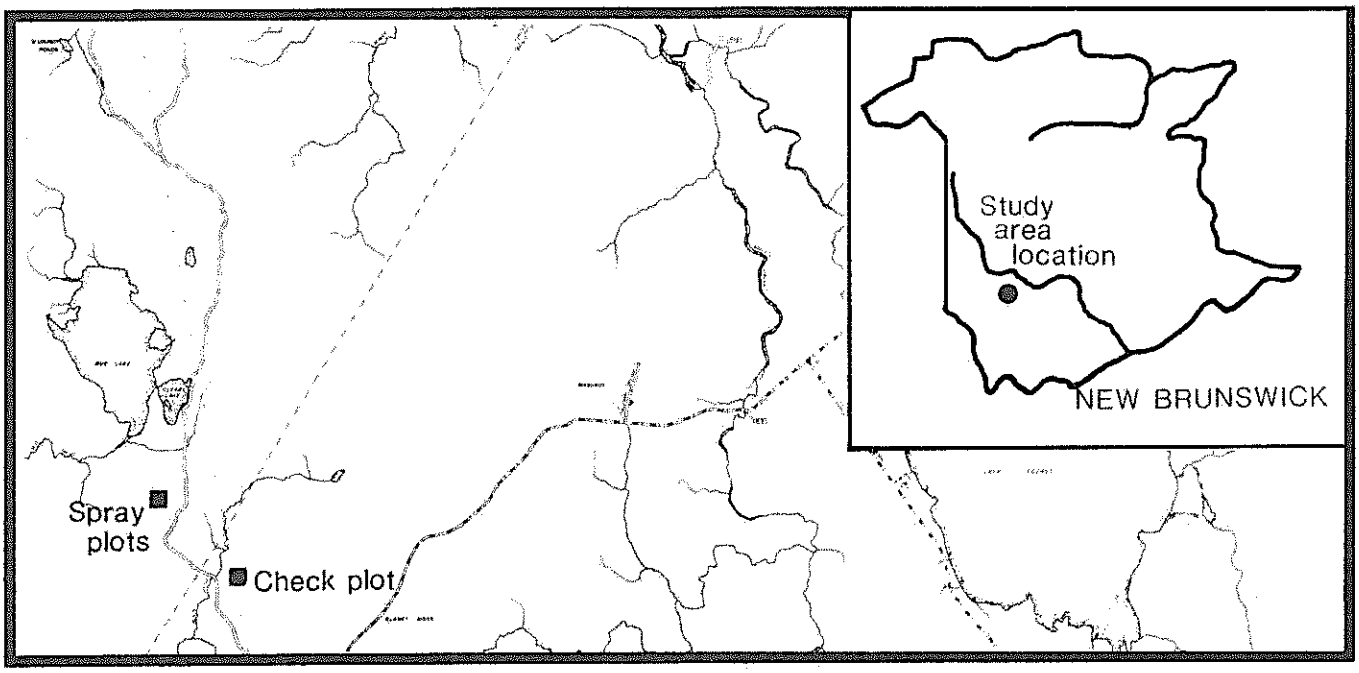

Fig.2 Location of study area.

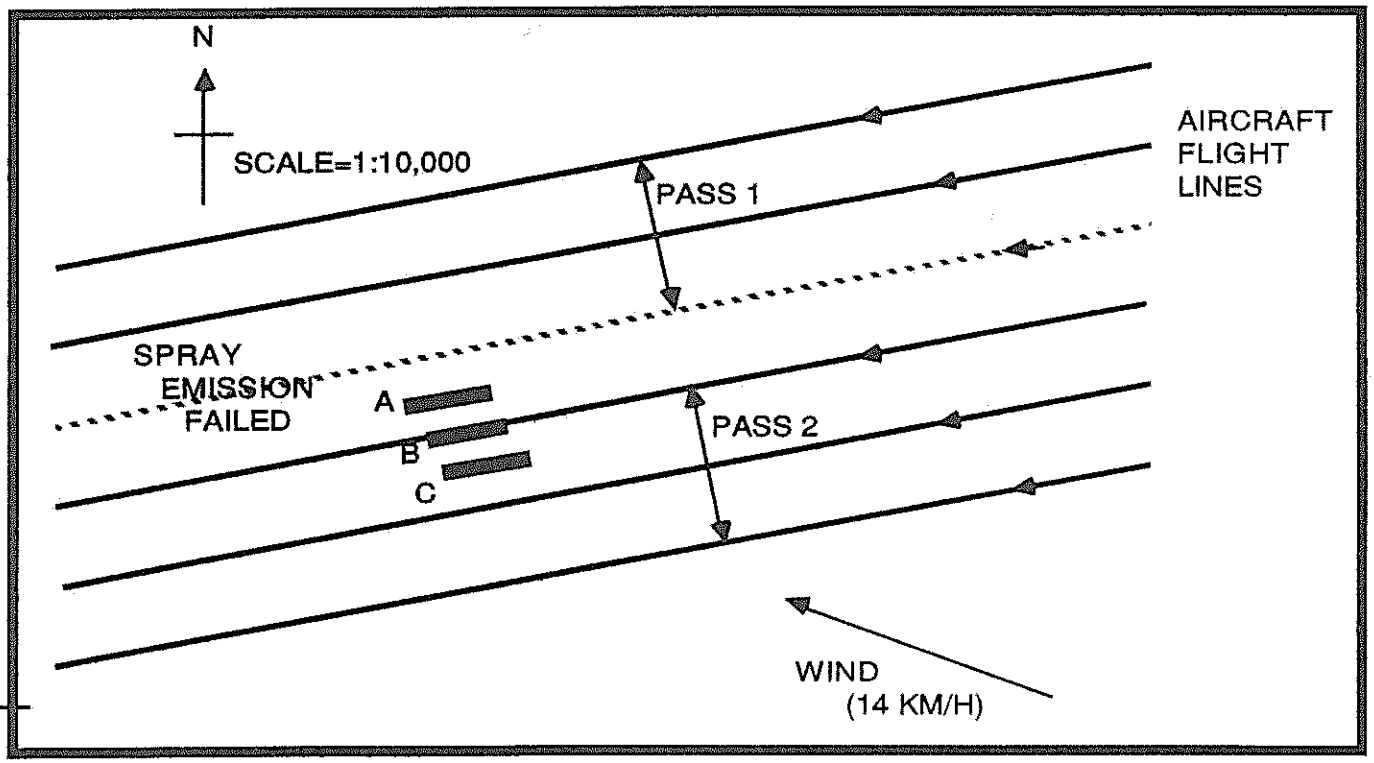

Fig3. location of three TBM's over plots A,B,and C.

red spruce (*Picea rubens* Sarg.) and black spruce (*Picea mariana* Mill.). White birch (*Betula papyrifera* Marsh.) and white pine (*Pinus strobus* L.) occurred as scattered individuals.

The fir and spruce (which will hereafter be referred to as "red" to distinguish the hybrid from the lowland black spruce) are between 30 and 40 years of age and have an average height of 8 m and an average diameter at breast height (dbh) of 12 cm. This area was also used in the 1981 aerial spray efficacy study and was described by Varty and Godin (1983). The "spray plots" (Fig. 2) had been treated with fenitrothion for the first time in 1981 (two applications of 210 g. a.i./ha). The "Check Plot" had never been treated with fenitrothion.

Experimental Design

The plot layout was designed to assess the variability of spray deposit across the conventional swath width of a Grumman (TBM) Avenger. Three sampling plots, A, B, and C, were established at 50 m intervals across the 134 m nominal swath (Fig. 3). They were not intended to correspond to the identified swath of a single aircraft, but were sited to exemplify the heterogeneity of deposit within a 100 m sector crosswind of a target block treated by an operational team of three aircraft. An untreated Check Plot was sited 700 m upwind of the block.

Sample trees were selected by size and crown isolation to standardize exposure to the drifting spray cloud. The sampling techniques were generally destructive, calling for extensive cutting of branch tips around the crowns at specified intervals. To avoid extensive degradation of the sampling universe, sampling functions were distributed among three sample sets of trees, each comprising of fir and spruce. Set (1), the "population trees," was used for estimates of larval population density and defoliation across the season; Set (2), the "drop tray trees," was used for measurement of deposit (dye recovery, droplet tallies, GC analysis) and of larval knockdown; Set (3), the "multiple drop tray trees," was reserved for spatial and temporal distributions of larval knockdown without disturbing the crowns themselves. The numbers of such trees in each plot, all of which comprised both fir and spruce, were:

	Plot A	Plot B	Plot C	Check
Set (1)	2	4	2	2
(2)	8	8	8	4
(3)	3			

These sample trees were representative of this even-aged stand: the fir were slightly larger and more defoliated than the spruce and were distributed evenly across the sampling plot; the spruce were mostly clumped together. The trees in the Check Plot were not measured but were approximately 8 m tall and were similar to trees in the treated plots. Sample tree measurements are detailed in Appendix 1, and averaged as follows:

	Plot A		Plot B		Plot C	
	bF	rS	bF	rS	bF	rS
Height (m)	7.4	6.6	7.9	6.8	9.9	5.9
Dbh (cm)	11.4	9.2	10.9	9.5	13.5	8.8
Crown vol. (M^3)*	6.2	4.5	4.0	4.5	10.5	3.5

*The volume of the cone derived from crown height and crown base diameter.

The plot was sprayed once (June 4, 1982) with the waterbased emulsion of fenitrothion at a rate of 210 g/ha of active ingredient in 1.46 L/ha. The formulation was by volume 11% technical fenitrothion, 1.5% Dowanol TPM solvent, 1.5% Atlox 3409F emulsifier and 85% brook water. Rhodamine WT aqueous dye was added at 1% (crystal content 0.2) as a fluorescent tracer, i.e. having a 1:55 ratio to fenitrothion by volume, or a 1:60 ratio by weight.

The insecticide was applied by a team of three Grumman (TBM) Avengers flying in echelon-formation at a specified height of 30 m above the forest canopy. The insecticide was delivered through 110-10 Teejet flat-fan nozzles which were mounted at the trailing edge of the aircraft wings. Two adjoining passes were made over the area with the planes circling and making the second pass from the same direction as the first. Although the location of each plane in relation to the plots was not precisely determined, it appeared, from the ground and the pointer's report, that their relative positions were as shown in Fig. 3.

The research plan required two applications of insecticide approximately 7 days apart. However, due to regulations, a delay in obtaining spray permits in 1982 caused postponement of the first

application to a late-spray timing and the planned second spray had to be eliminated. The original intention to compare the influence of timing (early versus late) could not be fulfilled.

Insecticide Deposit Assessment

Deposit was assessed by fluorometric analysis of rhodamine WT tracer dye on shoots, by tallies of droplet stains on needles, and by GC analyses of fenitrothion residue on foliage (buds and last year's shoots including the axils).

The rhodamine WT tracer, a water-soluble fluorescent dye, was assumed to be in constant volume ratio (1:55) with the insecticide in every droplet. That ratio was derived from the volume formulation which called for 1% aqueous dye (0.2 crystal) to 11% fenitrothion, as described. That relationship would hold if all the rhodamine were extracted from the foliage and if the rhodamine fluorescence was not degraded by environmental exposure or quenched by association with the other chemicals. Therefore, the dye recovery rate was tested by a laboratory experiment, simulating field collection conditions, as follows. Serial dilutions of a known volume of rhodamine formulated in fenitrothion emulsion with tap water to the operational prescription were prepared. A calibration relationship was established by plotting fluorometric readings against dilutions in the appropriate range (10^{-6} to 10^{-9}). The readings were obtained by use of a Turner 110 Fluorometer with a 110/850 UV lamp and 546 nm primary filter and 590 nm secondary filter for rhodamine detection. Similar calibrations for rhodamine in tap water and rhodamine in a 20% aqueous solution of ethyl alcohol produced identical relationships, showing that the insecticide formulation did not quench fluorescence.

A series of applications of fenitrothion emulsion full-formulation with rhodamine was made to foliage by microsyringe. The foliage of each test shoot, 4-cm long, was dabbed with the tip of the syringe until 1 μL was deposited. The residues were then dried for a prescribed time by exposing the shoot to room temperature and the full light of an east window, to simulate the temporal range of exposure of field samples of shoots before collection after aerial spray. The variables examined were drying time (0, 1, 3 and 6 h) and host species (fir, red spruce), and 10 replicates of each combination were treated with applications of dyed formulation. After drying, each shoot was stored individually in a vial in the freezer (-15° C) for one week, adequately representing the freezer storage of the field specimens (4-8 weeks).

After storage, each sample shoot was soaked and agitated for 0.5 h in 10 mL aqueous ethyl alcohol (20%). The eluate was then tested for fluorescence in the Turner instrument and the readings were converted to weights of rhodamine from the calibration lines. The means for each series (drying time/host species) were then compared with the values derived from known weights of rhodamine in the serial dilutions of dyed formulation applied directly to the 10 mL ethyl alcohol diluent, thus determining the recovery rate.

Field Collections

Foliage samples were collected from the spray plots during the 1-6 h period after spray application on 4 June 1982 for deposit measurement by fluorometry and droplet tally. Using pole pruners, one 45 cm branch tip was removed from each of the upper, middle, and lower sections of the crown and from all four cardinal directions of each of the eight fir and eight spruce drop tray trees in Plots A, B, and C. Five intact sample shoots were randomly selected from each branch, each shoot consisting of a 4-cm twig of last year's foliage, plus its complement of 3-4 buds (average length 17 mm in the case of fir, 6 mm and still tight in the case of spruce). The old foliage on all shoots was intact, i.e. not damaged by defoliators in 1981. Four shoots were stored together in a plastic vial for fluorometric analysis; the fifth was placed in a separate vial for droplet counting. All samples were kept cool in insulated containers with ice packs for 4 to 8 h before transportation to the laboratory. The foliage was stored in the laboratory freezer (-15° C) for several weeks until process ing for fluorometry and droplet density.

For fluorometric analysis, the four shoots per sample were separated into individual vials; each shoot was soaked (and occasionally agitated) in 10 mL of 20% ethyl alcohol for 30 min, before fluorometric reading of the eluate. Fir shoot eluates were measured at the Canadian Forestry Service - Maritimes laboratory in the Turner 110 Fluorometer. The spruce was measured at the New Brunswick Research and Productivity Council laboratory in a Varian Spectrofluorometer (SF 330) which had 10-fold greater sensitivity than the Turner. However, in tests of comparability, both machines produced similar measurements of the same foliage sample.

The shoot (from each branch sample) to be used for droplet counting was removed from the freezer and immediately placed in a dessicator with anhydrous calcium sulfate (Indicating Drierite Absorbent) for 30 min, to prevent moisture condensation as the shoot warmed to room temperature; otherwise condensation would smudge and disperse the red stain. For fir, droplet numbers were then determined on 10 new needles and 10 old needles closest to the junction of terminal bud and stem (the site of the budworm larval habitat). Droplets were counted separately on the upper and lower sides of each needle. For spruce, droplets were counted on 20 old needles close to the terminal bud (the buds had not flushed at the time of spraying). Each spruce needle was placed in a micro-pipette and rotated under the microscope to count the droplets on all four sides.

Measurements of droplet stain diameters were attempted but the sometimes irregular spread and smudging of the stains precluded comprehensive data assembly. However, a systematic sampling of stain diameter from the fir shoot samples (10 old + 10 new needles) in Plot A was conducted, deriving data from levels, aspects, and foliage class.

Fenitrothion deposit was also measured by gas chromatography to determine the degradation rate. Foliage samples were collected 1 h and 2, 4, and 6 days after spraying. In Plots A, B, and C, two 45-cm branch tips were cut from the midcrown of the eight fir and eight spruce drop tray trees - one branch from the north side of each tree and one from the south. From each branch, all the current foliage or buds, plus the previous year's growth, were removed and stored in pesticide-grade ethyl acetate in a freezer until analysis. For the Check Plot, each sample was a composite of midcrown branch tips from the four trees of each species, one from each north aspect, and one from each south, on each sampling day. The mean unit sample was 83 g and consisted of opening shoots, buds, one-year-old needles and the axils on which they were borne.

Assessment of Efficacy and Foliage Protection

In this experiment, the reduction of larval populations in the crown is adopted as the measure of spray efficacy, while foliage protection is the measure of operational success. Efficacy was determined by comparing pre- and post-spray larval population densities in the midcrown and by measuring larval mortality as fallout from the crowns. In both cases, the sprayed plots and the untreated Check Plot were compared. Foliage protection was assessed by comparing estimates of defoliation, treated plots vs Check.

Population sampling for larval densities in the crown

The population trends in the spray stand and the Check Plot were followed from second to sixth instar by sampling the midcrown. A 45-cm branch tip was collected approximately every 3 days from May 13 to June 23 from the population trees in each plot. The samples were transported to the laboratory, each branch in a separate plastic bag, where the numbers of larvae were counted. All branches were examined first by naked eye and then under the microscope. All attacked shoots or buds were opened and the larvae were classified as alive or dead and by habitat class. All larvae were stored for instar determination by a skilled technician using the Titus method (Anon. 1981).

Each branch area was calculated by multiplying the length of live foliage on the branch by the average width of live foliage. Larval density was then expressed per square metre of branch area. Also, all buds and new shoots on fir branch samples were counted and the density of larvae per 1000 shoots was calculated; this expression was deemed unreliable because of the abortive (frost-induced) reduction of shoot numbers during the spring.

Drop tray counts

Larval mortality (pre- and post-spray) was measured by fallout of larvae from the crowns to drop trays. Eight fir and eight spruce in each of Plots A, B, and C, and four fir and four spruce in the Check Plot were used for drop tray assessments. A polyethylene drop tray (1.9 x 0.9 m) was placed randomly but fully under the crown. Fallout of larvae to trays was counted daily from May 28 to June 22. From June 4 (aerial spray day) to June 9, counts were made morning and afternoon to document daily periodicity in the fall-out pattern induced by insecticide.

On June 11 (seventh day after aerial spraying), the trees were sprayed (Wash I) to run-off with a 1% aqueous formulation of pyrethrin applied from a hydraulic ground sprayer. This was to obtain a population value for the larvae surviving the aerial spray and still present in the column of foliage overhanging the drop tray. With larvae still falling 4 days after the wash, it was decided to apply a second wash treatment on June 17 to ensure that any survivors would be knocked down. Wash II was

applied by backpack sprayer (as the hydraulic sprayer was unavailable) with the same aqueous formulation of 1% pyrethrin, but delivering smaller quantities. Midcrown samples were taken on June 20 from the drop tray trees in plot B as a check for larval populations surviving the aerial spray and two wash sprays.

Efficacy values were determined for each plot by calculating the percentage of the total population that had been knocked down in the 6-day period following the aerial insecticide application and adjusting this for the natural fallout by use of Abbott's formula.

The diurnal pattern of fallout of larvae was assessed by frequent collection of fallout from drop trays under three fir and three spruce, designated as "multiple drop tray trees", in plot A. Collections of larvae were made for 4 days before spraying and 4 days after spraying. Pre-spray counts were made only once daily in the mid afternoon. On spray day, counts began 1 h after spraying and were repeated hourly until 2000 h. On days 2 to 4, fallout in the drop trays was tallied hourly from 0700 to 2000 h.

The test was also designed to determine the influence of crown aspect on fallout. Collections were made from 4 drop trays per tree placed radially at north, south, east, and west orientations, abutting the trunk.

Defoliation

Feeding damage was assessed as the percent of shoot attack and the percent of shoot destruction by third- to sixth-instar larvae, and as percent defoliation estimated after larval pupation. The shoot attack and shoot destruction rates were determined at each midcrown population sampling, using the same branches. On each branch, the numbers of healthy buds or shoots (no feeding damage), attacked shoots (feeding damage present) and destroyed shoots (axil destroyed) were tallied. The shoot attack and shoot destruction rates were the mean percentages of damaged shoots per branch, in samples taken at approximately 3-day intervals. The criterion for shoot attack was evidence of feeding damage to a bud or new shoot; for shoot destruction, it was the loss of the shoot axil, where any damage terminated growth.

A defoliation estimate, measured as the percentage of the needles destroyed, was determined after larval feeding was complete (July 26). One 45-cm branch tip was taken at midcrown from each of the population sampling trees in all plots. For each branch, the number of shoots in each of six categories was counted:

Category	Percent of the needles removed
1	No defoliation
2	1 - 25
3	26 - 50
4	51 - 75
5	76 - 100 (shoot axil intact).
6	Shoot, needles and axil completely destroyed

The defoliation estimate for a branch was then calculated as the weighted average of the shoots in each category (modified Fettes Method: Dorais and Kettela 1982).

