# AN ASSESSMENT OF THE IMPACT OF LARGE SCALE SPRAYING OPERATIONS ON THE REGIONAL DYNAMICS OF SPRUCE BUDWORM (LEPIDOPTERA: TORTRICIDAE) POPULATIONS

R. A. FLEMING,[1] C. A. SHOEMAKER, and J. R. STEDINGER
Department of Environmental Engineering, Cornell University, Ithaca, New York 14853

## Abstract

*Can. Ent.* 116: 633–644 (1984)

Exploratory data analysis was employed to investigate the regional dynamics of managed budworm populations based upon survey data reporting spruce budworm egg-mass densities and damage to balsam fir. The Maine Forest Service collected these data annually from 1975 to 1980 at approximately 1000 different locations each year throughout Maine's spruce–fir forest regions. Although spraying was often associated with 'better' conditions in heavily defoliated or infested areas, it was generally associated with somewhat 'poorer' conditions in areas which had experienced only light defoliation or infestation in the previous year. The analysis also indicated that while insecticide application may reduce budworm larval populations immediately after application, the largest relative decrease in defoliation rates appeared the year after insecticide application. Insecticide treatments were not as effective as expected. In the year following application, the maximum reduction observed in average defoliation was 20% and in average egg-mass density the maximum reduction was 50%. In many cases the reduction was substantially less. Spraying was not associated with any substantial decline in hazard rating.

## Résumé

Une analyse exploratoire de données a été effectuée afin d'étudier la dynamique régionale de populations de la tordeuse ayant fait l'objet de programmes de lutte, d'après les données des réseaux de surveillance des densités de masses d'oeufs et des dommages causés au sapin baumier. Le Service des Forêts du Maine a recueilli ces données annuellement de 1975 à 1980 dans environ 1000 localités différentes dispersées partout dans les boisés d'épinette et de sapin du Maine. Bien que les arrosages aient souvent été corrélés à une amélioration de la situation dans les régions fortement défoliées ou infestées, ils étaient corrélés à une certaine détérioration des conditions dans les régions qui avaient subi une défoliaison légère ou qui avaient été infestées l'année précédente. L'analyse a aussi indiqué que malgré que l'application d'insecticide puisse réduire les populations larvaires de tordeuse dans l'immédiat, les diminutions relatives les plus importantes du taux de défoliaison se produisent l'année suivant l'application. Les traitements insecticides n'ont pas été aussi efficaces qu'espéré. L'année suivant l'application, la réducion maximale observée de la défoliaison moyenne était de 20%, et celle de la densité moyenne des masses d'oeufs était de 50%. Dans plusieurs cas la réduciton était substantiellement moindre. Les arrosages n'ont pu être corrélés à aucune baisse substantielle du niveau d'alerte.

## Introduction

The spruce budworm, *Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae), is a destructive defoliator which attacks spruce, *Picea* spp., and balsam fir, *Abies balsamea* (L.) Mill., trees in North American boreal forests. Dense, mature stands of balsam fir, the most vulnerable host tree, suffer extensive damage; mortality can approach 100%. To protect the forest, aerial insecticide applications against the budworm began in Maine in 1954. Since the first large scale operation in 1975, an average of almost 0.8 million ha has been sprayed annually (Trial 1980; Trial and Thurston 1980). This constitutes almost 25% of Maine's spruce–fir forest protection district.

---

[1] Present address: Forest Pest Management Institute, Canadian Forestry Service, P.O. Box 490, Sault Ste. Marie, Ont. P6A 5M7.

This paper presents a statistical assessment of the effects of large scale insecticide applications on spruce budworm populations in Maine. The assessment is based on data collected by the Maine Forest Service in surveys of spruce budworm egg-mass densities and balsam fir damage at approximately 1000 sites per year from 1975 to 1980. The insecticide used was predominantly carbaryl (Sevin-4-oil®) at 0.84 kg AI/ha.

Our objective is to evaluate likely changes in observed egg-mass densities and defoliation as a function of previous egg-mass densities and balsam fir damage. Fleming *et al.* (1983) report the details of a study of unsprayed sites. In this paper we focus on the impact of insecticide applications.