Larval and Bud Development

At each population sampling, the larvae on each branch were stored in alcohol for instar determination. Head capsule widths were used to determine instars (Anon. 1981) and the larval development index was calculated as in Hardy *et al.*, 1977.

Bud or shoot lengths (20 samples) were measured on each branch to record foliage phenology. All measurements were made from the base of the bud scales to apex.

Weather

Detailed meteorological conditions (atmospheric stability) were monitored in the study area by R.B.B. Dickison and B.G. Steeves of the University of New Brunswick. Minisonde ascents were used to assess atmospheric stability, and wind speed and direction, as needed to recommend spraying.

A hygrothermograph was also set up in a Stevenson Screen in an open glade (Plot B) to record relative humidity and temperature throughout the study period. Hours of sunshine, wind speed, precipitation, and cloud cover were taken from the Fredericton weather station, 50 km NE of the plot (Anon. 1982). Degree-days were calculated from the thermograph charts, using a base temperature of 5.6°C (Hudes and Shoemaker, 1988).

Spray permit regulations required that the wind be easterly (away from human habitation), not exceed 16 km/h and offer minimal turbulence.

Data Analysis

Most data analyses were performed on IBM 3081 using procedures devised by SAS Institute Inc., Cary, North Carolina. Some data analyses were performed on a Hewlett-Packard HP-97 calculator using associated Hewlett-Packard programs. Statistical tests are identified with each analysis in the text.

RESULTS AND DISCUSSION

Meteorology

Measurements of the atmospheric instability layer at the study area (Dickison, pers. comm. 1982) indicated that conditions were unstable. Spraying took place (June 4, 1982 at 0834 to 0839 h ADT, approximately 2.5 h after sunrise) when the instability layer (intensity about 0.021° C m^{-1}) had reached a height of 380 m above the forest canopy. The mean wind direction was weakly trans-swath, about 53° off the orthogonal to the spray lines. The Avenger aircraft, flying at 30 to 50 m above the canopy, were well below the top of the instability layer. Heterogenity in deposit could be expected under such conditions, mainly because of the upward movement of air above the canopy and swath displacement downwind of the target.

Weather conditions at the time of spraying were: temperature (Stevenson Screen) 10° C, sky clear, wind speed 16 km/h from ESE (113° True), relative humidity > 90%. The day continued to be warm, breezy, dry and sunny, peaking at 23° C at 1600 h (Appendix Table V-2). Weather conditions at Plot B from May 17 to June 18 are recorded in Appendix Table V-1. The weather in the week following spray was consistently warm and sunny, except for the fourth day when the sky was overcast. Such conditions favoured high rates of larval feeding and growth.

Dye Recovery

The ratio of rhodamine to fenitrothion in the formulated emulsion was 1:55 (vol.) or 1:60 (wt.). However, laboratory tests of dye recovery from shoots showed that the longer residues on foliage were exposed to drying conditions, the lower the recovery rate.

Table 1. Recovery of rhodamine WT eluted with aqueous ethyl alcohol from 4 cm foliage samples, each treated with 1 μL dyed fenitrothion emulsion, and dried for 0-6 h. Mass of rhodamine added = 2080 ng

Drying time (h)	bF Dye recovered ng	bF Dye recovered %	rS Dye recovered ng	rS Dye recovered %
0	1880	90.4	1950	93.8
1	1890	90.9	1960	94.2
3	1670	80.3	1730	83.2
6	1650	79.3	1570	75.5

Fir and spruce foliage responded similarly. However, since field samples were collected on average 3-6 h after the spray, the recovery rate is about 80%. Therefore, the ratio of recovered rhodamine to fenitrothion is modified by 0.8, that is, a ratio of 1:69 by vol, or 1:75 by weight.

Insecticide Deposit

Among-plot variations

Significant differences ($P < 0.01$) occurred among insecticide deposits on fir in all three plots, while on spruce the deposits in Plots A and B differed significantly from those in C (Table 2). Mean deposit/shoot varied four-fold across the 100 m downwind transect. That it occurred as a gradient of increasing values downwind is probably a function of swath displacement.

With the aircraft passing in the positions shown in Fig. 3 and the wind from the southeast at 16 km/h, it is highly probable that the deposit on all three plots came from the overlapping swaths of the three planes in Pass 2. Spray emission failed in the third plane in Pass 1, while the other two planes were downwind of the plots.

Table 2. Deposit of insecticide in plots A, B, and C given as mean (± SD) rhodamine WT concentrations in ng per sample shoot.

Plot	N	Balsam fir	N	Red spruce
A	384	57.6 ± 51.6[a]	384	42.9 ± 95.2[a]
B	384	25.8 ± 24.4[b]	384	37.1 ± 77.0[a]
C	384	13.0 ± 10.8[c]	384	20.7 ± 22.0[b]

Statistical differences by Duncan's Multiple Range test; means with the same letter are not significantly different at $p < 0.05$.

Operational practice in large spray blocks in New Brunswick requires that two applications, usually separated by 5 to 7 days, be made by a three-TBM team. Homogeneous coverage is thus attained by incremental deposits from the adjacent parallel passes (Randall 1975). In this study, the single upwind pass by the TBM team permitted deposition from drift of only three swaths, a situation that is characteristic of the upwind edge of a block or the body of a narrow woodlot.

Difference in deposit between fir and spruce

Mass deposited per sample shoot was approximately the same on fir and spruce, based on 1152 samples from each host species (Table 2); the mean deposit per shoot was 32 ng rhodamine for fir and 34 ng for spruce, or about 2.5 µg fenitrothion per shoot.

Such similarity of deposit was unexpected because the fir shoot sample offered a larger collecting surface for droplets. The fir shoot of 4 cm axis bearing old needles was extended by 2-4 buds, each 1.7 mm long, each exposing the tops of about 100 needles, whereas the spruce shoot bore only unflushed buds. Moreover, the individual fir needle has 2-3 times the surface area of the individual spruce needle. However, the density of old needles - around 90-100 per 4-cm shoot - was similar on both host species.

The droplet count, based on sub-samples from 288 shoots each of fir and spruce, offered a lighter sampling intensity. The counts on fir averaged 0.44 droplets/old needle, and 0.13/old needle on spruce (Table 3), each data set with a wide coefficient of variation. It is not known whether this difference is real or spurious. Assuming that the average droplet on spruce had the same mass as the average droplet on fir, the probable explanation is that the smallest droplets on spruce were missed by the observers; droplets of all sizes were indeed much more conspicuous on fir than on spruce.

Tallies on spruce were limited to old needles, because the red dye was almost undetectable on bud scales. Counts on fir foliage discriminated between new needles (exposed tips reflexing away from the opening bud mass) and old needles, as well as between upper and lower surfaces of old needles. Mean density on the tips was 0.16/new needle, compared with 0.44/old needle (Table 3). Since the tips were about one quarter the length of the old needles, each class performed with similar efficiency per unit length. Tallies on upper and lower sides of the needles (Table 4) showed equal droplet densities, indicating the importance of air turbulence in impaction, rather than gravity (sedimentation).

Table 3. Mean density ± SD of droplets/needle on 1-year foliage and flushing buds of balsam fir, and 1-year foliage of red spruce, Magundy, 1982.

Needle class	Plot	Sample shoots	Mean density droplets/needle	Range	SD	CV
			Balsam fir			
1 yr	A	96	0.68	0 - 3.2	0.68	100
bud	A	89	0.20	0 - 1.4	0.26	130
1 yr	B	96	0.48	0 - 3.6	0.60	123
bud	B	50	0.27	0 - 2.3	0.48	181
1 yr	C	96	0.16	0 - 1.0	0.22	144
bud	C	87	0.07	0 - 0.6	0.12	178
1 yr	all	288	0.44	0 - 3.6	0.58	131
bud	all	226	0.16	0 - 2.3	0.30	182
			Red spruce			
1 yr	A	95	0.12	0 - 0.7	0.14	117
1 yr	B	95	0.25	0 - 2.9	0.37	151
1 yr	C	95	0.01	0 - 0.7	0.07	563
1 yr	all	285	0.13	0 - 2.9	0.25	199

In these tallies, deposit on spruce was more variable than on fir: coefficients of variation of droplets/old needle averaged 199% for spruce vs. 131% for fir (Table 3). This difference may be explicable as a droplet counting artifact in samples from Plot C, where the very low droplet density does not correspond with the dye mass measured fluorometrically (c.f. Table 2).

Table 4. Comparison of droplet densities from upper and lower surfaces of fir needles (old foliage), based on tallies from 10 needles/shoot, Magundy, 1982.

Leaf surface	Plot	Sample shoots	Mean density droplets/needle	Range	SD	CV
upper	A	89	0.33	0 - 2.3	0.40	120
lower	A	90	0.35	0 - 1.7	0.37	106
upper	B	51	0.24	0 - 1.2	0.27	114
lower	B	50	0.25	0 - 2.6	0.38	156
upper	C	87	0.08	0 - 0.6	0.14	169
lower	C	87	0.08	0 - 0.8	0.13	175
upper	all	227	0.22	0 - 2.3	0.31	141
lower	all	227	0.23	0 - 2.6	0.34	150

Vertical distribution in the crown

Fir in all three plots showed a strong gradient in deposit, decreasing from upper to lower crown levels (Table 5a,b) with highly significant differences ($P < 0.01$) among levels.

In spruce, a weak gradient of deposition from upper to lower canopy was obtained for the composite swath means, but it was variable for individual plots and generally lacked significant differences among crown levels. The ratios of deposits, relative to deposit on fir in the upper crown (Table 5a) were as follows:

	Fir	Spruce
Upper crown	1.0	0.8
Midcrown	0.5	0.6
Lower crown	0.2	0.5

Table 5a. Deposit of insecticide by crown level in Plots A, B, and C expressed as rhodamine WT concentrations in ng per sample shoot. Mean ± SD (n = 4 shoots x 4 orientations x 8 trees).

Level	N	A	B	C
Balsam fir				
Upper	128	99.2 ± 58.6^{a}	44.0 ± 29.7^{c}	18.3 ± 13.9^{d,e}
Middle	128	50.9 ± 27.2^{b}	24.6 ± 16.1^{d}	12.8 ± 9.2^{e,f}
Lower	128	22.6 ± 13.9^{d}	8.9 ± 5.2^{f}	7.9 ± 4.3^{f}
Red Spruce				
Upper	128	59.8 ± 122.4^{a}	43.6 ± 86.9^{a,b,c}	20.9 ± 23.2^{c,d}
Middle	128	29.2 ± 59.7^{b,c,d}	44.7 ± 96.6^{a,b}	21.4 ± 22.3^{c,d}
Lower	128	42.8 ± 91.5^{a,b}	23.0 ± 26.6^{c,d}	19.7 ± 20.7^{d}

Table 5b. Deposit of insecticide by crown level in Plots A, B, and C expressed as droplets/needle of old foliage. Mean ± SD.

Level	N	A	B	C
Balsam fir				
Upper	32	1.02 ± 0.76^{a}	0.78 ± 0.76^{a,b}	0.21 ± 0.27^{c}
Middle	32	0.68 ± 0.71^{b,c}	0.48 ± 0.52^{c,d}	0.13 ± 0.21^{c}
Lower	32	0.35 ± 0.32^{d,e}	0.18 ± 0.25^{e}	0.12 ± 0.18^{c}
Red Spruce				
Upper	32	0.20 ± 0.18^{b,c}	0.36 ± 0.34^{a}	<0.01 ± 0.02^{e}
Middle	31	0.10 ± 0.10^{c,d,e}	0.16 ± 0.12^{b,c,d}	<0.01 ± 0.02^{e}
Lower	32	0.06 ± 0.09^{d,e}	0.23 ± 0.53^{b}	0.03 ± 0.12^{e}

Species tested separately for statistical differences by Duncan's Multiple Range test; means with the same letter are not significantly different at $P < 0.05$.

The presence of two gradients (vertical and horizontal) in the fir canopy volume produced a 12-fold difference in average deposition between one side of the swath and another (Plot A upper, vs. Plot C lower).

The two gradients in spruce are evident but less clearly demonstrated (Table 5a). A threefold difference is seen between highest (Plot A upper) and lowest mean (Plot C lower).

Sample trees of both species were open-spaced codominants with free air circulation around individual crowns, so turbulent air was presumably able to penetrate the canopy deeply. Despite these favorable conditions and the narrowness of the sample plot, deposit density was coarsely heterogeneous within the canopy.

Deposit distribution in the crown relative to wind direction

No population investigators have found aspect to have any influence on the distribution of budworm larvae throughout the crown (Morris 1955, Harris 1964). Therefore, the most desirable spray deposition is one that is equal on all sides of the crown.

A possible cause of variation or inadequacy in spray efficacy is heterogeneity of deposit around the crown. Therefore, deposit was measured in the four compass directions to determine if a deposition pattern was associated with the wind direction (south-east). Although no consistently significant difference ($P < 0.05$) occurred on fir or on spruce (Table 6a and b), there was a trend showing a lighter deposit in the west quadrant, with the largest number of significant differences occurring for this aspect. Given a southeasterly wind, it is conceivable that the droplets were filtered out on the upwind sides of the trees and thus reduced the deposit on the leeward face. There was a converse trend toward heavier deposits on the east (windward) quadrant.

It is not known whether heavier deposit on the windward side is a general rule or a whim of specific circumstances. Armstrong and Yule (1978) calculated the ratio of all windward to leeward deposits from vertical distribution data to be 1.5:1, based on three white spruce trees. Recalculating their deposit data (using the outer third of their branches) to be more compatible with our sampling, we adjusted their ratio to 1.6:1. Our deposit ratios, based on 24 trees for each species (Table 6a) average 1.3 for fir and 1.0 for spruce, or in detail:

Table 6a. Matrix showing the mean deposit of dye ± SD by aspect in the upper, middle, and lower canopy levels in Plots A, B, and C and the significant differences between aspects. Concentrations of rhodamine WT in ng/shoot (N = 4 shoots).

Balsam Fir

	Plot A		Plot B		Plot C	
	N S E	Mean	N S E	Mean	N S E	Mean
Upper W	ns ns **	77 ± 43	** ** **	21 ± 14	ns ns ns	17 ± 17
E	ns ns	115 ± 50	ns ns	53 ± 25	ns ns	17 ± 12
S	ns	103 ± 62	ns	56 ± 25	ns	20 ± 16
N		102 ± 71		47 ± 84		21 ± 15
Middle W	* ** **	28 ± 34	* ** *	17 ± 13	ns ** *	9 ± 7
E	** ns	74 ± 46	ns ns	24 ± 10	ns ns	14 ± 10
S	ns	59 ± 30	ns	31 ± 20	ns	16 ± 10
N		44 ± 34		26 ± 16		12 ± 9
Lower W	ns ns **	17 ± 10	ns ns ns	10 ± 7	ns ns ns	8 ± 4
E	** *	31 ± 13	ns ns	8 ± 4	ns ns	7 ± 3
S	ns	22 ± 16	ns	9 ± 5	ns	8 ± 5
N		21 ± 12		10 ± 4		8 ± 5

Red Spruce

	Plot A		Plot B		Plot C	
	N S E	Mean	N S E	Mean	N S E	Mean
Upper W	* ns ns	30 ± 40	ns ns *	52 ± 111	ns ns ns	24 ± 31
E	ns ns	51 ± 119	** *	17 ± 18	** ns	14 ± 8
S	ns	72 ± 160	ns	59 ± 121	ns	16 ± 20
N		74 ± 137		45 ± 50		28 ± 26
Middle W	** ns ns	18 ± 26	ns ** ns	17 ± 17	ns ns ns	21 ± 26
E	** ns	18 ± 28	ns *	27 ± 37	ns ns	20 ± 16
S	ns	46 ± 108	ns	83 ± 133	ns	23 ± 25
N		35 ± 27		52 ± 127		28 ± 26
Lower W	ns ns ns	36 ± 88	ns ns **	21 ± 193	** ns **	13 ± 7
E	ns ns	36 ± 86	** **	12 ± 8	ns *	25 ± 24
S	ns	45 ± 96	ns	34 ± 41	*	14 ± 10
N		55 ± 98		24 ± 24		27 ± 30

* significantly different at $P < 0.05$

** significantly different at $P < 0.01$

Table 6b. Matrix showing the mean deposit of droplets ± SD by aspect in the upper, middle, and lower canopy levels in Plots A, B, and C and the significant differences between aspects. Mean droplets/needle on old foliage (1-year) (N = 10 needles).

Balsam Fir

	Plot A		Plot B		Plot C	
	N S E	Mean	N S E	Mean	N S E	Mean
Upper W	ns ns ns	0.8 ± 0.9	ns ** **	0.3 ± 0.5	ns ns ns	0.2 ± 0.4
E	ns ns	1.3 ± 0.8	ns ns	0.8 ± 0.3	ns ns	0.2 ± 0.2
S	ns	0.9 ± 0.6	ns	1.4 ± 1.1	ns	0.3 ± 0.3
N		1.0 ± 0.8		0.6 ± 0.4		0.2 ± 0.2
Middle W	ns ns ns	0.4 ± 0.3	ns ns ns	0.2 ± 0.2	ns ns ns	0.1 ± 0.1
E	ns ns	1.1 ± 1.0	ns ns	0.6 ± 0.5	ns ns	0.2 ± 0.2
S	ns	0.7 ± 0.3	ns	0.7 ± 0.8	ns	0.2 ± 0.4
N		0.6 ± 0.9		0.4 ± 0.3		0.1 ± 0.1
Lower W	ns ns ns	0.2 ± 0.2	ns ns ns	0.1 ± 0.1	ns ns ns	0.1 ± 0.2
E	ns ns	0.6 ± 0.4	ns ns	0.2 ± 0.1	ns ns	0.2 ± 0.2
S	ns	0.3 ± 0.2	ns	0.4 ± 0.4	ns	0.1 ± 0.2
N		0.3 ± 0.3		0.1 ± 0.2		0.1 ± 0.1

Red Spruce

	Plot A		Plot B		Plot C	
	N S E	Mean	N S E	Mean	N S E	Mean
Upper W	ns ns ns	0.1 ± 0.1	ns * *	0.1 ± 0.1	ns ns ns	< 0.1
E	ns ns	0.2 ± 0.2	ns ns	0.4 ± 0.4	ns ns	na
S	ns	0.3 ± 0.2	ns	0.6 ± 0.4	ns	< 0.1
N		0.2 ± 0.1		0.3 ± 0.4		< 0.1
Middle W	ns ns ns	< 0.1	ns ns ns	0.1 ± 0.1	ns ns ns	na
E	ns ns	0.1 ± 0.1	ns ns	0.2 ± 0.1	ns ns	na
S	ns	0.1 ± 0.1	ns	0.2 ± 0.2	ns	< 0.1
N		0.1 ± 0.1		0.2 ± 0.1		na
Lower W	ns ns ns	< 0.1	ns ns ns	0.1 ± 0.1	ns ns ns	< 0.1
E	ns ns	< 0.1	ns **	0.2 ± 0.1	ns ns	< 0.1
S	ns	0.1 ± 0.1	ns	0.1 ± 0.1	ns	0.1 ± 0.2
N		0.1 ± 0.1		0.7 ± 1.0		< 0.1

* significantly different at $P < 0.05$

** significantly different at $P < 0.01$

na no droplets detected

Ratio for windward/leeward deposits of rhodamine WT tracer dye

	A	B	C	Average
Fir	1.4	1.4	1.1	1.3
Spruce	1.1	1.1	0.8	1.0

Despite the disparity between Armstrong and Yule's spray situation and ours, the two data sets are similar in suggesting that the windward side of a conifer crown intercepts more deposit. On the other hand, atmospheric turbulence should tend to homogenize deposit in the outer crown, particularly in the upper crown where wind speed and turbulence are higher. In summary, it appears that crown aspect was not a major factor affecting efficacy of spray application in this experiment.

Nevertheless, aspect is a factor with potential operational implications. If the windward to leeward ratio were higher, say 2:1, it would be a major cause of heterogeneity of efficacy. In that case, two or more sprays with winds from different directions might be desirable to ensure good coverage by aspect. Aspect as a factor of distribution should be tested in other spray circumstances.

Variation of deposit among trees

Although the eight sample trees of each species in each plot were selected for consistency in height, crown volume, crown isolation, and foliage density, deposits per tree were highly variable (Table 7). Comparing the heaviest to the lightest deposit per tree, the range was 44-fold for fir and 8-fold for spruce. Nevertheless, within-tree heterogeneity (coefficient of variation among 48 shoots) was much higher in spruce than in fir.

Note that the mean deposits per shoot shown in Table 7 are slightly lower than the means given in Table 2. The difference is an artifact of analysis routine; in the analysis for Table 7, the shoot values of 5 ng or less were considered to be zero, because such values were at the limit of detection by the fluorometer above natural background.

Variance among shoots

The variation in deposit among individual shoots, both fir and spruce, is important because shoots (the budworm feeding sites) are the ultimate spray targets.

Because filtering by foliage reduces homogeneity in deposit, it is essential to determine efficacies associated with the range of deposits that may occur. The lowest deposits (insufficient to kill larvae) and the highest deposits (overdosing) represent waste in the distribution pattern. The optimum deposit - an optimization of droplet density and droplet mass just sufficient to kill a 3rd- or 4th-instar budworm in 95 of 100 trials - has yet to be defined.

Table 7. Deposits ng rhodamine/tree (= 48 shoots) and coefficients of variation (%) by plot for fir and spruce, Magundy, 1982.

	Plot A		Plot B		Plot C	
Tree no.	Total deposit	CV (48 shoots)	Total deposit	CV (48 shoots)	Total deposit	CV (48 shoots)
			Balsam fir			
1	4608	82	638	123	348	70
2	2749	60	1155	70	246	114
3	2378	78	1162	108	174	155
4	1888	93	1694	98	726	65
5	2445	78	1733	70	868	56
6	3345	95	1285	115	1081	71
7	2568	95	754	86	104	168
8	1956	66	1079	93	798	83
Mean/tree	2742	91	1187	101	543	106
Mean/shoot	57		25		11	
			Red spruce			
1	3598	175	1516	141	649	80
2	4250	177	1652	306	620	53
3	3339	130	1993	154	1771	100
4	644	198	713	104	731	88
5	874	230	969	85	898	132
6	1165	135	2539	172	1225	110
7	1514	235	2176	168	1165	64
8	534	89	2034	203	902	64
Mean/tree	1990	217	1699	199	995	106
Mean/shoot	41		35		21	

There was moderate variation in deposit among branches (as represented by 4-shoot-means) by aspect and canopy level (Tables 6a,b) with the coefficients of variation averaging 60% for fir and 140% for spruce (Appendix Tables II-3, -4). That variation resulted partly from the position of each

branch in the crown relative to the foliage filter around it as well as to the position of each tree in the plot. It was not a result of aspect or canopy level as can be seen from the relatively uniform coefficients of variation within each species.

Spruce data show consistently greater variation in deposit mass per shoot than do fir data (Appendix Tables II-1, -2). This difference may be accounted for, as noted earlier, by the relatively high density of spruce foliage (strong local filter) and the low density of fir (defoliation effect). However no information on the filter efficiencies of foliage at various densities is available.

The frequency distributions of rhodamine concentrations in ng/shoot (Fig. 4a, b), with 1152 samples per species, present a peak deposit frequency at very low concentrations (< 15 ng/shoot) and a smooth exponential skew to values as high as 302 ng for fir and 650 ng for spruce. The distributions on fir and spruce are essentially the same; 537 fir samples and 569 spruce samples had less than 15 ng/shoot.

The gradients of deposits from Plots A to C are depicted in Figures 4d and 4e (ng/shoot) and 4f (droplets/fir needle). For fir, the differences among plots are quite pronounced; A was rich in high-deposit shoots and relatively impoverished in very low-deposit shoots; C had mainly low-deposit shoots and scarcely any high-deposit shoots; B was intermediate. For spruce, distributions in A and B were similar, both well endowed with a strong skew compared with C. As will be shown, these frequency distributions have a powerful influence on efficacy.

The frequency distribution of droplets/old needle on fir (Figures 4c and 4f) shows patterns corresponding to those for ng rhodamine. No droplets were detected on 76 of the 288 shoots examined. The frequency distribution for droplets on spruce is not shown due to our lack of confidence in the accuracy of tallies.

Relationship between rhodamine deposit and droplet tally

The rhodamine concentrations (see Table 6a, values in ng dye per sample shoot) can be crudely converted to droplets per needle, if we specify the average droplet diameter.

An emitted droplet of 100 μ, containing an aqueous emulsion of fenitrothion-Atlox-Dowanol, has a volume of 52×10^{-4} mm^3, i.e. 52 x 1.03 (SG) = 536 ng, while the same droplet evaporated to lose almost all of its water (86%) would have a diameter about 50 μ and weigh approximately 70 ng. The rhodamine detected on foliage represents the evaporated formulation in the rates of 1:90, i.e. 1 ng of rhodamine = 90 ng formulation emulsion = 90/70 = 1.3 droplet of 50 μ diameter. Table 6a shows rhodamine values in ng/fir shoot sample ranging from 7 to 115, and values per spruce shoot from 12 to 83 ng. Therefore, the hypothetical number of near 50 μ droplets/fir shoot ranges from 9 to 150, or roughly 0.09 to 1.50 droplets/needle, assuming 100 needles/shoot. For spruce, the number of near 50 μ droplets ranges from 16 to 108, or 0.18 to 1.23/needle, assuming 88 needles per 4 cm shoot. These estimates are compatible with the observed deposit values (Table 6b), especially for fir.

We also examined the direct relationship between rhodamine weights from four shoots and droplet tallies from one shoot within the basic five-shoot sample from each branch. When these samples were grouped per single tree (48 rhodamine weights, 12 droplet tallies), the correlation between rhodamine weight and droplet tally, tested by Pearson product-moment comparison, was high in the fir data and weak in the spruce data (Appendix Tables II-3, -4). The high correlation coefficient on fir indicates that droplet tally is a reliable alternative method of estimating deposition. The low correlation on spruce is the result of a higher coefficient of variation in rhodamine deposit data (see Table 7), and presumed inaccurate tallies from spruce needles (due to the difficulty of detecting small droplets as already stated). Therefore, the use of droplet tallies to estimate deposit on spruce may be an unreliable method unless sampling intensity can be increased and errors in counting can be decreased. Possibly droplet detection could be upgraded by use of a stronger dye concentration or by examination of droplets under UV stimulation (fluorescence vs. normal color).

From the 24-tree fir data set (based on the 4 + 1 shoot clusters/ branch), droplets per 4 cm shoot (old foliage) are plotted against rhodamine deposit (old foliage + flaring buds) (Fig. 5a). The correlation (r value 0.74) shows a fairly reliable relationship.

The relationship has potential for reliable prediction. When the data from each set of 8 fir trees per plot are plotted separately (Fig. 5b), correlations between ng rhodamine/whole shoot and droplets/4

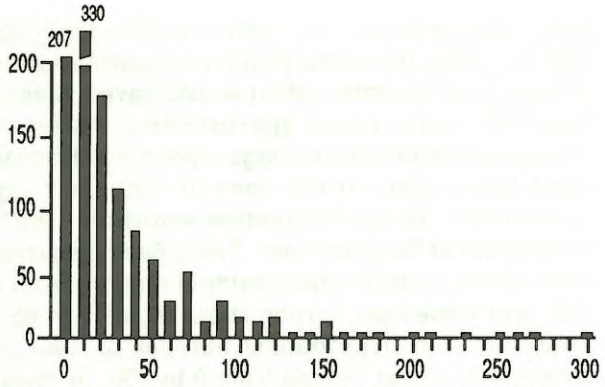

Fig. 4A Frequency distribution from 1152 balsam fir samples (plots A+B+C) showing deposits as ng rhodamine/shoot.

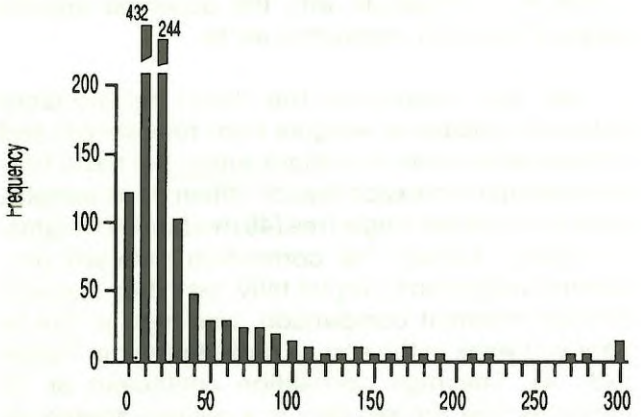

Fig.4B Frequency distribution from 1152 red spruce samples (plots A+B+C)showing deposits as ng rhodamine/shoots.

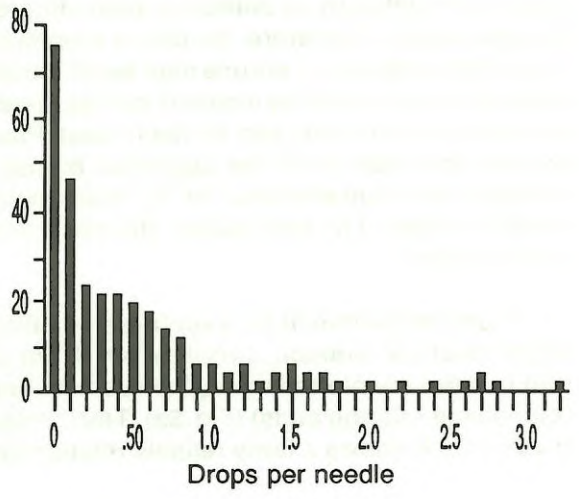

Fig.4C Frequency distribution from 288 balsam fir samples (10 old needles /shoot),summing plots A+B+C,showing deposits as droplets/ needle.

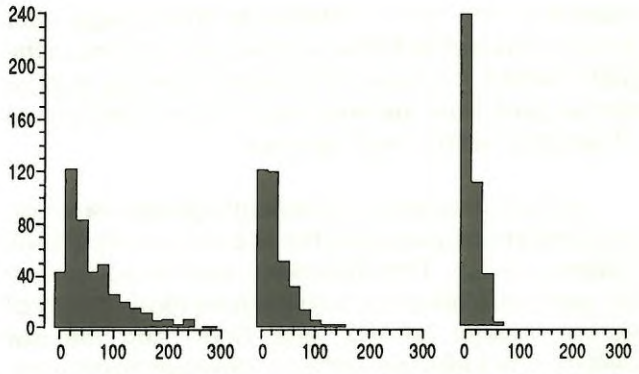

Fig.4D Frequency distributions from 384 fir samples per plot,showing deposit as ng rhodamine/ shoot,Magundy,1982.

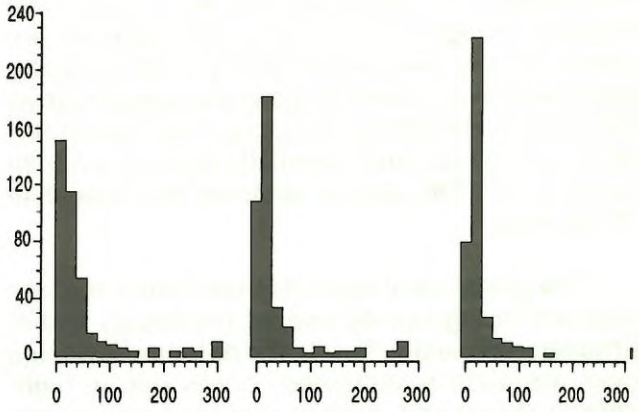

Fig.4E Frequency distributions from 384 spruce samples per plot, showing deposit as ng rhodamine/shoot Magundy,1982.

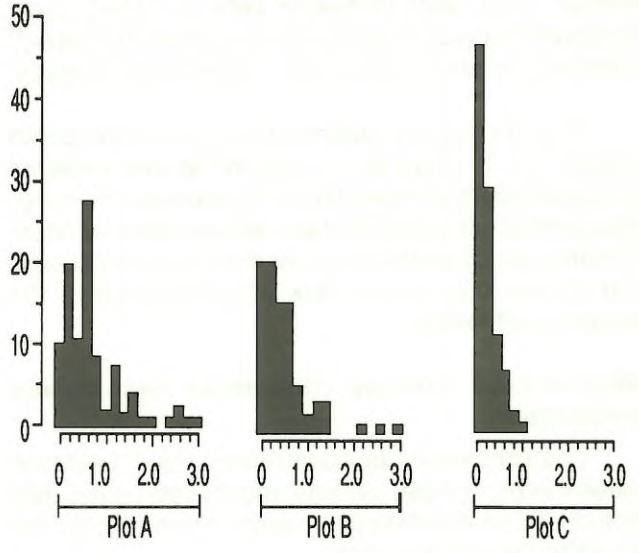

Fig.4F Frequency distributions from 96 fir samples (x 10 needles)per plot,showing deposit as droplets/old needle,Magundy,1982.

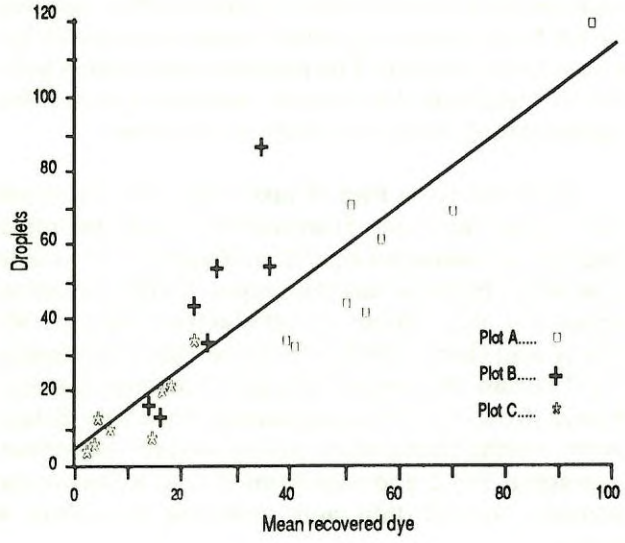

Fig.5a Relationship between ng rhodamine/shoot and mean droplets/100 old needles,based on 48 shoots per tree for dye recovery ,and 12 shoots per tree for droplet tallies,Magundy,1982.

cm old foliage are strong: A:r^2 0.88, B:r^2 0.84, C:r^2 0.74. However the slope of Plot B does not conform with the slopes in the other two plots, suggesting some irregularity in data collection or deposit pattern.

Droplet diameter spectrum

The measurement of stain diameter to characterize the droplet spectrum was restricted to Plot A, fir only, where smudging of stains by moisture condensation on foliage on the spray morning was least widespread. A small systematic sample of 599 intact stains on fir, converted by Kristmanson and Picot's (1984) spread factor of 2.9, indicated that 90% of the droplets had a diameter of < 60 μ at impact, and that percentages by crown level did not significantly deviate from the mean. The Number Mean Diameter (NMD) was 36.2 μ and the Mass Mean Diameter (MMD) (= Volume Mean Diameter, VMD) was 46.7 μ, details in Appendix V. This matches Picot's (1985) criterion that the droplet size range for maximum impingement on conifer foliage is between 15 and 55 μ, based on study of the TBM Teejet output. Barry *et al.* (1977), in an experiment using helicopters to spray western spruce budworm on Douglas fir with a mexacarbate formulation, found that 96% of the droplets impacting on needles were < 15 μ, and that mean size was related inversely to wind speed. Such very small particles were at the limit of detectability in our experience, hard to find

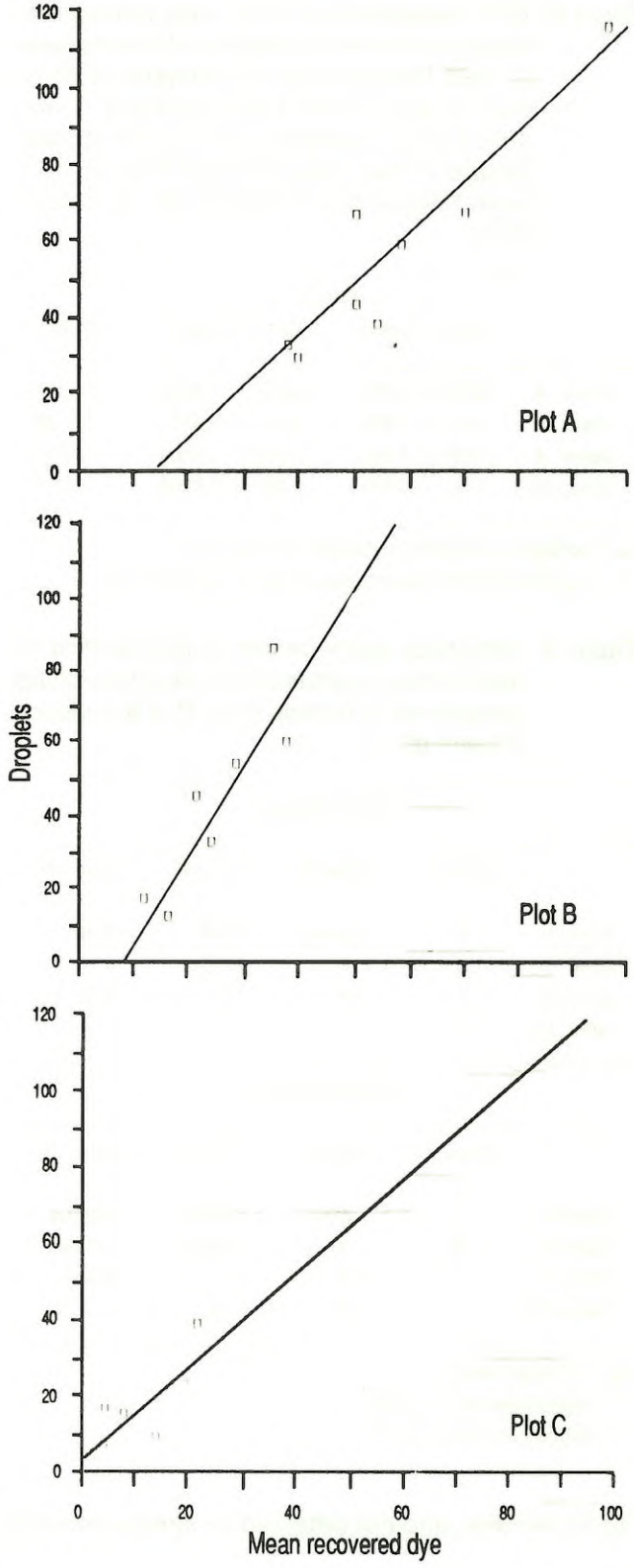

Fig.5b Relation ship between rhodamine ng/shoot,and droplets/shoot (=100 old needles) for 8 fir trees in each of plots A,B,C,Magundy,1982.

Table 8. GC measurements at two-day intervals of mean concentrations of fenitrothion residues (± SD) from branch-tip samples of fir in Plot B and from amalgamated (non-directional) samples of fir and spruce foliage in the upwind Check Plot, in μg/g fresh foliage; N = 8 (Plot B), N = 4 (Check Plot).

	Plot B		
	North Aspect	South Aspect	Check
June 4	5.74 ± 2.86	4.00 ± 2.48ns	0.27
June 6	3.97 ± 1.78	2.71 ± 0.95*	0.48
June 8	2.59 ± 1.54	2.56 ± 1.01ns	0.39
June 10	1.50 ± 0.65	1.84 ± 0.72ns	0.11

ns = no significant difference between aspects.

* = significant difference between aspects at $P < 0.05$.

Table 9. Statistical significance of distribution of fenitrothion residues (GC) from branch tip samples of fir foliage from Plot B, t-values shown; df = 7.

North Aspect				
	June 4	June 6	June 8	June 10
June 4	X	1.43ns	2.92*	4.32**
June 6	X	X	1.47ns	4.11**
June 8	X	X	X	2.61**
June 10	X	X	X	X

South Aspect				
	June 4	June 6	June 8	June 10
June 4	X	1.25ns	1.63ns	2.22ns
June 6	X	X	0.38ns	2.15ns
June 8	X	X	X	3.08*
June 10	X	X	X	X

ns = not significant

* = significant at $P < 0.05$

** = significant at $P < 0.01$

on fir needles, and not detected on spruce needles.

Degradation of Deposits

Deposits of fenitrothion on foliage in a forest stand decline by volatilization, photo-degradation, hydrolysis, and rain wash. Yule and Duffy (1972) reported a half-life of 4 days for fenitrothion applied by air to fir foliage at operational dosages (2 to 4 ppm on fir foliage). The possible variation in half-life in response to various weather parameters (temperature, moisture, wind) is unknown.

Samples from Plot B taken at 2-day intervals from spray day (June 4) showed the expected rapid decline, as assessed by GC analyses of fir foliage (Table 8). The spray day readings in Plot B, averaging about 5 μ g/g, indicate a satisfactory deposit rate (Varty and Godin 1983, Courshee 1983) (Appendix III). The half-life over a 7-day period averaged about 4 days (6 days on the south aspect of the tree, 3 days on the north) during warm spring weather (maximum averaging 25°C and minimum 6°C in a Stevenson screen). No GC data were available from Plots A and C.