The primary purpose of spraying was to reduce defoliation which occurs during May and June while budworm larvae molt through a succession of larval instars. Pupation, moth dispersal, and egg-mass deposition follow during July. Eggs hatch by mid-August and the non-feeding first-instar larvae disperse and spin hibernacula. In early May of the following summer, the second-instar larvae emerge from hibernation and move to feeding sites.

The Maine Forest Service conducts its egg-mass density and tree damage surveys in early August shortly after oviposition is complete. In a particular stand, the defoliation in year $t$ is caused by the larvae in year $t$, which are the survivors of the egg-masses laid in year $t-1$. The observed egg-mass density at a site in year $t$ is part of the progeny of the local budworm population in year $t$ plus any egg-masses laid by immigrating moths. Since the immediate effect of spraying is larval mortality, a spray application during year $t$ is expected to reduce both the defoliation and the egg-mass density observed that year relative to what would have been observed otherwise.

The sampling density of the combined egg-mass and tree damage surveys was as high as one sample per 12 $km^2$ in areas where stand types varied or where stands had been sprayed. The lowest sampling density was one sample per 66 $km^2$. At each sampling site observers collected one upper mid-crown branch from each of four dominant or co-dominant fir trees. The branches were bagged separately and examined in field laboratories. The egg-masses were counted on 1–4 branches as indicated by a sequential sampling procedure. These counts were used to estimate the "sample egg-mass density" (the density of new, healthy, budworm egg-masses per $m^2$ of foliated branch surface area at the sampling site). Also recorded were tree vigor, the presence of dead tops, and the percent defoliation of balsam fir from the current year and from the previous 2 years. Webb *et al.* (1956) and Trial and Thurston (1980) describe aspects of the survey procedure in detail. The survey data were used to calculate tree hazard ratings (cf. Trial and Thurston 1980). These ratings provide an estimate of the risk of further defoliation and deterioration in tree vigor in the absence of insecticide application. In addition to the hazard ratings, the Maine Forest Service uses aerial surveys of budworm infestations to determine appropriate areas for insecticide application. Environmental, financial, and political constraints also determine which areas can receive insecticide application.

## Methods of Analysis

To compare different forest areas, the ranges of the three variables were divided into the classes listed in Table I. The six egg-mass-density classes correspond to those used in the sequential sampling procedure. This procedure identified the egg density at a site as being within one of the discrete egg classes (Table I) with a previously specified degree of confidence. As a result, the precision of the estimates of egg density depended on their proximity to a class boundary. Because of this characteristic of the data set, it was appropriate to use these discrete egg density classes where possible, rather than the mean egg densities. The classifications of the hazard rating system (cf. Trial and Thurston 1980, p. 72) were modified to obtain six classes of defoliation and hazard with sufficiently large sample sizes to support the analysis.

Table I. Designation of classes by range of variable

| Variable | Class | Class description | Variable range |
|---|---|---|---|
| Egg density (masses/m$^2$ of foliage) | 1 | None | EGG < .05 |
| | 2 | Light | .05 ≤ EGG < 10.7 |
| | 3 | Moderate | 10.7 ≤ EGG < 25.8 |
| | 4 | High | 25.8 ≤ EGG < 43.0 |
| | 5 | Very high | 43.0 ≤ EGG < 107.6 |
| | 6 | Extreme | 107.6 ≤ EGG |
| Defoliation (% of new foliage consumed) | 1 | Trace-light | DEF < 15 |
| | 2 | Light | 15 ≤ DEF < 30 |
| | 3 | Moderate | 30 ≤ DEF < 50 |
| | 4 | Heavy | 50 ≤ DEF < 80 |
| | 5 | Severe | 80 ≤ DEF < 90 |
| | 6 | Very severe | 90 ≤ DEF < 100 |
| Hazard (danger of more forest damage without spraying) | 1 | Low | HAZ < 5.3 |
| | 2 | Moderately low | 5.3 ≤ HAZ < 11.4 |
| | 3 | Moderately high | 11.4 ≤ HAZ < 15.6 |
| | 4 | High | 15.6 ≤ HAZ < 19.5 |
| | 5 | Very high | 19.5 ≤ HAZ < 23.4 |
| | 6 | Exreme | 23.4 ≤ HAZ ≤ 26.0 |

Because defoliation and egg-mass density were measured together at each sampling point, the survey provides a relatively precise record of the relationship between the defoliation in a stand and the egg-mass density that resulted from oviposition by local and immigrating moths later the same summer. Unfortunately, data were seldom collected in the same stand in consecutive years. Hence, to assess how forest conditions one year affected those in the following year, the spatial scale of the analysis had to be expanded beyond individual sampling points. Since the Maine Forest Service plots their survey results in terms of 6.4 km × 8.0 km 'blocks' of forest, for convenience we adopted this scale and their mapping system to delineate block boundaries.

Excluded from consideration were all blocks which contained both sprayed and unsprayed sites in a given year. A block's egg-mass density, defoliation, and hazard rating were estimated by averaging all sites sampled that year within that block.

Averaging the results from all sampled sites to obtain block estimates does not account for the variability of observed conditions within a block. Moreover, because only one or two sites were sampled within most blocks in any year (only one site was sampled in 60% of the cases examined) the averages were often no more precise than a single observation from a randomly selected site within a block. In Fig. 1, box plots (McGill *et al.* 1978) show the variability among sample egg-mass densities in both sprayed (*s*) and unsprayed (*u*) blocks with four or more samples. Since sampling density was increased in areas where variability was expected (Trial and Thurston 1980), Fig. 1 also represents a likely upper limit to the sampling error due to using a single sample site to estimate conditions throughout a block.

## Results and Discussion

**Effect of insecticide treatment on egg-mass density and defoliation in year of application.** Figure 2 shows the relationship between the mean egg-mass densities of forest blocks in successive years. The letters *i*, *s*, and *u* respectively distinguish the densities in blocks which were sprayed only in the initial year (year *t*), the second year ($t+1$), and unsprayed in both years. The bars indicate the vertical range of two standard errors on each side of the means. Their length depends on the class sample size and the within-class variance. Because the sample means are the average of a large number (at least 25) of