The design of the experiment incorporated a comparison of deposits on the north aspect of the crown versus the south aspect (see Appendix III for the 80 sample analyses). Analyses (Table 8) showed little significance in the differences between aspects, confirming the analysis of rhodamine distributions (Table 6a).

Most differences in deposit among collection dates in Plot B are significant in the north aspect and insignificant in the south aspect (Table 9). The weight of evidence is that the smooth down-trend with time is real, not due to chance, but it is inferred that sampling intensity (16 sample branches per date) was marginally adequate. The sampling effort was constrained by the high cost of GC analysis ($55 per sample).

The values in the Check Plot are so obviously lower than those in Plot B that no analysis of difference is needed (Table 8). However, the presence of substantial residues on fir and spruce in the Check Plot was surprising. The Check Plot has never been sprayed with fenitrothion and therefore is unlikely to have accumulated significant residues (Eidt and Mallet 1986, Ayer *et al.* 1984), even though drifting may have occurred in 1981 or earlier; individual sample values (June 6 & 8) as high as 1.05 (Appendix III) suggest a more recent influx. In 1982, the nearest operational block was 6 km to the northwest, and was sprayed on the morning of June 3 (one day before the experimental spray); the 16 km/h wind from the northwest could conceivably have drifted the spray cloud into the experimental area. Whatever the source, the deposit on the Check Plot was real because it coincided with a sharp

increase in larval fallout.

The average deposit of 5 μg/g from clipped branch tip foliage in Plot B, can be applied to calculations of mean dosage per shoot. Since an average 4 cm fir shoot plus 1.7 cm flushing buds weighs about 1 g, then the mean weight of fenitrothion deposit would be $1 \text{ g} \times 5 \times 10^{-6} = 5$ μg/shoot. Since the recovered tracer dye has a ratio of 1:75 fenitrothion, then the mean rhodamine deposit should weigh about 67 ng/shoot. For a spruce shoot weighing 0.7 g and having 5 μg/g, the rhodamine deposit would be about 46 ng/shoot. This is similar to the values from fluorometric measurement, as reported in Table 5a (cf. especially Plot B, mid-crown).

Nature of the Target

In general, the target for insecticide deposit can be described as the larva and its single-shoot habitat, that is, the new bud and the few cm of adjacent old shoot. However, drop tray counts in 1981 (Varty and Godin 1983) and also in this study suggest that few larvae are killed by direct impact of a droplet, since the fallout of larvae within an hour of the spray application was very low. The highest mortality occurred during the warm hours of the day, presumably when the larvae left their inner lair to feed, spin silk or expel frass in the outer habitat. That outer habitat is the foliage within a 1 cm radius of the mine or tube. The deposit of insecticide on those needle surfaces and associated silk strands appears to be most important. The probability of contact depends upon droplet density and insecticide persistence (i.e. space and time for larval activity).

It is hypothesized that efficacious timing of spray application is related to larval movement across foliage exposed to droplet impaction. The probability of larval contact with spruce droplets increases with the frequency and extent of excursions from the silk tube or bud mine. We observed that larval production of silk strands (a measure of larval movement around the habitat periphery) increased with instar and was more abundant on fir than on spruce during the third and fourth larval stadia.

Bud flushing phenology had a profound effect on larval choice of habitat. The vegetative buds of fir flushed from mid to late May; between May 13 and 27, the larvae abandoned their needle mining habit in favor of bud mining (Appendix Table VI-3) and all feeding was on the hidden bases of new leaves until the buds had fully flared around June 9. Flowering buds (male strobili and ovuliferous buds) were very rare in the fir samples.

On red spruce in 1982 there were two population groups: one group infesting pollen buds, the other mining needles and vegetative buds. The pollen buds were clearly favorable habitats in which the larvae developed rapidly and produced abundant silk; they were first occupied from mid to late May after initial needle mining, and supplied sites for one quarter to half the midcrown population of third and fourth instar larvae. The other larvae mined needles until the end of May and began mining vegetative buds from the outside in early June, but did not dwell within the new shoots until mid June. Relationships between larval instar and bud growth are shown in Fig. 6.

On spray day, June 4, the vegetative buds of fir were all beginning to flare, averaging 1.7 cm long, with many green leaf tips fully exposed. Larval development index (LDI) was 4.5 (similar numbers of fourth and fifth instars) and virtually all larvae were sequestered within the bud. During casual surveillance of populations on fir and spruce throughout the afternoon, larvae were only rarely observed on the outer surface of fir buds, and not at all on the surface of spruce buds. The vegetative buds of spruce on spray day were only 0.6 cm long, slightly swollen but with no green tip exposed. Most larvae were still feeding on old needles, but some buds were being mined from the outside; the larvae observed on spray day invariably were found within a silken shelter tube, incorporating several needles at the bases of buds. The other portion of the spruce population was hidden within the male strobili and were further ahead in development. The LDI for the population on spruce was 4.2, but the two components were not separately identified. According to Hansen and Dimond (1982), populations on red spruce develop more slowly and have lower survival than on balsam fir, as observed in the State of Maine. They also confirmed that the needle-mining stage within a silk tube along the twig axis is prolonged on red spruce. They believed this to be a period when enhanced efficacy of sprays could be obtained.

Spray Efficacy

The industrial measures of operational success within a season are foliage retention and satisfactory wood increment, but those criteria are not satisfactory research gauges of efficacy for a specific spray,

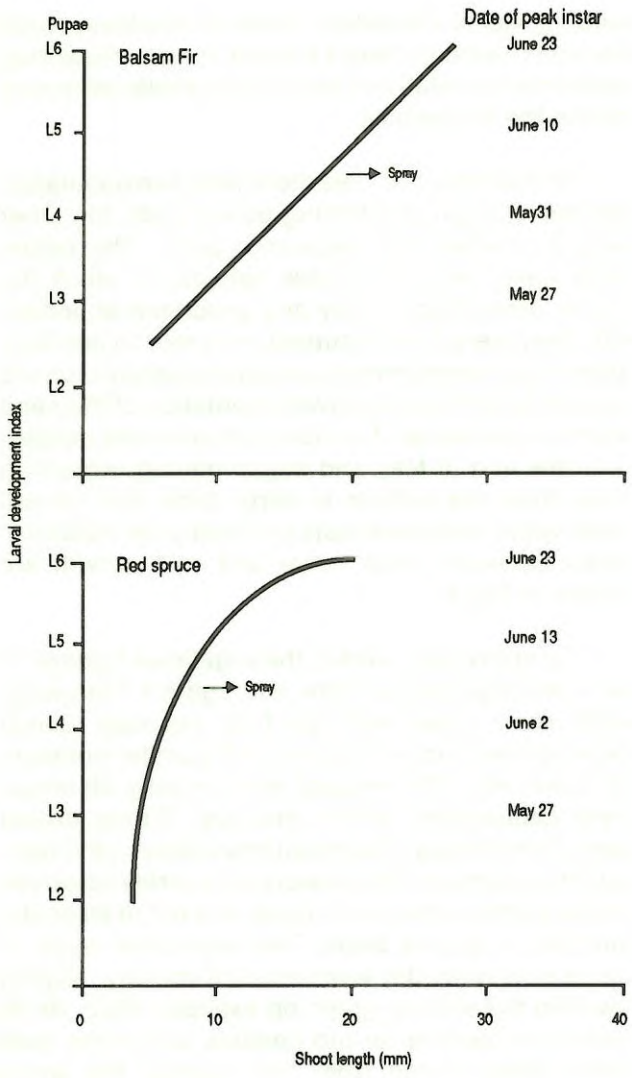

Fig.6 Larval and shoot development on balsam fir and red spruce Magundy,1982.

because of the variable intervention of tree vigor and natural control. Therefore we have relied upon direct response of larval populations to the presence of the insecticide as the preferred measure of efficacy. The two measures of larval mortality used in this study were: 1) the change in midcrown population densities across the season and 2) counts of the fallout of larvae to drop trays.

Midcrown population trends

Summing the population estimates for Plots A, B, and C makes a normal representation of the seasonal dynamics of larval populations on fir and spruce (Fig. 7a). However, the wide scatter in mean densities by date would permit deviations from the trends depicted. It is believed that the scatter should be attributed less to inaccuracies in larval tallies, than to variance in the distribution of populations in midcrown branches, and could be overcome only by larger samples. Separation of populations by plots (Fig. 7b) does not ease the problem of high variance/inadequate sampling.

However, the sampling effort did establish that Plots A, B, and C had essentially similar L3 (3rd-instar larvae) densities in mid May, around 450 larvae/m^2 foliage on fir and around 300 larvae/m^2 foliage on spruce. A month later, densities had declined to around 170 L5-L6/m^2 on fir foliage and to around 130/m^2 on spruce. These densities were double the populations recorded in adjacent sectors of the same stand a year earlier (Varty and Godin 1983), in spite of two spray applications in 1981.

Figure 7a groups values as pre-spray and post-spray, each with its own line plot. The general trends from second to sixth instar, showing decline by 60-70%, are within the norms of population behavior (Morris 1963). The sharp break between pre-spray and post-spray trends in the fir-dwelling population indicates a spray efficacy of about 30%, but the contradictory reversal of trends in spruce is hard to rationalize except as an artifact related to lower worker accuracy in searching spruce for second and third instars compared with searching for fifth and sixth. However, the trends recorded in the untreated Check Plot for fir and spruce are incomprehensible, possibly explicable as a variance artifact or by population redistribution among crown levels (Fig. 7c). Moreover, the usefulness of the Check Plot was further eroded by the unexpected influence of insecticide drift (as already hypothesized). For these reasons, it was impossible to derive insecticide efficacy estimates from these survivorship curves. The information is reported only to record the pitfalls in efforts to estimate population densities in conifer crowns, in support of the discussion on budworm sampling reported by Varty and Godin (1983). A much larger sampling effort would be needed to overcome the problems of variance from branch to branch within the midcrown level, and of population redistribution among levels.

Care must be taken in procedures for cutting, bagging, transporting, and storing branches. Larvae become increasingly sensitive to sample handling as the instars advance; sixth instars especially are

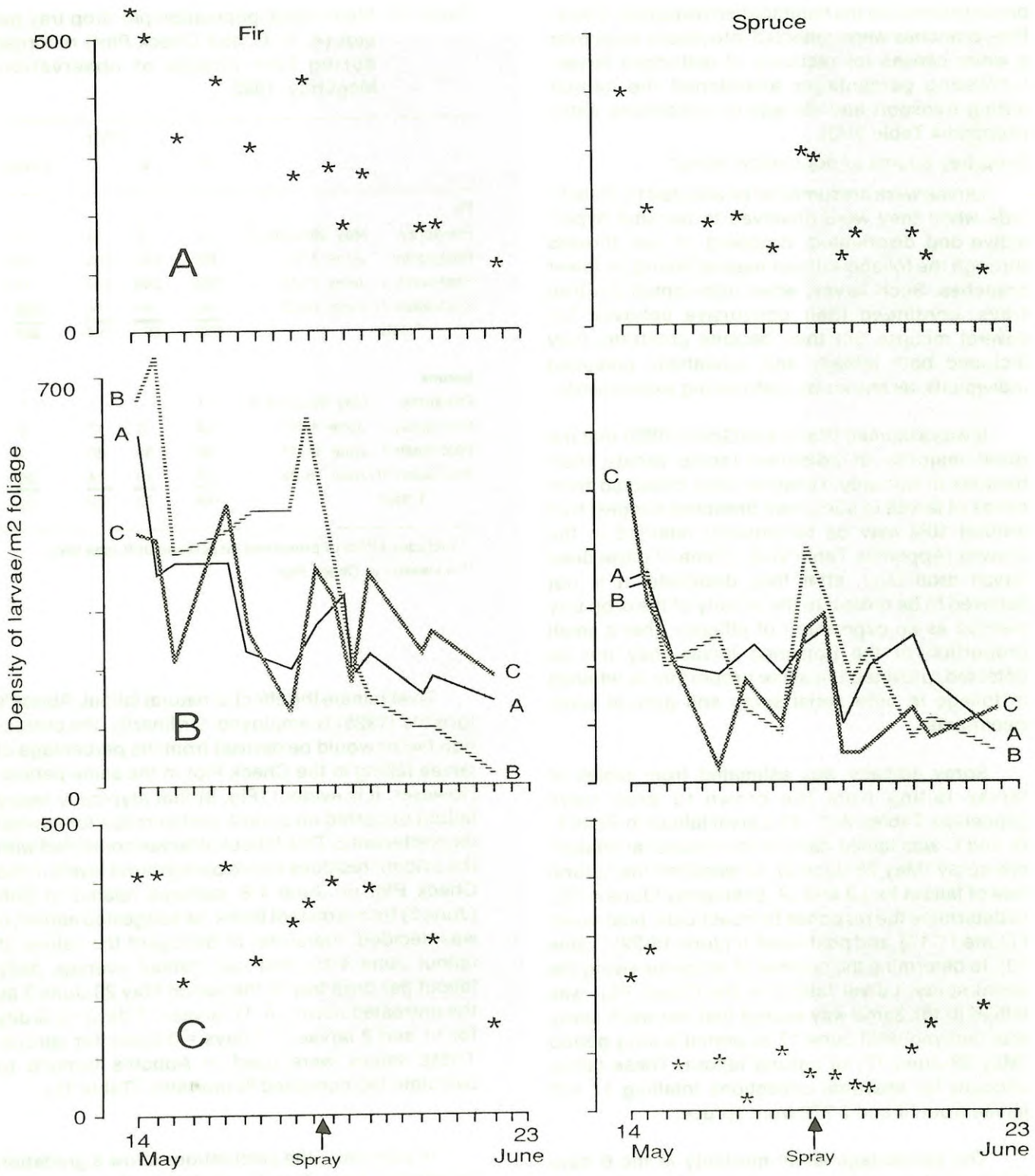

Fig.7 Estimates of population densities of spruce budworm larvae/M² mid crown foliage from fir and spruce.
7A;mean densiity from all plots (A+B+C) with trends plotted pre and post spray.
7B;means by plot:A-2 trees,B-4 trees,C-2 trees/species,showing wide scatter due to sampling variance.
7C;means in check plot,based on samples from 2 trees/species.

prone to abandon the habitat when disturbed. Therefore, branches were collected into plastic bags over a white canvas for recovery of dislodged larvae. Increasing percentages abandoned the habitat during transport and storage on successive dates (Appendix Table VI-3).

Drop tray counts of population fallout

Larvae were presumed to be affected by insecticide when they were observed to become hyperactive and disoriented, dropping on silk threads through the foliage without reestablishing on lower branches. Such larvae, when intercepted by drop trays, continued their convulsive behavior for several minutes but then became prostrate; they included both lethally and sublethally poisoned individuals, as shown by diet-rearing experiments.

It was assumed (Varty and Godin 1983) that the great majority of poisoned larvae vacate their habitats in this way. However data collected from tallies of larvae in midcrown branches suggest that around 10% may be temporarily retained in the crowns (Appendix Table VI-3). Some of these dead larvae drop later, after they desiccate. It is not believed to be critical to the validity of the drop tray method as an expression of efficacy, that a small proportion of the poisoned larvae may not be detected, provided the same proportion is retained in foliage in both aerial spray and ground wash treatments.

Spray efficacy was estimated from tables of larvae falling from the crown to drop trays (Appendix Tables VI-1, -2). Larval fallout in Plots A, B, and C was tallied daily in four seasonal phases: pre-spray (May 28-June 3), to establish the natural rate of fallout for L3 and L4; post-spray (June 4-10), to determine the response to insecticide; post-wash I (June 11-17), and post-wash II (June 18-22) (Table 10), to determine the number of larvae surviving the aerial spray. Larval fallout in the Check Plot was tallied in the same way except that the wash spray was delayed until June 17 to permit a long period (May 28-June 17) of natural fallout. These tallies account for seasonal collections totalling 17 416 larvae from fir and 2 772 from spruce.

The percentage larval mortality in the 6 days following the aerial spray is estimated from Table 10 as

$$\frac{\text{Fallout Post-spray June 4-10}}{\text{Total fallout May 18-June 22}} \times 100 \quad \text{(Table 11)}$$

Table 10. Mean larval population per drop tray per plot (A, B, C, and Check Plot) recorded during four phases of observation, Magundy, 1982.

		Plot			
		A	B	C	Check
Fir					
Pre-spray	May 28-June 3	11	9	10	17
Post-spray	June 4-10	390	245	285	72*
Post-wash I	June 11-17	190	248	455	17**
Post-wash II	June 18-22	42	49	44	288
Totals		633	551	794	394
Spruce					
Pre-spray	May 28-June 3	1	1	1	< 1
Post-spray	June 4-10	44	16	17	2
Post-wash I	June 11-17	86	39	80	2
Post-wash II	June 18-22	13	19	14	29
Totals		144	75	112	34

* includes effect of presumed insecticide drift (see text).

** no wash I in Check Plot.

To eliminate the effect of natural fallout, Abbott's formula (1925) is employed. Ordinarily, the correction factor would be derived from the percentage of larvae falling in the Check Plot in the same period. However, it is evident (Fig. 8) that atypically heavy fallout occurred on June 4, and perhaps for several days afterward. This fallout of larvae coincided with the evident residues above background levels in the Check Plot on June 4-8, perhaps related to drift (June 3) from a distant block, as suggested earlier. It was decided, therefore, to disregard the values of fallout June 4-10, and use instead average daily fallout per drop tray in the period May 28-June 3 as the untreated norm, i.e. 17 larvae ÷ 7 days = 2.5/day for fir and 2 larvae ÷ 7 days = 0.3/day for spruce. These values were used in Abbott's formula to calculate the corrected % mortality (Table 11).

In summary, the calculations show a gradation of efficacy from A to C, related to the deposition gradient, and a general efficacy against larval populations on fir about twice as great as efficacy on spruce. The mean efficacy on all plots was 45% on fir and 22% on spruce, which, in operational terms, would be regarded as unsatisfactory, leaving too many survivors.

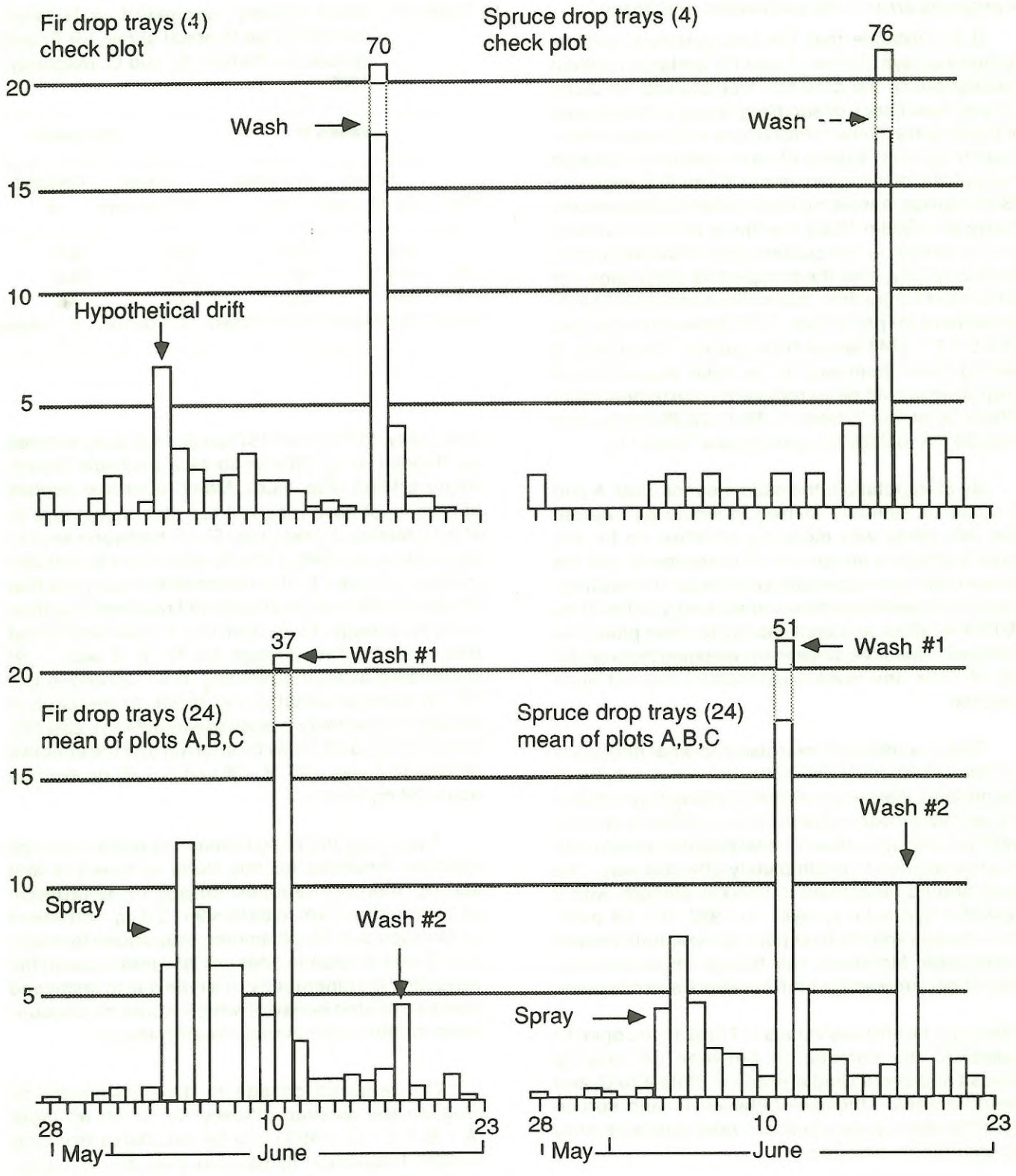

Fig.8 Fallout of larvae to drop trays under fir and spruce in the spray block (average ofA,B and C plots and in the check plot,represented as the daily percentage of the total population falling between 28 May and 23 June.

A propable error in the calculation of efficacy

It is probable that the two pyrethrin washes (ground sprays of June 11 and 17) left large residual populations in the drop tray tree crowns. On June 20, a special check of surviving larvae in the crowns of the drop tray trees in Plot B (one mid-crown 45 cm branch tip from 8 trees of each species) indicated that density of living larvae was 80/m^2 fir foliage and 78/m^2 spruce. Assuming from earlier measurements (Varty and Godin 1983) that there were on average 6m^2 of foliage in the column perpendicularly over each drop tray, then the prospective population not accounted for by drop tray collections would be 80 larvae per 6 m^2 per 8 trees = 3840 larvae from fir, and 78 x 6 x 8 = 3744 larvae from spruce. The effect of adding these numbers to the total population in drop trays would be to reduce the corrected spray efficacies in Plot B from 41.8% to 22.3% for fir, and from 20.6% to 2.8% for spruce (see Table 11).

By extrapolation, the estimates for Plots A and C could be similarly revised. It would be inferred that this spray was modestly effective on fir, but quite ineffective on spruce. This argument and the revised values are speculative because the assumptions (representativeness and accuracy of the June 20 Plot B tallies, and applicability to other plots) are unproven. Therefore, while acknowledging the probability of error, the revised estimates have not been adopted.

This is a research exercise and what matters is not the site-specific estimates but the reliability of the method. We conclude that the drop tray method is a sensitive means of determining efficacy, but the wash technique to obtain a total population estimate must be applied in a completely effective way. The wash should be applied in overkill dosages with a powerful hydraulic sprayer. In 1982, the 1% pyrethrin dosage and the backpack sprayer both proved inadequate. Moreover, the foliage above the tray should be sampled for both survivors and cadavers.

Although the efficacy values in Table 11 are open to question, the correlation between decreasing deposit and decreasing efficacy in Plots A to C, and the differential efficacies between fir and spruce from the same spray cloud, are valid results bearing on operational practice.

Estimating the efffective dosage

Most shoots got some deposit, however light. Of 1152 shoots of each species processed fluorometrically, 207 fir and 137 spruce samples showed no deposit or so little as to be a probable fluorometry artifact (Fig. 4a,b). Many other low-deposit shoots must have received too little insecticide to elicit a budworm response. Since budworm knockdown on fir was 59% in Plot A, 42% in Plot B, and 33% in Plot C (Table 11), it is reasonable to suppose that 41, 58, and 67% of the shoots had received less than effective dosage. Thus, from Fig. 9, it can be inferred that the effective dosage for fir in A was > 30 (expressed as ng rhodamine), in B > 20 and in C > 10, on average about 20 ng/shoot. In the case of spruce, budworm knockdown was 30% (A), 20% (B), and 15% (C), and it may be inferred that the effective dosage in A was > 25, B > 36 and C > 35, on average about 32 ng/shoot.

Table 11. Spray efficacy, expressed as % larval mortality due to aerial spray, for fir and spruce on Plots A, B, and C, Magundy, 1982.

	Balsam fir		Red spruce	
Plot	Fallout (% tot. pop)	Corrected %	Fallout (% tot. pop)	Corrected %
A	61.6	59.2	30.6	30.3
B	44.5	41.8	21.1	20.6
C	35.9	33.0	14.9	14.6
Check	18.2 (actual)	14.4 (revised)	6.7 (actual)	6.1 (revised)

Assuming that 26 ng rhodamine was an average effective threshold for this stand of mixed fir and spruce, then the required dosage of fenitrothion emulsion/shoot would be 26 x 90 = 2.3 µg, equivalent to 34 droplets of 50 µ diameter, evaporated formulation. That calculation does not take into account the variability in vulnerability of larvae due to instar and weather-related behavior which would be encountered in other operational circumstances.

The required dosage in droplets/needle to produce the average efficacy for fir on all plots (A + B + C ÷ 3 = 45%) can be calculated from the droplet frequency distribution (Fig. 4c). By inference, 55% of the shoots (100% - 45%) received a dosage insufficient to induce larval fallout; thus about 0.3 droplets/ old fir needle would be the threshold for response. On a whole shoot basis, this would be about 40 droplets, i.e. similar to the

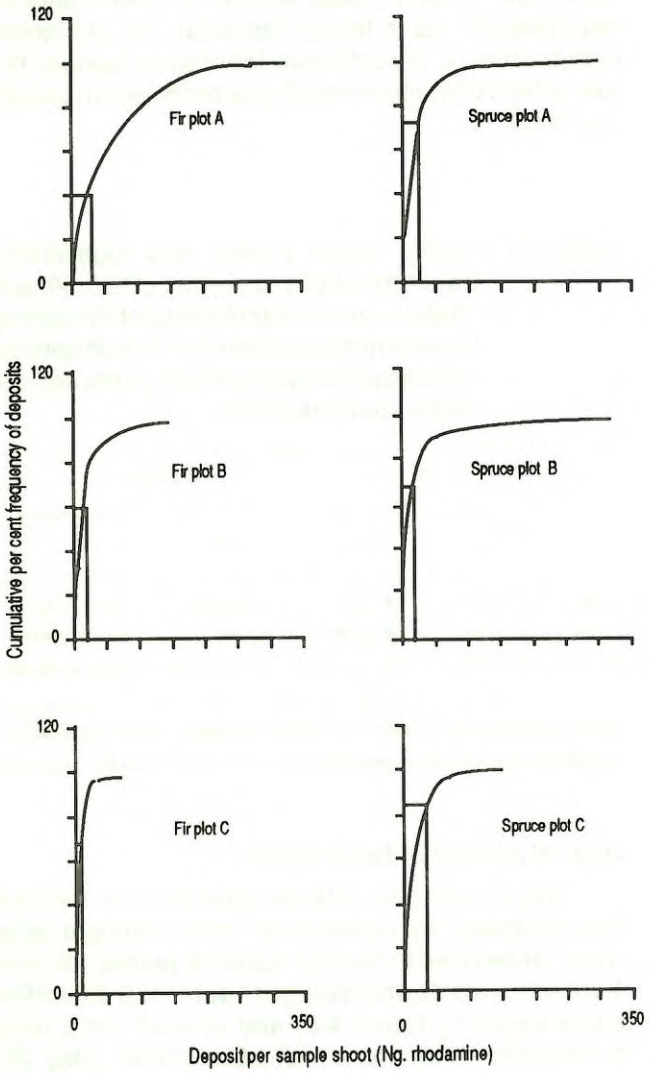

Fig.9 Cumulative percent frequency distribution of rhodamine WT (ng) deposit on sample shoots of balsam fir an red spruce (N=384)per plot,Magundy,1982.

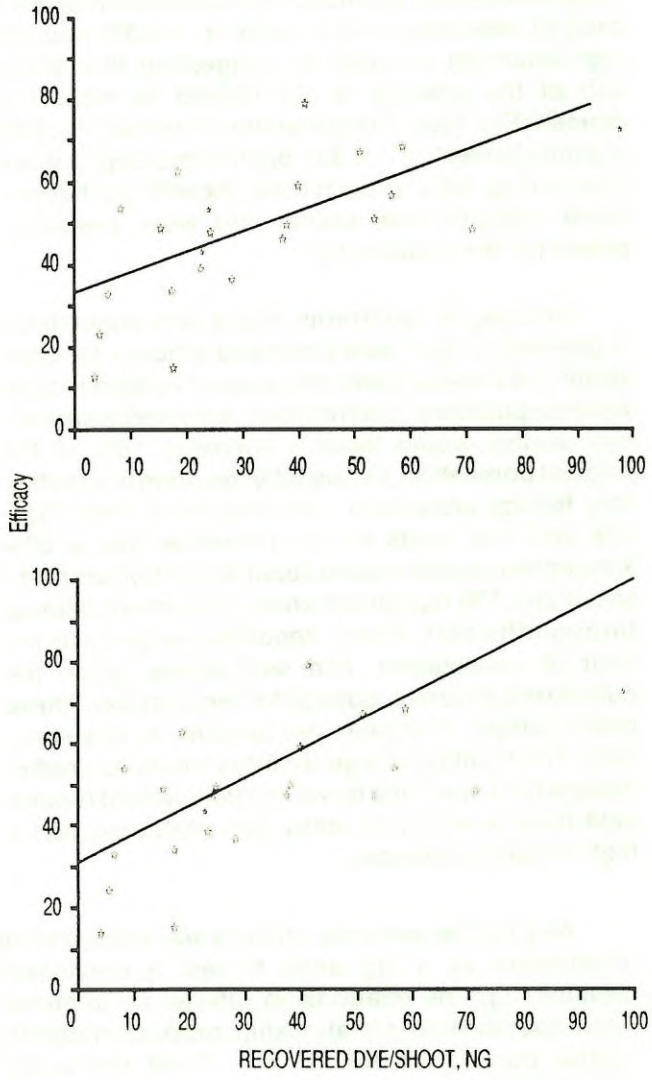

Fig.10 Relationship between percent efficacy/tree and mean deposit of rhodamine/shoot/tree for balsam fir and for red spruce,Magundy,1982.

calculation above by conversion of rhodamine deposit.

Larval fallout in relation to spray deposit

Methods described by Busvine (1971) were used to relate larval mortality to spray deposit, and applied to our single-tree data (Appendix Table VIII-1) from the 24 drop tray trees in Plots A, B, and C. Percent fallout during June 4-10, corrected by Abbott's formula to discount natural fallout, was calculated for each sample tree.

Deposit was assessed as (a) ng rhodamine/ shoot, derived from the mean of 48 shoot samples (3 crown levels x 4 aspects x 4 shoots), and (b) droplets/old needle, derived from counts on 120 fir needles/tree (3 levels x 4 aspects x 10 needles/ shoot), or from 240 spruce needles (20 needles/ shoot).

Percent fallout is plotted against these two expressions of deposit (without transformation of either variable), on a single tree basis, for fir and spruce (Fig. 10). From the fir data relating ng

rhodamine/shoot to efficacy, the correlation (coefficient of determination) is weak (r^2 = 0.36) and the high intercept is puzzling, suggesting that about half of the efficacy is not related to measured deposit (Fig. 10a). The correlation in the spruce data is similarly weak (r^2 = 0.33), but the intercept is more logical (Fig. 10b). In each case, the 95% confidence limits indicate wide scatter and weak predictive power for the relationship.

We suggest, arbitrarily, that a 60% knockdown is generally a desirable threshold efficacy for each spray in a 2-spray treatment against epidemic budworm populations. Such efficacy achieved in successive sprays would leave a surviving 16% of the original population, i.e., usually resulting in satisfactory foliage protection. The projection from Figs. 10a and 10b leads to the inference that a 60% knockdown would require about 65 ng rhodamine/fir shoot and 130 ng/spruce shoot, as a mean deposit through the plot. These deposits are close to the limit of expectation, and well above, given the authorized emission dosage for fenitrothion. These relationships, if reliable, are specific to this spray only. The building of a generalized model to predict dosage for a specified larval mortality would require data from a variety of spray circumstances and a high sampling intensity.

As a further exercise, efficacy was related to ng rhodamine as a log dose to test a curvilinear relationship; the relationship offered no improvement over the linear relationship, producing slightly better correlation for fir (r^2 = 0.48) but worse (r^2 = 0.25) for spruce; therefore details are not reported.

The correlation of efficacy with droplets/old needle was r^2 = 0.17 (coefficient of determination) for fir, which indicates no useful relationship and is explicable as the product of inadequate sampling intensity; details are not reported.

Finally, the dosage/response data (Appendix Table VIII-1) were plotted by probit methods (using linear, common log and natural log transformations of dosage). These applications predicted reasonable LD_{50} dosages, as might be expected because most of the individual tree efficacies were in the 30-70% range, but the predictions in the extremes (LD_{25}, LD_{75}) were not always realistic (Table 12). Therefore probit analysis data are not further presented, and the method is not promising. Whereas the probit transformation method was designed for data based on direct dose/response relationships, as in topical applications of insecticide to insects in replicated laboratory assays, the use of field efficacies introduces problems in sampling variance.

Table 12. Probit values (linear and logarithmic transformation) to predict LD 25, 50, and 75 doses (ng rhodamfine/shoot) for spruce budworm populations on fir and spruce, plotting percentage efficacy/tree against mean deposits/shoot.

	Fir		Spruce	
	Linear	Log	Linear	Log
LD 25	-21 (-99-+2)	4 (1-8)	41 (25-68)	36 (21-116)
LD 50	42 (29-68)	34 (22-63)	96 (68-229)	192 (78-216331)
LD 75	105 (76-216)	294 (121-3137)	151 (103-398)	1030 (204-567x10^6)

Values in parentheses are the 95% fiducial limits expressed in ng rhodamine/shoot.

Log transformation can involve either natural or common logs, with the same result.

Diurnal pulsing of larval fallout

The diurnal rate of larval drop from fir in Plot A was assessed by collections from "multiple drop trays" orientated to the four cardinal points, taken at 1-2 h intervals during daylight hours for 3 days after aerial spraying (June 4-6) and at least once daily during the whole period of observation (May 28-June 22). As in 1981 (Varty and Godin 1983), larval mortality in the same stand was found to increase during the warm hours of the day (Fig. 11). No data are presented for spruce because the larval populations on the trees selected for intensive drop tray counts were too low (fallout of less than five larvae per day after spraying) to offer a reliable pattern.

Many larvae were observed to spin down from the fir crowns within 2 h of spray application. While it seemed like a spectacular immediate response to the spray application, that early fallout represented only 0.4% of the larval population at risk (Fig. 11). A similar immediate response occurred on spruce.

However observations of individual larvae indicated that the populations on fir and spruce were quiescent within bud mines or in silk sheaths alongside buds during the cool hours of the morning; none was seen mobile outside the shelter until

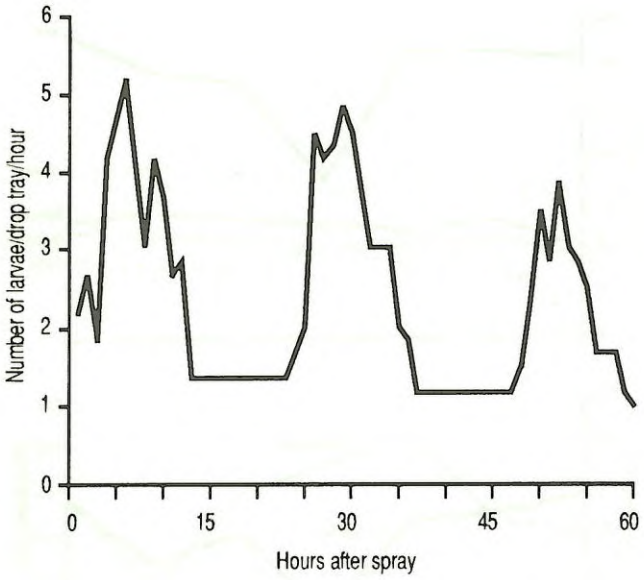

Fig.11 Collections of larvae per drop tray from fir, taken hourly in daylight for three days after spray application. The cumulative overnight fallout was averaged per hour (actual pattern is unknown).

noon. The implication is that the early fallout may have represented individuals who were less well concealed and whose bodies were directly exposed to impact by flying droplets.

On the spray day and the 2 days following, the weather was warm and sunny (Appendix Table V-2). The peaking of mortality that occurred throughout the mid afternoon further supports the hypothesis discussed by Varty and Godin (1983), that dermal contact with the insecticide is maximized by larval movement on the foliage of the outer habitat, and movement is associated with high temperature.

Larval fallout in relation to crown aspect

The fallout of larvae from May 28-June 22 under three multiple drop trays of each species is summarized in Table 13 and detailed in Appendix Tables V11-1 and-2. Of the 4485 larvae collected under fir, 68% fell from June 4 to 10, that is, during the 7 days arbitrarily designated as the spray-effect period. Under spruce, the total collection was 325, of which 37% fell in the spray-effect period. These percentages incorporated fallout due to natural causes, about 5%, based on pretreatment rates.

Table 13. Fallout of larvae by crown aspect under multiple drop tray trees in two collection periods.

	Fir			Spruce		
Aspect	June 4-June 10	May 28-June 22	%	June 4-June 10	May 28-June 22	%
N	668	1039	64.3	29	113	25.7
E	622	860	72.3	37	68	54.4
S	890	1311	67.9	41	68	60.3
W	863	1275	67.7	15	76	19.7
Total	3043	4485	67.8	122	325	37.5

Populations were fairly evenly distributed around the crown; fallout percentages by quadrant during the spray-effect period were similar under the fir crowns, dissimilar under the spruce. However, lacking data on deposit, no conclusions as to the influence of aspect on spray-induced fallout can be drawn.

Larvae were collected in inner, mid and outer sections of the trays (increasing distance from the trunk). Few larvae were collected in the outer section of the tray outside the vertical projection of the crown. The inference is that larvae spin down on silk with little lateral displacement by wind; trays placed anywhere under the crowns of such middle-aged trees give satisfactory representation of fallout (Appendix VII).

Larval fallout relative to post-spray weather

Field observations of larval behavior in 1981-2 indicated that larval movement in the outer habitat takes place during the warmer hours of the day (afternoon and evening). This corresponds to the diurnal pattern of fallout already shown. From these observations arose the hypothesis that favorable weather (warm, calm, dry) stimulates high locomotive activity while unfavorable weather (cold, windy, wet) is inhibitory. As already noted, this locomotion stems from the larval impulse to lay silk from needle to needle in the perimeter of its microhabitat; this movement exposes larvae to contact with sparse droplets and, therefore, governs vulnerability. The budworm literature lacks information on such behavioral patterns except for Wellington and Henson's (1947) observation that cold weather ($< 10°C$) reduces locomotive ability, while very warm conditions ($> 38°C$) reverse the normal photopositive response.

A period of 4 days immediately post-spray was selected as the most significant interval to relate weather variation to larval vulnerability. That period, June 4-7, was unusually warm (daily maximum > 20° C), free of rain, slightly breezy, and consistent from day to day. Only one day, June 7, was exceptionally cloudy and low in humidity (Appendix Table V-2). Given the hypothesis, conditions would be considered favorable to high levels of silking activity, thus conducive to constantly high vulnerability. Such weather precluded the opportunity to test the influence of adverse conditions.

The gauge of larval response to vulnerability is daily fallout, expressed as daily percent efficacy. For this purpose, the tally for each calendar day is derived from the afternoon collection of day n plus the morning collection of day n + 1, since this fallout is produced by the warm period from noon to dusk. The efficacy curve is expressed as a smooth decline, such as is expected from a set of circumstances with constant vulnerability, steadily declining toxicity of residues, and a declining population at risk (i.e. a population reduced by each successive day's fallout) (Fig. 12). The temperature variables (maximum daily, mean daily, minimum daily and degree days) were fairly constant over the 4-day period. Sunshine and humidity were sharply lower on day 3, evidently exerting no dramatic influence on efficacy.

These data offer prima facie evidence of a relationship between diurnal temperature and larval vulnerability to spray, but until a wider range of conditions is tested by field and laboratory experiments, its generality will remain hypothetical.