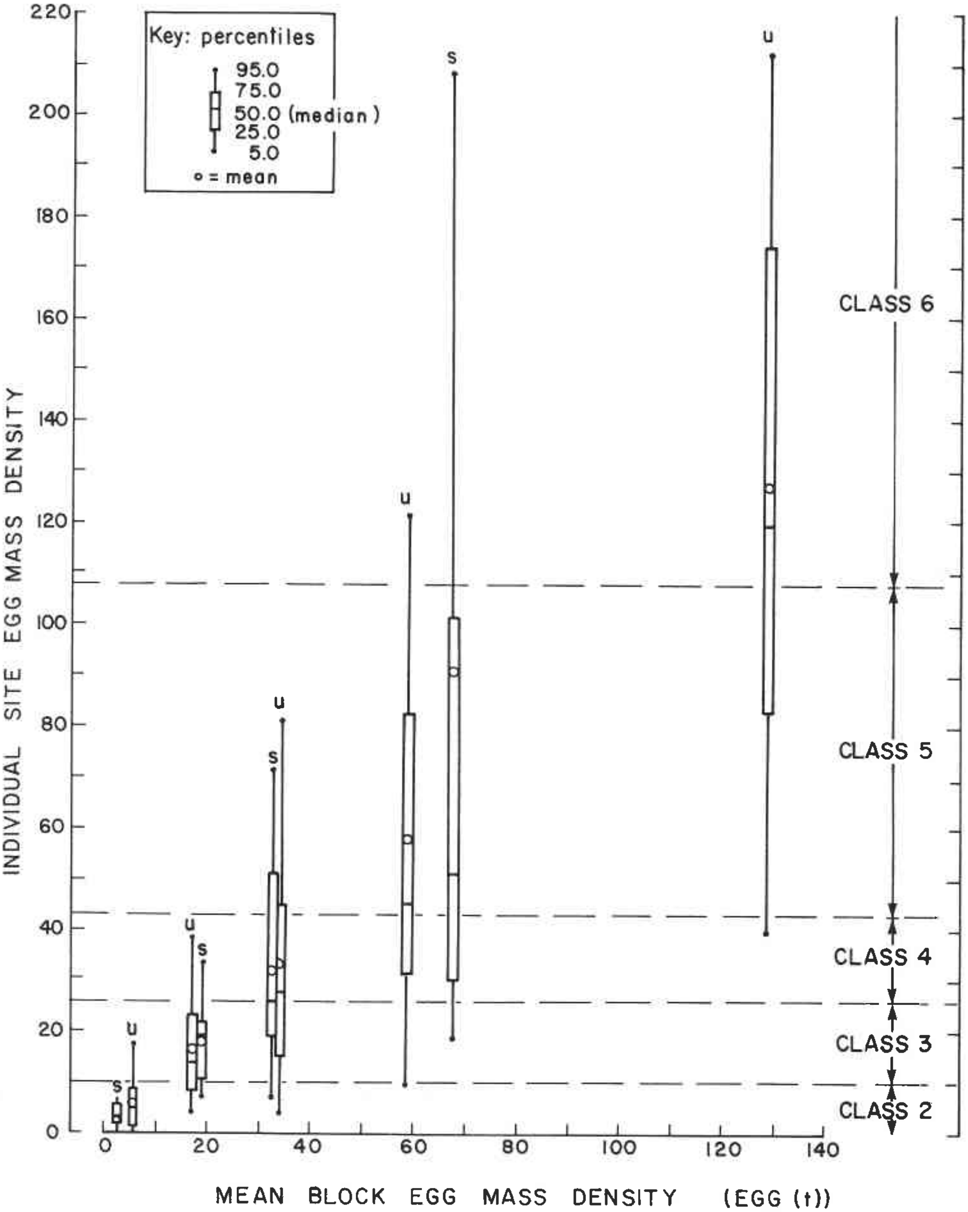
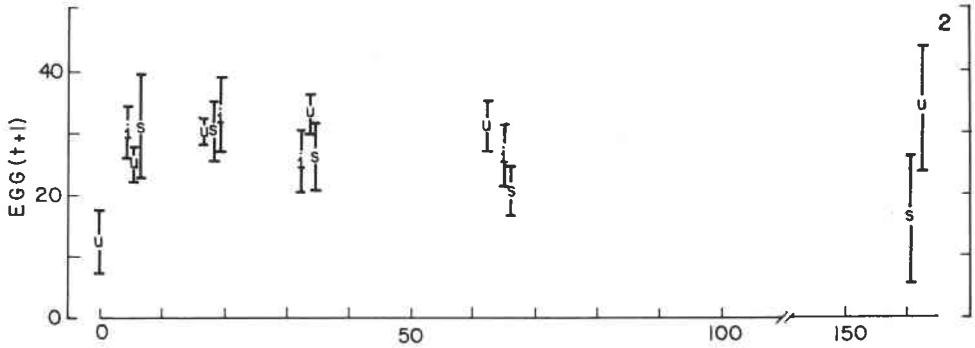


FIG. 1. Relationship between the number of new healthy egg-masses per m$^2$ of foliated branch surface area at individual sampled sites within a forest block and the block mean. Only unsprayed (*u*) and sprayed (*s*) blocks with 4 or more sampled sites were considered. All sample sizes exceed 30 sites.

essentially independent observations, they will have a distribution which is closely approximated by a normal distribution (Conover 1980, pp. 51–53). Thus 95% of two such standard error intervals should, on the average, contain the true mean for year $t + 1$. Hence, when the ranges of two standard errors about the sample averages do not overlap, one can be confident the true means are different. Since initial egg-mass densities are restricted to a common class, the standard errors of their averages are small, and hence are not shown. Because sampling sites were seldom sprayed in consecutive years, sites sprayed in year