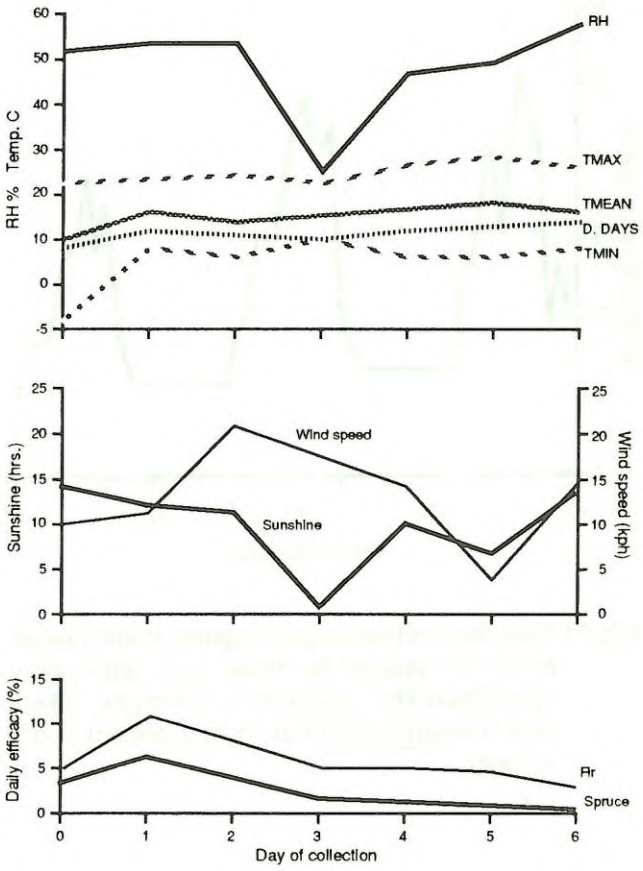

Fig.12 Mean daily % efficacy under 24 fir and 24 spruce trees for the first 7 post-spray days, with corresponding mean daily weather measurements.

Defoliation

Estimates from periodic samples of buds attacked and destroyed, summed from Plots A, B, and C (Fig. 13), show that the patterns of damage to fir and to spruce were quite different. On fir, the infestation of buds began in mid May; the proportion infested rose sharply in late May, then climbed more slowly until mid June when L5 and L6 began to attack neighboring shoots. On spruce, the progression was more complicated; mining of the pollen buds (male strobili) began in mid May, but most of the sampled population stayed in silken sheaths within needle clusters until late May when they began to mine vegetative buds (Appendix Table VI-3).

Because the swelling spruce buds were still small and the budworm relatively large in early June, larvae often attacked more than one bud, so bud destruction climbed sharply after mid June. The significance of these rates of attack (Fig. 13) is that serious damage on fir (> 10%), even though the population density in early June was high, did not begin until about June 10; on spruce, with moderate population density in early June, serious damage did not begin until about June 20. Thus the spray window was potentially open until mid June, i.e., acceptable delay without incurring penalty. Red spruce may be more tolerant to bud mining because it produces larger numbers of lateral shoots than does fir (Hansen and Dimond 1982).

Figure 13 does not reveal any obvious influence of the spray treatment. The rates of increase in defoliation are about the same in the treated plots (sum A + B + C) as in the Check Plot for both host species. Logically, however, it must be assumed

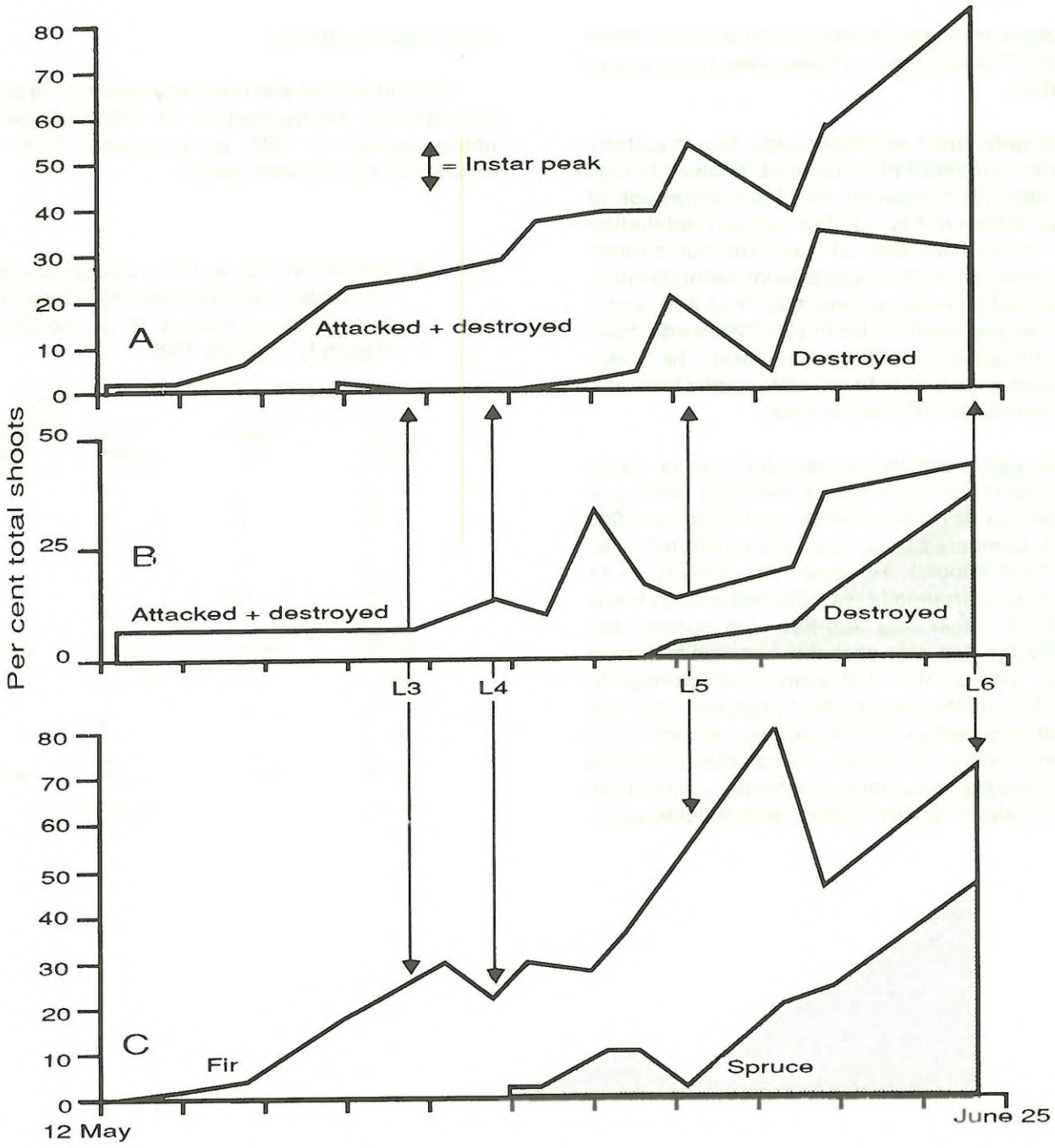

Fig.13 Seasonal percentages of total shoot numbers
(A) attacked +destroyed,and destroyed only,8 balsam fir trees (sprayed plots);
(B) attacked + destroyed,and destroyed only,8 red spruce trees (sprayed plots);
(C) attacked on 2 spruce and 2 fir trees in the check plot.

that without treatment (higher larval survival), Plots A, B, and C would have suffered even more severe defoliation.

The defoliation estimate made after pupation, using the modified Fettes Method, showed foliage loss (Table 14) consistent with the progression of damage shown in Fig. 13. The percent defoliation shown in the two sets of data are not directly comparable because the assessment methods differ. The Defoliation Index summed for Plots A, B, and C (Table 14) averaged 4.1 for fir (55-75% needle loss) and 1.7 for spruce (10-20% needle loss). The Check Plot values were 5.1 for fir (80-90% needle loss) and 1.4 for spruce (5-10% needle loss).

The higher defoliation rate on fir can be partly accounted for by the higher population density in mid June on fir (170 larvae/m^2 or 140 larvae/1000 shoots), compared to spruce (130 larvae/m^2 or 90 larvae/1000 shoots). However, the density of fir shoots was substantially (ca. 25%) reduced by frosts May 18-24, while bud abortion on spruce was relatively light (ca. 5%), probably because of the late flushing. The point is that spring frost damage to buds, differentiating among host trees, can influence the relative severity of defoliation by increasing the larva/shoot ratio. It is because a complex of factors affects foliage production and retention, rather than budworm alone, that defoliation was rejected as the index of spray efficacy.

On neither host was there any evidence of larval back-feeding (consumption of 1981 foliage by mature larvae) in 1982, as anticipated from the larva/shoot ratios noted earlier.

Table 14. Defoliation indices for fir and spruce drop tray trees, one midcrown branch per tree, from survey in Plots A, B, C, and Check, Magundy, July 26, 1982.

	Fir		Spruce	
Plot	Shoots examined	Defoliation index	Shoots examined	Defoliation index
A 1	88	1.8	108	1.9
2	294	4.9	257	1.9
B 1	70	4.9	34	1.9
2	55	4.2	69	2.0
3	79	4.0	146	1.6
4	120	2.9	95	1.1
C 1	147	4.8	186	1.3
2	73	4.0	66	3.1
	Total 926	Mean 4.1	Total 961	Mean 1.7
	Defoliation	65%	Defoliation	9%
Check 1	58	5.0	136	1.4
2	28	5.4	97	1.4
	Total 86	Mean 5.2	Total 233	Mean 1.4
	Defoliation	93%	Defoliation	5%

CONCLUSIONS

Spray efficacy is maximized by satisfying the following requirements:

a) high rate of deposition (a large fraction of the emission) within the target forest area;
b) deposition with high homogeneity throughout the canopy;
c) deposit mass dispersed as a high density of droplets per needle;
d) spray applied at a vulnerable stage of larval development on fir or spruce;

Further, but hypothetical, requirements may be:

e) weather in the few days following application favorable to larval movement around the outer microhabitat;
f) post-spray weather favorable to residue persistence.

High deposition rates in industrial fir-spruce aerial spray blocks (> 5000 ha) are probably the general rule, although data from operations are lacking. However, Crabbe and McCooeye (1985) found 80-94% of the TBM-generated spray cloud to be filtered out within 1200 m downwind of the spray line. So high a rate of deposit is attributed to incremental interceptions of spray from successive swaths. However at 400 m downwind, Crabbe and McCooeye reported only 44-67% of the emission accounted for by the forest and ground foliage. Therefore, problems in attaining high deposition may occur in narrow blocks (woodlots) or along the windward edge of industrial blocks; swath displacement may cause thinning of deposit along edge swaths. In the experiment at Magundy in 1982, we used a site which characterized the windward edge of a block, i.e. a zone of generally light, irregular deposit with a lack of incremental drift to homogenize the coverage.

Every spray application is a unique event, so there are limits as to how far one may go to draw conclusions or present generalizations from a single experimental study. This is a unique data set describing an intensive survey of deposit distributions and larval population responses within a 100 m transect crosswind of the swath produced by a team of three TBM aircraft. It is a step towards developing a methodology to assess efficacy appropriate to spray research.

High heterogeneity of deposit pattern was found throughout the crown. However, measurements of tracer mass showed that fir and red spruce had about the same receptivity (capability to intercept droplets passing by the shoot tips), despite dissimilarities of species shoot morphologies. Therefore, between-host differences in larval population response to insecticide intervention were due to host or insect biological factors, not to differences in dosage (deposit on shoots).

Large variation in mean deposit per plot (four-fold in fir, two-fold in spruce) occurred from upwind to downwind edges of the transect; the gradient increased toward the downwind plot. Moreover, a strong gradient in vertical distribution through the canopy (highest in the upper crown), was found, even though, in this open stand structure, strong penetration of the canopy by air turbulence seemed to be favored. This combination of gradients (cross-swath, through-crown) resulted in a wide variation in mean depositions in segments of the canopy volume (twelve-fold in fir, three-fold in spruce). Variation among trees increased the heterogeneity. Distributions in the other components of the stand expanded the heterogeneity still further; while the small differences between windward and leeward sides of the tree were not significant, large differences among branches and large differences among the shoot samples from each branch were shown. Spruce trees (within-tree analysis) had more heterogeneous distributions than firs, perhaps due to the higher density of spruce foliage (not defoliated by budworm in earlier years) compared with that of fir (defoliated in 1981).

For greatest efficacy, the patterns of deposit distribution and larval population distribution should be coincident. While we found a gradient of deposit decreasing with crown level (Table 2), we have no information on population density by level in our plots. However the budworm literature does offer some evidence of such a population gradient, from eastern (Morris 1955) and western budworm studies (Harris 1964, Campbell *et al.* 1984). Frequency distributions showed that most shoots received a small quantity of insecticide (as indicated by 10-50 ng rhodamine) and only a few shoots had quite large deposits (up to 650 ng rhodamine). The distributions were characterized by an exponential increase in numbers of shoots with decreasing loads of insecticide. In effect, many shoots received too little deposit, a few too much.

Tracer mass and droplet density gave similar expressions of distribution pattern. However the droplet tallies, using a lower sampling intensity,

offered a less reliable assessment of deposit variation. Also, the tallies from spruce were less reliable than those from fir because droplets were less visible on spruce. Droplet distribution was sparse, averaging 0.44/fir needle and 0.13/spruce needle on old needles. The highest mean deposit (Plot A, upper crown, fir) was 1.02 droplets/needle, which produced a satisfactory rate of larval fallout. Such values of droplet density on fir were the product of a satisfactory deposit. The gas chromatographic measurement of residues, averaging 5 ppm fenitrothion at mid-swath, indicated a satisfactory initial deposit. Periodic sampling thereafter produced an estimate of a half-life of 4 days, as reported by earlier investigators.

This analysis of spatial distribution of the insecticide was derived from a single date in the middle of the spray window, phenologically an average spray timing. The spray target - the microhabitat of the budworm - is the individual shoot, but it is a dynamic target changing with the flushing phenologies of fir and spruce. Most of these infested shoots are in the outer crown and sampling was restricted to that zone.

The larva itself is not the primary target. We interpret fallout data as evidence that the larva acquires an effective insecticide dose not by direct impact of droplets on its body, but by transfer from deposits on the microhabitat (foliage, silk, debris). Our basic hypothesis is that larvae are poisoned mainly by dermal contact with residues persisting on the foliage within the microhabitat and that the frequency of such contact is conditioned by larval movement to spin a protective network of silk strands. On this spray day - a mid-season, optimal date - the larvae were mostly fourth and fifth instars, slightly more advanced on fir than on spruce. They occupied different habitats; the fir-dwelling population was mining within the flaring buds, while the spruce-dwelling population was largely concealed in shelters at the shoot tip close to but outside the as yet unflared buds, or mining inside mature flower buds. Although ingestion of poisoned foliage plays a role in larval mortality, we have rejected it as the primary pathway in these spray circumstances, because droplet penetration to the feeding substrate within the bud mine would occur rarely.

An attempt to discern the influence of the spray by monitoring survivor population trends was unsuccessful, but was useful in describing the differences between fir- and spruce-dwelling populations, to account for differences in defoliation. Population densities in mid May (second instar) in the mid-crown of fir were high (450 larvae/m^2 branch tip foliage), but by late June declined to about 110 larvae/m^2 (sixth instar). Corresponding populations on spruce were 300 and 80 larvae/m^2. However variance among plots, dates, and branch samples was high, so that clear differences between pre-spray and post-spray densities, attributable to insecticide intervention, could not be demonstrated. The reliable use of survivor population density on branches would require a higher sampling intensity than was available.

The drop tray method - counting the larval fallout from trees - proved to be promising for assessing efficacy. It produced measures of spray efficacy per plot corresponding to the gradation of deposit across the swath and to the variation in deposit on single trees. It showed that efficacy on spruce was lower (about half) than on fir, in spite of similar deposits. Although the deposit on average was satisfactory, and frequency distributions of deposits on shoots indicated reasonable coverage, the general rate of efficacy on spruce was clearly inadequate. The drop tray method, sampling population mortality independently of branch measurements, is an appropriate way to compare efficacy on different host species. Moreover, it yields information on the secondary defoliator species which contribute to crown damage.

The pattern of larval fallout - numbers pulsed to the warm hours of successive days after spray - leads to the supposition that larvae are stimulated to move around the outer perimeters of their microhabitats during warm (daytime) weather. Larvae undertake this movement to spin silk strands as defences and signal lines against predators or other intruders, but it leads them to make dermal contact with residues of fenitrothion persisting on foliage and silk. Thus, the rate of larval movement is a factor in vulnerability. In general, the older the instar, the more territory the larva will cover and the more silk it will spin. Countering this increasing vulnerability is the age-related susceptibility to insecticide, that is, larger quantities of poison are needed to kill larger bodies.

Any factor which inhibits larval movement while residues persist should lower vulnerability to contact with insecticides. It is inferred that low overnight temperatures inhibited larval movement beyond the bud mine or silk sheath, since fallout was confined to the warm hours. It is speculated that abnormally low temperatures during the day should inhibit

larval locomotion and therefore lower spray efficacy. However, the week following spray day (June 4) was consistently warm (an even sine-curve every 24 hours), which presumably offered the same stimulus day after day to high rates of locomotion, at least on fir. The expectation of a steady decline in daily efficacy, corresponding to the diminishing toxicity of residues, was fulfilled. This relationship thus fits the hypothesis that post-spray weather is a factor in spray efficacy, but does not by itself prove the thesis. Fenitrothion residues had significant effects on larval fallout for about 7 days, but the most important period was the 3-4 days following spray. The difference between efficacy on fir and efficacy on spruce may be accounted for in terms of different larval behaviors corresponding to the different flushing phenologies, but exploratory research has yet to be conducted.

The rate of defoliation and the final damage on each host tree species were measured. Much heavier defoliation showed on fir, greater than might have been expected from the difference in larval density. Although defoliation is the ultimate measure of operational success, it is believed that for research purposes it is better to measure efficacy in terms of larval population reduction. However, since most of the damage was inflicted by sixth-instar larvae, the inference is that the spray window extends quite late in terms of larval development for moderate population densities.

In summary, homogeneity of deposit is a major factor in spray efficacy and techniques to increase it should be sought. Droplet distribution was too sparse, so emission devices shifting the droplet diameter spectrum downwards are desirable.

Larval populations on spruce and fir responded differently to the same insecticide distributions, indicating different vulnerabilities related to larval behavioral differences, implicating host flushing dates and the incidence of pollen buds.

The scope of this research is not broad enough to produce general advice on timing of sprays relative to insect development. According to Hansen and Dimond (1982), larvae on fir are less vulnerable to spray (carbaryl) during needle mining and bud mining (second instar to early fourth) and more vulnerable after bud break, particularly after shoot elongation (late fourth and fifth instars). For red spruce, they believe that larvae feeding from silk tubes along the twig axis are vulnerable to sprays. However, our experiment offers little support for these recommendations. Although the deposit of insecticide was high and the weather was favorable to larval movement and residue persistence, the overall efficacy was poor on spruce and moderate on fir, notwithstanding Larval Development Indices of 4.2 and 4.5, respectively. More experience in various spray circumstances is needed before firm recommendations can be offered.

The main result of this research is the development of a methodology to measure deposit, estimate efficacy, and relate the two. It is, however, a research methodology, not applicable to survey of operational results. It serves as a step towards the goal of achieving a target mortality of pests with a specified emission rate appropriate to the biological and physical conditions present.

ACKNOWLEDGMENTS

We are indebted to G.N. Gesner, CFS-Maritimes, for field crew leadership and data assembly. We acknowledge the preparation of an early draft of this report by M.E. Godin, then with Forest Protection Ltd. Some of the data on deposits were provided by the New Brunswick Research and Productivity Council (C.J. Wiesner) and meteorological information was provided by the University of New Brunswick (R.B.B. Dickison). Spray materials and delivery were provided by Forest Protection Ltd. (courtesy H.J. Irving) and the experiment took place on Provincial forest land. Funds for data aquisition contracts were provided by the Department of Supply and Services and the Canadian Forestry Service.

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APPENDIX I

Details of sample tree sizes and differences

Appendix Table I-1. Measurements of sample trees at Magundy, 1982.