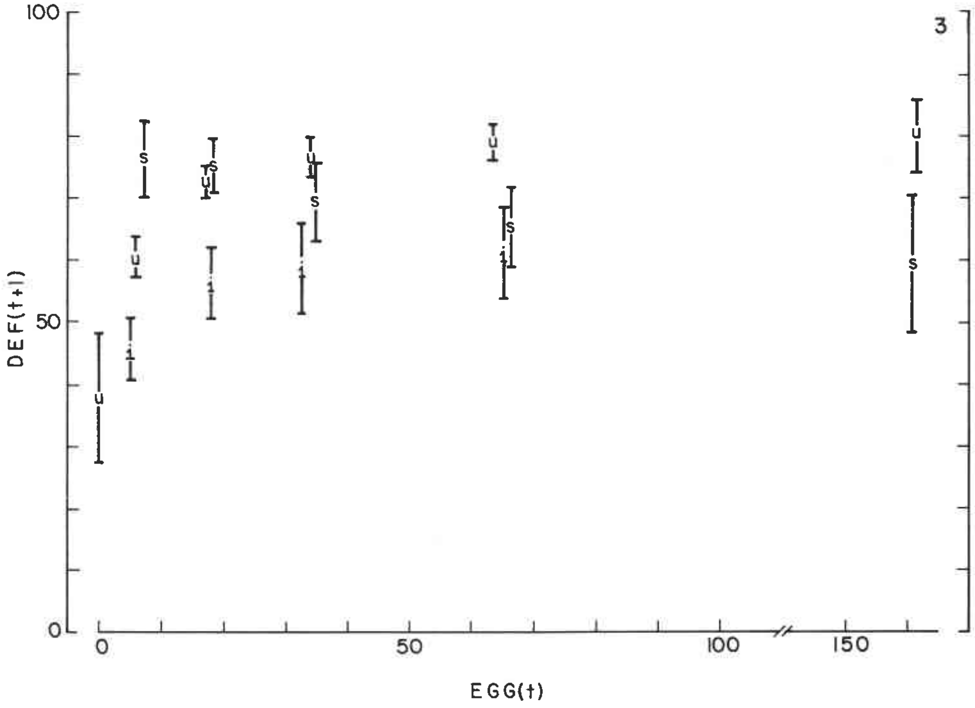


FIG. 2. Relationship between mean egg-mass densities (in number of new healthy egg-masses per m$^2$ of foliated branch surface) EGG($t$) and EGG($t+1$), in successive years. The vertical bars indicate the EGG($t+1$) interval of two standard errors about the mean. The symbols *i*, *s*, and *u* respectively indicate histories of spraying only in the initial (*i*) and second (*s*) year, and of not spraying in either year (*u*). Sample sizes exceed 25 forest blocks.

FIG. 3. Relationship between the percent current defoliation, DEF($t+1$), and the egg-mass-density class average (in number of new healthy egg-masses per m$^2$) in the previous year, EGG($t$). The vertical bars indicate the DEF($t+1$) interval of two standard errors about the mean. The symbols *i*, *s*, and *u* distinguish histories of spraying only in the initial (*i*) and second (*s*) year, and of not spraying in either year (*u*). Sample sizes exceed 25 forest blocks.

$t$ or $t+1$ were almost certainly unsprayed in year $t+1$ or $t$, respectively. However, some of the sites apparently unsprayed in both years may have actually been sprayed (and not sampled) in year $t$, and hence, their initial condition might not be well represented by EGG($t$), the average density in the sampled (and unsprayed) sites.

Figure 3 shows the current year's defoliation DEF($t+1$) as a function of egg-mass density in the preceding year. Unlike Fig. 2, in Fig. 3 ovipositing by immigrant moths does not obscure the direct influence of conditions one year on those in the next (although the samples were not obtained at the same sites). Figure 3 suggests that with increasing egg-mass densities, the defoliation of unsprayed (*u*) forest blocks approaches a mean of about 80%. Sampling error partially explains why this does not reach 100% defoliation as suggested by Miller (1977, fig. 3). For example, blocks with modest egg-mass densities could be assigned to the highest density class if they are only sampled at sites with unrepresentatively high densities. Since observations in such a block in the subsequent year are expected to indicate average conditions, some bias towards the overall mean defoliation rate (less than 100%) occurs at large egg-mass densities (Fig. 3). Such reasoning applies to observations obtained for both the highest and lowest classes of the variable plotted on the horizontal axis whenever the variable plotted on the vertical axis was not measured in the same forest stand as the value plotted on the horizontal axis. Sampling error causes problems in other instances as well; it contributes to a 'flattening' of plots of mean block conditions in successive years whenever such comparisons are made. Sampling the same forest stand in consecutive years would reduce such errors.