Tree Number	BALSAM FIR DBH (cm)	BALSAM FIR Total Height (m)	BALSAM FIR Crown Volume (m^3)	RED SPRUCE DBH (cm)	RED SPRUCE Total Height (m)	RED SPRUCE Crown Volume (m^3)
			PLOT A			
1	11.5	8.2	7.2	8.0	6.0	3.4
2	14.5	8.0	16.8	10.5	6.1	4.1
3	11.0	5.8	6.9	11.0	8.2	9.8
4	10.0	7.3	4.2	8.0	6.1	3.0
5	11.0	7.8	2.1	11.5	7.5	5.2
6	11.0	7.4	3.8	8.0	6.0	2.9
7	12.5	7.5	4.7	8.0	6.1	2.4
8	10.0	6.8	4.1	9.0	6.5	3.6
			PLOT B			
1	10.5	7.2	2.9	11.0	7.6	6.6
2	10.0	7.8	3.7	9.0	7.3	1.9
3	11.5	8.3	4.0	8.5	6.2	2.4
4	10.5	8.5	2.6	7.0	5.8	1.9
5	11.0	8.3	4.2	7.0	5.1	2.1
6	13.5	9.2	6.7	9.5	7.6	5.0
7	8.0	5.4	2.2	11.0	6.4	6.8
8	12.5	8.6	5.4	13.0	8.0	9.0
			PLOT C			
1	13.5	8.5	15.2	8.0	5.6	2.9
2	16.0	10.0	8.4	8.5	5.9	3.0
3	13.0	9.7	5.8	8.0	6.1	3.7
4	12.5	9.9	8.5	7.5	5.3	1.9
5	12.5	9.5	11.6	9.0	6.0	3.0
6	10.0	10.6	5.5	7.5	5.4	2.5
7	12.0	8.7	4.4	11.5	7.4	6.5
8	18.5	12.0	24.9	10.0	5.8	4.4

Appendix Table I-2. Statistical differences within and between plots by sample tree dimensions, Magundy, 1982. (Derived by Students t-test, df = 7).

	Within plots (Balsam fir vs Red spruce)		
Variable	Plot A	Plot B	Plot C
DBH	*	ns	**
Total Height	ns	ns	**
Crown Volume	ns	ns	*

	Between plots (Balsam fir)		
Variable	A vs B	A vs C	B vs C
DBH	ns	ns	*
Total Height	ns	**	**
Crown Volume	ns	ns	*

	Between plots (Red spruce)		
Variable	A vs B	A vs C	B vs C
DBH	ns	ns	ns
Total Height	ns	**	*
Crown Volume	ns	ns	ns

** significantly different at $P < 0.01$
* significantly different at $P < 0.05$

APPENDIX II

Variability of spray deposits.

Appendix Table II-1. Coefficients of variation (%) by aspect and canopy level on balsam fir (rhodamine fluorometry) from mean deposit/4 shoots, Magundy, 1982.

Appendix Table II-2. Coefficients of variation (%) by aspect and canopy level on red spruce (rhodamine fluorometry) from mean deposit/4 shoots, Magundy, 1982.

Appendix Table II-3. Pearson product-moment correlation coefficients for the relationships between two measures of spray deposit (rhodamine ng and droplets/old needle) on balsam fir, Magundy, 1982.

Appendix Table II-4. Pearson product-moment correlation coefficients for the relationships between two measures of deposit (rhodamine ng and droplets/old needle) on red spruce, Magundy, 1982.

Appendix Table II-1. Coefficients of variation (%) by aspect and canopy level on balsam fir (rhodamine fluorometry) from mean deposit/4 shoots, Magundy, 1982.

		C.V. Plot				
Level		Plot A	Plot B	Plot C	Mean	Level mean
Upper	W	55.6	70.4	70.1	65.4	
	E	43.3	47.5	75.3	55.4	
	S	60.0	50.7	81.5	64.1	
	N	69.9	72.9	71.9	71.6	64.1
Middle	W	121.6	76.8	79.3	92.6	
	E	62.0	41.6	69.3	57.6	
	S	51.6	65.7	58.4	58.6	
	N	77.8	63.8	73.6	71.7	70.1
Lower	W	59.0	87.8	57.4	68.1	
	E	43.6	46.2	37.7	42.5	
	S	74.6	56.8	62.6	64.8	
	N	56.8	38.1	57.3	50.7	56.5
Means (Aspect)		78.7	78.3	68.9		
		49.6	45.1	60.8		
		62.1	57.7	67.6		
		68.2	58.3	67.6	63.6	
Means (plot)		64.6	60.1	66.7	63.6	

Appendix Table II-2. Coefficients of variation (%) by aspect and canopy level on red spruce (rhodamine fluorometry) from mean deposit/4 shoots, Magundy, 1982.

Level		C.V. Plot				
		Plot A	Plot B	Plot C	Mean	Level mean
Upper	W	132.2	212.3	129.2	158.2	
	E	231.0	103.6	56.6	130.4	
	S	233.0	204.2	110.1	179.1	
	N	184.4	110.0	94.2	129.5	149.3
Middle	W	150.0	103.4	127.7	127.0	
	E	152.0	135.2	82.2	123.1	
	S	234.6	159.9	108.6	167.7	
	N	78.8	246.2	94.1	139.7	139.4
Lower	W	248.6	88.6	58.8	132.0	
	E	238.8	63.1	95.3	132.4	
	S	214.5	119.6	66.8	133.6	
	N	177.9	99.5	110.2	129.2	131.8
Means (Aspect)		177.3	134.8	105.2		
		207.3	100.6	78.0		
		274.0	161.2	95.7		
		147.0	151.9	99.5	140.7	
Means (plot)		188.9	138.1	94.5	140.2	

Appendix Table II-3. Pearson product-moment correlation coefficients for the relationship between two measures of spray deposit (rhodamine ng and droplets/old needle) on balsam fir, Magundy, 1982.

	PLOT A		PLOT B		PLOT C	
Tree no. (N=48)	Corr. coeff.	Prob. > R	Corr. coeff.	Prob. > R	Corr. coeff.	Prob. > R
1	0.52	0.0001	0.53	0.0001	0.24ns	0.1078
2	0.57	0.0001	0.35	0.0141	0.41	0.0036
3	0.69	0.0001	0.75	0.0001	-0.04ns	0.8096
4	0.44	0.0015	0.37	0.0157	0.35	0.0147
5	0.69	0.0001	0.47	0.0007	0.46	0.0009
6	0.67	0.0001	0.58	0.0001	0.54	0.0001
7	0.37	0.0095	0.58	0.0001	-0.06ns	0.6766
8	0.40	0.0044	0.43	0.0024	0.39	0.0067
By plot (N= 384)	0.59	0.0001	0.50	0.0001	0.52	0.0001

Unsorted (N =1152) correlation coefficient = 0.61
(Pooled) 0.0001

Appendix Table II-4. Pearson product-moment correlation coefficients for the relationship between two measures of spray deposit (rhodamine ng/shoot and droplets/old needle) on red spruce, Magundy, 1982.

	PLOT A		PLOT B		PLOT C	
Tree no. (N=48)	Corr. coeff.	Prob. > R	Corr. coeff.	Prob. > R	Corr. coeff.	Prob. > R
1	0.35	0.0160	0.54	0.0001	0.08ns	0.5965
2	0.46	0.0009	0.08ns	0.5699	-0.23ns	0.1093
3	0.34	0.0188	0.69	0.0001	-	-
4	0.04ns	0.7950	0.50	0.0002	-	-
5	0.64	0.0001	0.22ns	0.1334	-	-
6	0.55	0.0001	0.50	0.0003	-	-
7	0.22ns	0.1397	0.03ns	0.8244	-0.08ns	0.5708
8	0.43	0.0021	0.06ns	0.6788	-0.27ns	0.0670
By plot (N=384)	0.22	0.0001	0.17	0.0007	-0.11	0.0329

Unsorted (N =1152) correlation coefficient = 0.15
(Pooled) 0.0001

APPENDIX III

Insecticide deposit by GC analysis

Appendix Table III-1. Fenitrothion deposit (μg/g) analyzed from balsam fir foliage from midcrown (north and south aspects) in Plot B, and from fir and spruce midcrowns in the Check Plot, Magundy, 1982.

Appendix Table III-1. Fenitrothion deposit (μg/g) analyzed from balsam fir foliage from the midcrown (north and south aspects) in Plot B, and from fir and spruce midcrowns in the Check Plot, Magundy, 1982.

Date	Crown aspect	Insecticide deposit, fenitrothion (μg/g)									
		Plot B Tree no.								Check*	
		1	2	3	4	5	6	7	8	Fir	Spruce
June 4	N	2.08	4.84	6.55	9.07	4.45	10.61	3.53	4.82	0.43	0.21
	S	2.33	2.65	1.91	5.09	7.69	7.68	2.10	2.54	0.19	0.22
June 6	N	1.20	3.21	3.96	3.53	6.69	2.63	4.43	6.07	0.74*	0.96*
	S	1.93	1.92	3.42	1.50	3.02	2.17	3.68	4.06	0.13*	0.08*
June 8	N	3.73	1.39	4.83	0.69	2.60	4.22	1.01	2.23	0.23*	0.12*
	S	1.59	1.26	4.29	2.89	2.82	3.35	1.77	2.97	1.05*	0.14*
June 10	N	1.11	1.47	2.29	0.75	1.96	1.96	0.53	1.93	0.12*	0.05*
	S	2.05	1.41	3.15	1.75	1.09	2.16	0.91	2.22	0.17*	0.10*

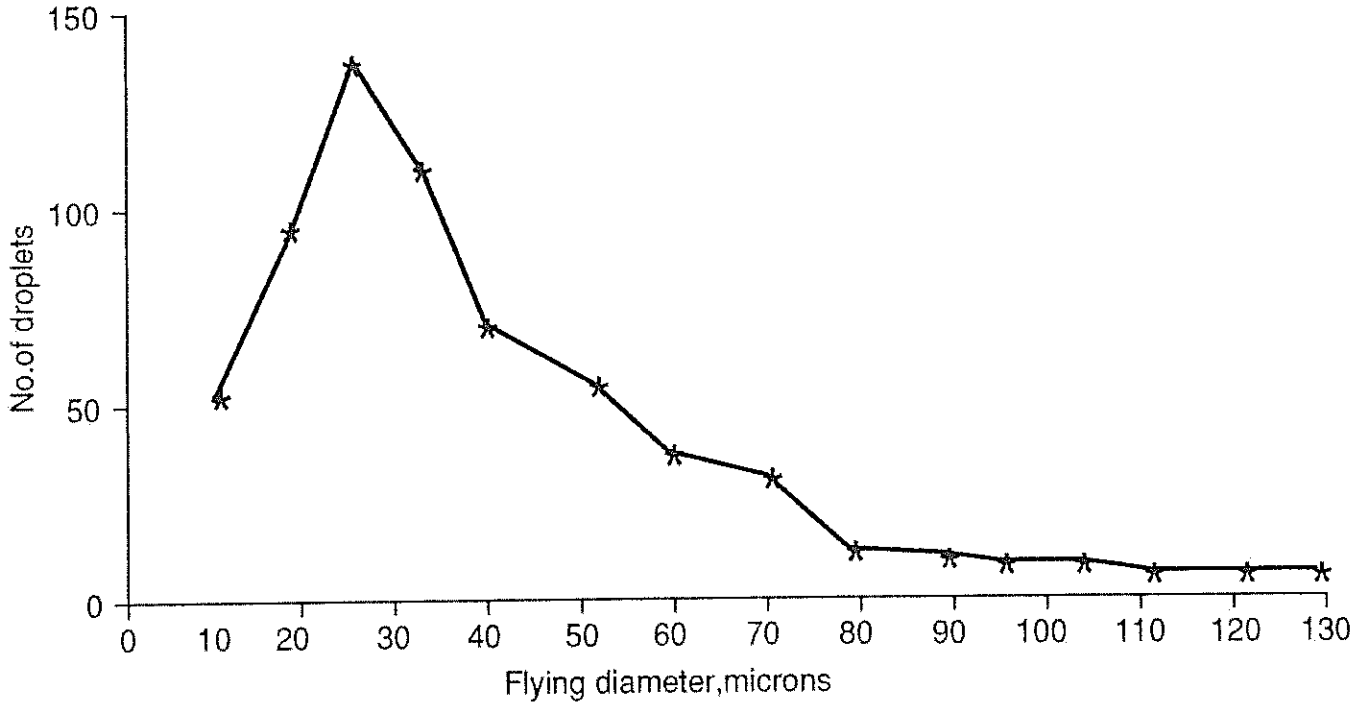
*Samples on June 6, 8, 10 in the Check Plot were gathered randomly in the midcrown without reference to aspect; the designations N and S do not apply.

APPENDIX IV

Droplet diameter spectrum

Appendix Figure IV-1. Distribution of diameter classes (converted from stain diameters) from 599 droplets impinging on old and new needles collected from shoots at 3 levels and 4 aspects on 8 fir trees in Plot A, Magundy, 1982.

Appendix Table IV-1. Diameter class distributions by numbers and mass for droplets sampled from balsam fir needles (old and new shoots) taken from 3 levels and 4 aspects in Plot A, Magundy, 1982.



Appendix Figure IV-1. Distribution of diameter classes (converted from stain diameters) from 599 droplets impinging on old and new needles collected from shoots at 3 levels and 4 aspects on 8 fir trees in Plot A, Magundy, 1982.

Appendix Table IV-1. Diameter class distribution by numbers and mass for droplets sampled from balsam fir needles (old and new shoots) taken from 3 levels and 4 aspects in Plot A, Magundy, 1982.

	Size class							
Mean diam (μ)	9	17	26	34	43	52	60	69
# drops	53	87	135	111	68	52	33	30
% in class	8.84	14.52	22.55	18.53	11.35	8.68	5.51	5.01
Mass/drop (g)	$4.81E^{-7}$	$3.24E^{-6}$	$1.16E^{-5}$	$2.59E^{-5}$	$5.24E^{-5}$	$9.28E^{-5}$	$1.42E^{-4}$	$2.17E^{-4}$
Sum mass (g)	$2.55E^{-5}$	$2.82E^{-4}$	$1.57E^{-3}$	$2.87E^{-3}$	$3.56E^{-3}$	$4.82E^{-3}$	$4.69E^{-3}$	$6.51E^{-3}$
% of mass ($\times 100$)	$6.30E^{-4}$	$6.97E^{-3}$	$3.88E^{-2}$	$7.09E^{-2}$	$8.80E^{-2}$	$1.19E^{-1}$	$1.16E^{-1}$	$1.61E^{-1}$
%	0.06	0.70	3.88	7.09	8.80	11.90	11.60	16.10
Cum. % of mass	0.06	0.76	4.64	11.73	20.53	32.43	44.03	60.13
Cum. # drops	53	140	275	386	454	506	539	569
% #	8.84	23.36	45.91	64.44	75.79	84.47	89.98	94.99
mass	$2.55E^{-5}$	$3.08E^{-4}$	$1.88E^{-3}$	$4.75E^{-3}$	$8.31E^{-3}$	$1.31E^{-2}$	$1.78E^{-2}$	$2.43E^{-2}$

Appendix Table IV-1. (Continued)

	Size class							
Mean diam (μ)	78	86	95	104	112	121	129	TOTALS
# drops	30	10	7	5	1	1	1	599
% in class	5.01	1.67	1.17	0.83	0.17	0.17	0.17	100.00
Mass/drop (g)	$3.13E^{-4}$	$4.20E^{-4}$	$5.66E^{-4}$	$7.45E^{-4}$	$9.27E^{-4}$	$1.17E^{-3}$	$1.42E^{-4}$	--
Sum mass (g)	$9.39E^{-3}$	$4.20E^{-3}$	$3.96E^{-3}$	$3.72E^{-3}$	$9.27E^{-4}$	$1.17E^{-3}$	$1.42E^{-3}$	--
% of mass ($\times 100$)	$7.74E^{-2}$	$7.27E^{-2}$	$7.00E^{-2}$	$9.17E^{-2}$	$2.29E^{-2}$	$2.89E^{-2}$	$3.51E^{-2}$	--
%	7.74	7.27	7.00	9.17	2.29	2.89	3.51	100.00
Cum. % of mass	60.13	67.87	75.14	82.14	91.31	93.60	96.49	100.00
Cum. # drops	579	586	591	596	597	598	599	
% #	96.67	97.83	98.66	99.49	99.66	99.83	100.00	
mass	$2.74E^{-2}$	$3.04E^{-2}$	$3.32E^{-2}$	$3.69E^{-2}$	$3.79E^{-2}$	$3.90E^{-2}$	$4.04E^{-2}$	

Numbers mean diam. = 36.2 μ
Mass mean diam. = 46.7 μ
Mass median diam. = 63 μ
Numbers median diam. = 28 μ

No. of droplets = 599
Sampled mass = $4.04E^{-2}$g
Mass of average droplet = $6.74E^{-5}$g
Assumptions: Spread factor = 2.9
Specific gravity = 1.26

APPENDIX V

Weather records

Appendix Table V-1. Temperature and sunshine during the spray window, Magundy, May 17 - June 18, 1982.

Date	Temperature (°C) Max.	Min.	Degree-days (base 5.56°C)	Hours of Sunshine	
May 17	16	-2	119	13.5	
18	19	-7	123	14.3	
19	22	-6	129	10.5	
20	26	-3	140	5.7	
21	16	-3	144	14.3	
22	19	-9	148	14.3	
23	22	-4	154	14.3	
24	15	-4	158	3.2	
25	20	4	163	4.4	
26	31	0	175	14.0	
27	23	7	181	14.3	
28	27	0	190	13.6	
29	27	8	201	10.7	
30	29	10	212	15.9	
31	29	6	224	5.2	
June 1	27	12	238	7.6	
2	17	12	247	0.0	
3	20	5	254	14.0	
4	23	-3	261	14.3	(Spray day)
5	24	7	271	12.2	
6	24	4	280	11.5	
7	21	8	288	0.0	
8	27	6	399	10.4	
9	30	6	311	7.0	
10	27	8	323	13.7	
11	24	6	332	9.5	
12	24	3	340	12.6	
13	17	7	346	6.1	
14	12	6	350	0.0	
15	24	10	361	5.1	
16	20	10	370	0.5	
17	24	9	381	3.5	
18	28	6	392	10.2	

Appendix Table V-2. Daily weather data, Magundy, June 4-10, 1982.

	Spray day	Post-spray period (days) +1	+2	+3	+4	+5	+6
Temperature (°C) - max	23	24	24	21	27	30	27
- min	-3	7	4	8	6	6	8
- mean	10	15	14	14	16	18	17
Degree-days (base 5.6)	7	10	9	8	11	12	12
- seasonal accumulation	261	271	280	288	299	311	323
Relative humidity (%) mean	52	55	54	23	44	48	58
Sunshine* (h)	14	12	11	0	10	7	14
Wind* (km/h) - mean	10	12	21	17	14	4	14
- max	26	26	41	28	24	19	22
- direction	S	SSW	NE	NE	ENE	E	E
Precipitation (mm)	0	0	0	0	0	0	0
Sky	Clr	Clr	Clr	Ovt	Clr	Clr	Clr

* Wind and sunshine were measured at Fredericton.
Clr = clear, Ovt = overcast.

APPENDIX VI

Tallies of spruce budworm larvae collected from Plots A, B, C, and Check Plot, fir and spruce, May and June 1982, Magundy

Appendix Table VI-1. Counts of larvae falling from fir trees to drop trays, Magundy, May 28-June 22, 1982.

Date	A (8 trees)	B (8 trees)	C (8 trees)	Check (4 trees)
Pre-spray				
May 28	15	15	15	20
May 31	27	24	10	15
June 1	28	24	20	26
June 3	18	8	39	8
Total	88	71	84	69
Spray day				
June 4 #1	63	76	99	71
#2	285	155	249	17
June 5 #1	530	318	470	31
#2	269	120	152	17
June 6 #1	448	262	337	23
#2	155	98	108	11
June 7 #1	369	229	177	10
#2	44	26	53	13
June 8 #1	310	217	182	18
#2	71	55	63	7
June 9 #1	248	178	166	21
#2	81	56	60	24
June 10	248	171	162	24
Total	3121	1961	2278	287
Wash #1 June 10				
June 11	1069	1631	3193	No wash 24
June 12	174	130	115	17
June 13	62	39	48	12
June 14	53	34	42	4
June 15	60	46	74	8
June 16	45	35	76	3
June 17	60	66	95	1
Total	1523	1981	3643	69
Wash #2 June 17				
June 18	253	267	241	1108
June 19	37	42	30	31
June 21	37	70	71	13
June 22	8	17	44	2
Total	335	396	356	1154
Grand totals:	5067	4409	6361	1579

Sum: 17416

Appendix Table VI-2. Counts of larvae falling from spruce trees to drop trays, Magundy, May 28-June 22, 1982.

Date	A (8 trees)	B (8 trees)	C (8 trees)	Check (4 trees)
Pre-spray				
May 28	3	4	2	2
May 31	1	6	1	0
June 1	2	1	2	0
June 3	2	1	2	0
Total	8	12	7	2
Spray day				
June 4 #1	11	4	8	0
#2	70	8	13	0
June 5 #1	92	27	30	2
#2	35	2	14	0
June 6 #1	34	16	19	0
#2	29	13	8	2
June 7 #1	27	20	3	0
#2	2	2	7	1
June 8 #1	16	13	6	1
#2	8	6	6	1
June 9 #1	8	5	9	0
#2	4	7	4	1
June 10	15	3	6	1
Total	351	126	133	9
Wash #1 June 10				
June 11	516	258	565	No wash 0
June 12	79	19	34	2
June 13	39	7	8	0
June 14	20	8	13	2
June 15	13	1	4	0
June 16	7	4	5	5
June 17	11	6	8	0
Total	685	303	637	9
Wash #2 June 17				
June 18	64	109	96	103
June 19	11	18	10	5
June 21	21	11	5	4
June 22	8	19	5	3
Total	104	155	116	115
Grand totals	1148	596	893	135

Sum: 2772

Appendix Table VI-3. Status and habitat of larvae collected from midcrown branch samples from balsam fir and red spruce, Magundy, May 13-June 24, 1982.

Date	Tallies					Percentages			
		Live in habitat				Live fraction = 100%			
	Dead	Needles	Buds	Free*	Total	Dead	Needles	Buds	Free*
Balsam fir									
May 13	33	628	27	23	711	5	93	4	3
16	59	504	38	33	635	9	88	6	6
19	89	281	54	36	460	19	76	14	10
24	95	103	307	62	567	17	22	65	13
27	14	25	262	64	365	4	7	75	18
31	44	0	329	129	502	9	0	72	28
June 2	33	3	328	92	456	7	1	77	22
5	145	0	261	86	492	29	0	75	25
7	125	0	212	75	412	30	0	74	26
9	99	0	145	109	353	28	0	57	43
14	60	0	158	104	321	19	0	60	40
18	73	0	127	106	306	24	0	55	45
24	35	0	67**	92	194	18	0	42	58
Totals	904	1544	2315	1011	5774	16%			
Red spruce									
May 13	14	335	11	26	386	4	90	3	7
16	56	241	53	38	388	14	73	16	11
19	26	142	12	24	204	13	80	7	13
24	17	73	32	29	151	11	54	24	22
27	12	37	56	43	148	8	27	41	32
31	25	11	78	35	149	17	9	63	28
June 2	11	0	107	87	205	5	0	55	45
5	17	0	163	65	245	7	0	71	29
7	32	0	41	31	104	31	0	57	43
9	22	0	57	86	165	13	0	40	60
14	9	0	73	83	165	5	0	47	53
18	11	0	67	72	150	7	0	48	52
24	11	0	42**	79	132	8	0	35	65
Totals	263	839	792	698	2592	10%			

*"Free" indicates that larva had become dislodged from its habitat and was found crawling randomly.
** Almost half the collection on June 24 was of pupae.

APPENDIX VII

Daily drop tray tallies of budworm larvae relative to crown aspect

Appendix Table VII-1. Larval fallout under fir, May 28-June 22 1982, from the multiple drop tray trees in Plot A, Magundy.

Appendix Table VII-2. Larval fallout under spruce, May 28-June 22 1982, from the multiple drop tray trees in Plot A, Magundy.

Appendix Table VII-1. Larval fallout under fir, May 28-June 22, 1982, from the multiple drop tray trees in Plot A, Magundy.

		Balsam Fir #1 tree																							
		Pre-Spray						Post-Spray							Adjustment							Post-Wash				
Tray Section		May 28	29	30, 31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	Total
North	I	0	2	0	0	0	1	20	31	27	13	22	19	19	25	17	8	2	5	1	0	7	4	2	3	
	M	1	1	2	2	0	0	22	26	16	6	8	13	6	6	7	2	24	0	0	0	5	0	0	1	
	O	0	0	0	0	1	0	14	7	4	0	0	1	0	2	2	0	0	1	0	0	0	0	0	0	
Total		1	3	2	2	1	1	56	64	47	19	30	33	25	33	26	10	26	6	1	0	12	4	2	4	408
East	I	2	0	0	1	4	1	25	40	26	10	13	11	11	8	10	2	3	1	2	3	8	2	4	0	
	M	0	1	0	1	0	3	14	52	17	7	10	14	5	7	11	6	3	1	1	0	8	3	0	1	
	O	0	0	0	0	0	0	4	4	5	0	2	1	1	3	1	0	0	0	0	0	0	0	0	0	
Total		2	1	0	2	4	4	43	96	48	17	25	26	17	18	22	8	6	2	3	3	16	5	4	1	373
South	I	1	0	2	2	1	3	23	60	35	18	36	38	29	31	18	6	5	9	0	6	11	1	0	0	
	M	0	3	1	1	2	0	25	42	40	13	36	32	43	23	18	8	7	3	7	2	25	3	7	0	
	O	0	1	0	0	0	1	1	4	4	3	4	2	2	2	0	0	0	0	0	1	1	0	0	0	
Total		1	4	3	3	3	4	49	106	79	34	76	72	74	56	36	14	12	12	7	9	37	4	7	0	702
West	I	0	0	2	3	3	1	20	30	30	23	7	17	17	21	7	3	5	3	2	0	4	0	1	1	
	M	0	1	4	2	0	2	18	18	34	18	28	33	22	19	23	6	5	0	3	3	5	3	2	0	
	O	3	0	0	2	1	0	8	5	6	4	9	1	3	2	4	0	0	0	0	0	0	7	1	0	
Total		3	1	6	7	4	3	46	53	70	45	44	51	42	42	34	9	10	3	5	3	9	10	4	1	505
Total		7	9	11	14	12	12	194	319	244	115	175	182	158	149	118	41	54	23	16	15	74	23	17	6	1988

I = inner section of tray (closest to trunk), area 0.6 m^2
M = mid section of tray (under outer branches), area 0.6 m^2
O = outer section of tray (slightly outside the vertical projection of the crown), area 0.6 m^2

Appendix Table VII-1. (Continued)

Balsam Fir #2 tree

Tray Section	Pre-Spray						Post-Spray							Adjustment							Post-Wash				Total
	May 28	29	30, 31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	
North I	1	1	1	1	1	1	32	31	15	12	14	11	20	8	12	1	1	3	1	3	26	5	6	0	
M	0	1	3	0	1	0	15	20	17	7	12	20	14	7	9	6	1	1	2	0	1	2	1	1	
O	0	0	0	0	0	0	3	1	2	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	
Total	1	2	4	1	2	1	50	52	34	19	26	31	37	15	22	7	2	4	3	3	27	7	7	1	358
East I	1	0	0	0	0	0	31	26	30	12	23	31	6	11	12	5	2	2	4	1	9	4	4	0	
M	0	0	1	0	1	0	20	29	9	7	15	20	3	6	5	5	3	0	3	0	3	2	3	3	
O	0	2	2	0	0	0	11	3	3	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	
Total	1	2	3	0	1	0	62	68	42	19	38	51	9	20	17	10	5	2	7	1	13	6	7	3	387
South I	0	1	1	0	1	0	14	20	21	3	14	7	7	3	6	0	0	0	1	0	4	0	5	0	
M	0	0	4	1	0	2	20	19	26	16	19	17	22	12	6	6	2	1	0	0	16	3	6	1	
O	2	1	2	0	0	1	7	4	2	0	0	1	3	0	0	0	0	0	1	0	1	3	1	1	
Total	2	2	7	1	1	3	41	43	49	19	33	25	32	15	12	6	2	1	2	0	21	6	12	2	337
West I	1	2	1	0	2	2	19	32	14	9	7	7	2	8	2	0	2	0	2	2	11	0	3	1	
M	0	3	2	2	0	1	26	37	51	29	28	34	41	28	26	4	4	2	2	1	17	7	18	3	
O	1	0	7	0	0	2	26	37	22	4	9	7	3	5	9	2	2	2	2	1	5	3	12	2	
Total	2	5	10	2	2	5	71	106	87	42	44	48	46	41	37	6	8	4	6	4	33	10	33	6	658
Total	6	11	21	4	6	9	224	269	212	99	141	155	124	91	88	29	17	11	18	8	94	29	59	12	1740

Appendix Table VII-1. (Continued)

Balsam Fir #3 tree

Tray Section	Pre-Spray: May 28	29	30, 31	June 1	2	3	Post-Spray: 4	5	6	7	8	9	10	Adjustment: 11	12	13	14	15	16	17	Post-Wash: 18	19	21	22	Total
North I	1	0	2	2	0	1	17	29	14	10	12	5	9	12	7	2	4	0	2	7	27	6	2	1	
M	1	0	2	1	0	0	9	8	7	3	4	1	5	1	3	3	0	1	0	2	30	0	3	0	
O	1	0	0	0	0	0	1	2	8	1	0	0	0	0	0	0	1	0	0	0	2	0	1	0	
Total	3	0	4	3	0	1	27	39	29	14	16	6	14	13	10	5	5	1	2	9	59	6	6	1	273
East I	1	0	1	2	0	2	9	11	8	3	7	6	7	4	0	0	1	0	0	0	17	1	1	2	
M	0	0	0	1	0	0	2	0	0	1	1	1	0	1	0	1	0	0	0	0	1	0	1	0	
O	0	0	1	0	0	0	1	0	2	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	
Total	1	0	2	3	0	2	12	11	10	5	9	7	7	5	0	1	2	0	0	0	18	1	2	2	100
South I	2	0	0	0	0	1	12	21	15	6	6	12	6	9	4	0	0	2	1	1	15	0	2	0	
M	3	0	2	1	0	0	10	9	16	8	12	7	8	7	9	9	2	2	2	1	23	2	6	1	
O	4	0	2	0	0	0	2	0	4	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	
Total	9	0	4	1	0	1	24	30	35	15	19	20	15	16	13	9	2	5	3	2	38	2	8	1	272
West I	1	0	1	0	0	0	6	6	9	2	3	1	2	0	0	0	1	0	0	0	17	0	0	1	
M	0	0	1	1	0	0	3	1	10	4	6	6	4	3	2	0	0	0	1	1	10	1	2	0	
O	0	0	2	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	1	0	4	1	0	0	9	7	21	7	10	7	6	3	3	0	1	0	1	1	27	1	2	1	112
Total	14	0	14	8	0	4	72	87	95	41	54	40	42	37	25	15	10	6	6	12	142	10	18	5	757

Appendix Table VII-2. Larval fallout under spruce, May 28-June 22, 1982, from the multiple drop tray trees in Plot A, Magundy.

	Pre-Spray						Post-Spray							Red Spruce #1 tree Adjustment							Post-Wash				
Tray Section	May 28	29	30, 31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	Total
North I	0	0	1	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	6	1	0	0	
M	1	0	0	0	0	0	0	0	4	1	0	2	0	0	0	1	0	0	0	0	14	1	2	0	
O	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	
Total	1	1	2	0	0	0	0	0	4	3	0	2	1	0	0	1	0	0	0	0	20	3	3	0	41
East I	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	1	2	0	1	
M	0	0	3	0	0	0	0	0	2	1	0	0	0	0	1	1	0	0	0	0	3	2	1	0	
O	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	0	0	3	0	0	0	1	1	5	1	0	0	0	0	1	2	0	0	0	0	4	4	1	1	24
South I	0	0	0	0	0	0	4	0	2	0	0	0	1	0	0	0	0	0	0	0	2	1	0	0	
M	0	1	0	0	0	0	2	2	2	1	0	0	0	0	1	0	0	0	0	0	6	0	0	0	
O	1	0	0	1	0	0	3	0	1	0	0	1	0	3	1	0	0	0	0	0	1	0	0	0	
Total	1	1	0	1	0	0	9	2	5	1	0	1	1	3	2	0	0	0	0	0	9	1	0	0	37
West I	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	2	1	1	0	
M	0	2	1	0	0	0	0	0	1	0	0	2	0	0	0	0	1	1	0	0	13	1	2	0	
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	
Total	1	3	2	0	0	0	1	1	1	0	0	2	0	0	0	1	2	1	1	0	15	3	3	0	37
Total	3	5	7	1	0	0	11	4	15	5	0	5	2	3	3	4	2	1	1	0	48	11	7	1	139

Appendix Table VII-1. (Continued)

		Balsam Fir #3 tree																							
		Pre-Spray						Post-Spray							Adjustment							Post-Wash			
Tray Section		May 28	29	30, 31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	Total
North	I	1	0	2	2	0	1	17	29	14	10	12	5	9	12	7	2	4	0	2	7	27	6	2	1	
	M	1	0	2	1	0	0	9	8	7	3	4	1	5	1	3	3	0	1	0	2	30	0	3	0	
	O	1	0	0	0	0	0	1	2	8	1	0	0	0	0	0	0	1	0	0	0	2	0	1	0	
Total		3	0	4	3	0	1	27	39	29	14	16	6	14	13	10	5	5	1	2	9	59	6	6	1	273
East	I	1	0	1	2	0	2	9	11	8	3	7	6	7	4	0	0	1	0	0	0	17	1	1	2	
	M	0	0	0	1	0	0	2	0	0	1	1	1	0	1	0	1	0	0	0	0	1	0	1	0	
	O	0	0	1	0	0	0	1	0	2	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	
Total		1	0	2	3	0	2	12	11	10	5	9	7	7	5	0	1	2	0	0	0	18	1	2	2	100
South	I	2	0	0	0	0	1	12	21	15	6	6	12	6	9	4	0	0	2	1	1	15	0	2	0	
	M	3	0	2	1	0	0	10	9	16	8	12	7	8	7	9	9	2	2	2	1	23	2	6	1	
	O	4	0	2	0	0	0	2	0	4	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	
Total		9	0	4	1	0	1	24	30	35	15	19	20	15	16	13	9	2	5	3	2	38	2	8	1	272
West	I	1	0	1	0	0	0	6	6	9	2	3	1	2	0	0	0	1	0	0	0	17	0	0	1	
	M	0	0	1	1	0	0	3	1	10	4	6	6	4	3	2	0	0	0	1	1	10	1	2	0	
	O	0	0	2	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total		1	0	4	1	0	0	9	7	21	7	10	7	6	3	3	0	1	0	1	1	27	1	2	1	112
Total		14	0	14	8	0	4	72	87	95	41	54	40	42	37	25	15	10	6	6	12	142	10	18	5	757

Appendix Table VII-2. Larval fallout under spruce, May 28-June 22, 1982, from the multiple drop tray trees in Plot A, Magundy.

		Pre-Spray						Post-Spray							Red Spruce #1 tree Adjustment							Post-Wash				
Tray Section		May 28	29	30, 31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	Total
North	I	0	0	1	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	6	1	0	0	
	M	1	0	0	0	0	0	0	0	4	1	0	2	0	0	0	1	0	0	0	0	14	1	2	0	
	O	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	
Total		1	1	2	0	0	0	0	0	4	3	0	2	1	0	0	1	0	0	0	0	20	3	3	0	41
East	I	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	1	2	0	1	
	M	0	0	3	0	0	0	0	0	2	1	0	0	0	0	1	1	0	0	0	0	3	2	1	0	
	O	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total		0	0	3	0	0	0	1	1	5	1	0	0	0	0	1	2	0	0	0	0	4	4	1	1	24
South	I	0	0	0	0	0	0	4	0	2	0	0	0	1	0	0	0	0	0	0	0	2	1	0	0	
	M	0	1	0	0	0	0	2	2	2	1	0	0	0	0	1	0	0	0	0	0	6	0	0	0	
	O	1	0	0	1	0	0	3	0	1	0	0	1	0	3	1	0	0	0	0	0	1	0	0	0	
Total		1	1	0	1	0	0	9	2	5	1	0	1	1	3	2	0	0	0	0	0	9	1	0	0	37
West	I	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	2	1	1	0	
	M	0	2	1	0	0	0	0	0	1	0	0	2	0	0	0	0	1	1	0	0	13	1	2	0	
	O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	
Total		1	3	2	0	0	0	1	1	1	0	0	2	0	0	0	1	2	1	1	0	15	3	3	0	37
Total		3	5	7	1	0	0	11	4	15	5	0	5	2	3	3	4	2	1	1	0	48	11	7	1	139

Appendix Table VII-2. (Continued)

Red Spruce #2 tree

Tray Section	Pre-Spray						Post-Spray							Adjustment							Post-Wash				Total
	May 28	29	30, 31	June 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	21	22	
North I	0	0	0	0	0	0	2	2	0	0	1	0	0	1	0	0	0	0	0	0	2	0	1	0	
M	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	16	2	1	0	
O	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	1	0	
Total	0	1	0	0	0	0	3	2	1	0	1	1	0	1	0	1	0	0	0	0	21	6	3	0	41
East I	0	1	0	0	0	0	3	2	1	0	1	1	0	0	0	0	0	0	0	0	2	1	1	0	
M	0	0	2	0	0	0	1	0	4	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	
O	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	0	1	2	0	0	0	5	2	7	0	1	1	0	0	0	0	1	0	0	0	3	1	2	1	27
South I	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	1	1	0	0	
M	0	0	0	0	0	0	2	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	0	0	0	0	0	0	2	0	3	0	3	2	0	0	0	1	0	0	0	0	1	1	0	0	13
West I	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	3	3	0	0	
M	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	1	0	0	0	0	6	2	0	0	
O	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	
Total	1	0	1	0	0	0	0	0	1	1	2	0	2	0	0	2	0	0	0	0	9	5	2	0	26
Total	1	2	3	0	0	0	10	4	12	1	7	4	2	1	0	4	1	0	0	0	34	13	7	1	107

Appendix Table VII-2. (Continued)

Red Spruce #3 tree

Tray Section	Pre-Spray: May 28	29	30, 31	June 1	2	3	Post-Spray: 4	5	6	7	8	9	10	Adjustment: 11	12	13	14	15	16	17	Post Wash: 18	19	21	22	Total
North I	0	0	1	0	0	0	0	2	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	
M	0	0	2	1	0	0	1	0	1	0	1	0	0	0	1	2	0	0	0	0	4	1	2	1	
O	1	0	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	
Total	1	0	4	1	0	0	2	4	2	1	2	0	0	0	1	2	0	1	0	0	6	1	2	1	31
East I	0	0	0	0	0	0	1	2	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	
M	1	0	0	0	0	0	0	1	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	
O	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	1	0	1	0	0	0	1	3	6	1	0	2	0	0	0	1	0	0	0	0	0	1	0	0	17
South I	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	
M	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	0	2	0	0	0	0	0	0	0	
O	0	0	1	0	0	0	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	0	0	1	0	0	0	2	1	2	2	3	2	0	0	1	0	2	0	0	0	1	0	0	1	18
West I	0	0	2	0	0	0	1	3	1	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	
M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	
O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	0	0	2	0	0	0	1	3	1	0	0	0	0	1	0	0	0	0	0	0	4	1	0	0	13
Total	2	0	8	1	0	0	6	11	11	4	5	4	0	1	2	3	2	1	0	0	11	3	2	2	79

APPENDIX VIII

Relationships between spruce budworm larval fallout (efficacy %) and spray deposit.

Appendix Table VIII-1. Larval fallout % (fallout June 4-10/fallout May 28-June 22) and associated spray deposit (rhodamine ng and droplet counts) on single balsam fir trees, Magundy, 1982.

Appendix Table VIII-1. Larval fallout % (fallout June 4-10/fallout May 28-June 22) and associated spray deposit (rhodamine ng and droplet counts) on single balsam fir trees, Magundy, 1982.

Tree no.	Larval fallout (%)	Rhodamine in vert. col. 24 samples (ng)	Rhodamine /shoot (ng)	Droplets in vert. col. max. 6 samples	Droplets/ sample (10 needles)
			Plot A		
1	65.2	2738	114	105	17.5
2	66.9	1610	67	65	10.8
3	65.9	1415	59	62	10.3
4	57.8	863	36	35	5.8
5	48.4	1032	43	48	8.0
6	46.9	1418	59	42	7.0
7	52.7	944	29	21	3.5
8	75.7	1438	60	39	6.5
Means	59.9	1432	60	52	8.6
			Plot B		
1	45.8	336	14	5	0.8
2	43.8	684	28	22	3.7
3	47.0	540	22	18	3.0
4	43.1	888	37	113	18.8
5	45.2	1032	43	72	12.0
6	31.5	622	26	61	10.2
7	31.2	471	20	21	3.5
8	37.3	564	24	51	8.5
Means	40.6	642	27	45	7.6
			Plot C		
1	50.6	225	9	14	2.3
2	30.0	200	8	11	1.8
3	21.8	181	8	1	0.7
4	59.8	411	17	6	1.0
5	46.8	399	17	16	2.7
6	39.8	601	25	23	3.8
7	12.3	179	7	1	0.2
8	16.4	508	21	43	7.2
Means	34.7	338	14	14	2.4