Initially we confine our discussion of Figs. 2 and 3 to comparisons of forest blocks sprayed only in the second year, year $t+1$, (denoted by an *s*), and those unsprayed in both years (denoted by *u*). We consider blocks sprayed only in the initial year (year *t*) later in the paper. Comparison of the *u* and *s* labelled plots in Figs. 2 and 3 reveals a general pattern: Above an initial density of 40 masses/m$^2$, blocks sprayed in the second (*s*) year often sustain significantly lower mean densities (Fig. 2) and significantly lower mean defoliation (Fig. 3) in year $t+1$ than unsprayed (*u*) blocks with comparable initial densities. The situation is less clear for initial densities below 40 masses/m$^2$. The rapid depletion of foliage by large larval populations (Morris 1963, p. 290) may explain these results. 'Thinning' of foliage allows spray droplets to penetrate to the normally less exposed foliage within the enclosure of a tree's branches and thus provides greater overall spray coverage (Morris 1963, p. 290). Furthermore, heavy foliage depletion often results in increased larval movement over the branches in search of feeding sites (Morris 1963, p. 19). Both these factors could increase the fraction of larvae contacting spray residue and thus increase spray mortality.

Curiously, Fig. 3 indicates that for blocks with initial densities below 10 masses/m$^2$, those which were sprayed in the second (*s*) year suffered significantly greater mean defoliation [$DEF(t+1)$] than those unsprayed (*u*) in both years. Further research revealed a possible cause: among these blocks, those sprayed in year $t+1$ generally contained stands in poorer condition in year *t* (according to measures for tree vigor, previous defoliation, and the presence of dead tops) than those not sprayed. Since trees in poor condition generally produce relatively little new foliage (Kleinschmidt *et al.* 1980), greater percent defoliation (measured with respect to the amount of new foliage produced) could occur at sites which actually experienced less defoliation (measured as needle dry weight).

In spray assessment trials, the Maine Forest Service found sprayed stands often sustained almost 50% less defoliation than unsprayed stands (Trial and Thurston 1980, p. 41). In contrast, Fig. 3 indicates a maximum absolute difference in mean defoliation of about 20%. Consider two possible explanations for this apparent contradiction. First, the 50% defoliation reduction in the spray assessment trial was measured in stands where applications were properly timed. In practice, however, good timing is difficult to achieve: Asynchrony in foliage expansion and larval development, poor weather conditions, and logistical difficulties have all posed problems (Trial and Thurston 1980, pp. 34–42).

Effective insecticide applications occur when the larval population is in the vulnerable fourth instar stage and when foliage expansion provides an adequate spray target. When these two events do not coincide, the Maine Forest Service usually bases spray timing primarily on bud development. Problems can ensue when larval development outruns foliage expansion: Many buds (Miller 1977 reports up to 70% during outbreak) may be mined by young larvae, and slow shoot expansion can result in many relatively large insects attacking a small food resource. In both cases much damage can occur before insecticide application. Often, the few large larvae surviving spraying may be enough to consume what remains of the new foliage. Under these circumstances, spraying can do little to reduce current defoliation in the year of application. For example, where insecticide applications were delayed in 1979, 89% defoliation was observed (Trial and Thurston 1980, p. 41).

Second, sampling error could also explain the differences between spray assessment trial results and those in Fig. 3. As described above, because the block unit of forest area is used in Fig. 3, sampling error biases defoliation percentages towards their overall mean at extreme egg-mass densities. Visual inspection of Fig. 3 indicates that removal of such bias at high densities would increase the defoliation accorded to unsprayed blocks and decrease the defoliation accorded to sprayed ones.

In Figs. 2 and 3, we distinguish forest blocks by their average condition in year *t* as described by only one variable (egg-mass density). We also distinguished a block's initial conditions with respect to both egg-mass density and defoliation, simultaneously. The results of that analysis were consistent with the trends which appear in Figs. 2 and 3, but the sample sizes were too small to draw definitive conclusions. Figures 2 and 3 focus on only the mean responses of forest blocks that received a particular treatment. However, as Fig. 1 illustrates, tremendous variability exists among reported egg-mass densities for sites within a block and among blocks. Thus Figs. 2 and 3 describe only average trends

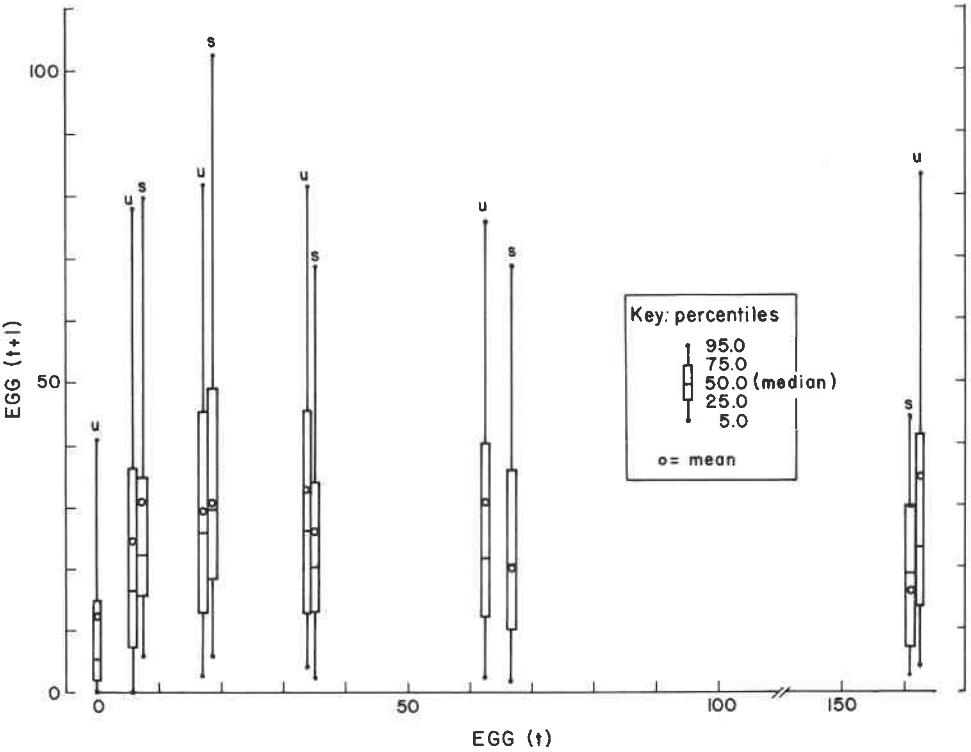


FIG. 4. Variability in the relationship between egg-mass densities (in number of new healthy egg-masses per $m^2$ of foliage), EGG($t$) and EGG($t+1$), in successive years. The relationship is shown for forest blocks unsprayed in year $t$ and sprayed ($s$) or unsprayed ($u$) in year $t+1$. Sample sizes exceed 25 blocks.

and cannot be used to infer what might happen at a particular place at a particular time. This point is demonstrated in Fig. 4.

The box plots in Fig. 4 illustrate the distribution of individual block egg-mass densities associated with each initial egg-mass density class. Each box plot is located above the class average of its corresponding initial egg-mass densities. The large scatter masks any clear relationship between the observed egg-mass densities for an individual forest block in successive years. The extent to which this scatter is due to noise in the survey procedures and the extent to which it is intrinsic to the budworm–forest system because of variability in forest conditions, local weather, and geography is uncertain. The increased sampling intensity in sprayed blocks may explain the lower variability of their egg-mass densities compared with those of unsprayed blocks for initial densities exceeding 30 masses/$m^2$.

Figure 5 illustrates the variation in the impact of spraying on the relationship between mean defoliation and egg-mass density from year to year. Variability in spray effectiveness from year to year is evident: sprayed blocks of forest have higher defoliation in 1978 and lower defoliation in 1979 than initially similar unsprayed blocks.

On a year-to-year basis, Fig. 5 illustrates the extremes of our data set in terms of the decrease (1979) and increase (1978) in defoliation for sprayed blocks relative to comparable unsprayed blocks. Comparing these years with the overall average (Fig. 3) suggests that while 1979 was not particularly unusual, 1978 was extraordinary. The large number of warm dry days in 1978 (Table II) indicates weather was favorable for fast larval growth and development that year (Miller 1971).

There are at least three possible consequences of this warm weather in 1978. First, since the fast larval development observed in 1978 was accompanied by a high rate of food consumption (Trial and Thurston 1978, p. 39), much of the damage inflicted on new foliage may have occurred before spray application. Second, Trial and Thurston (1978,

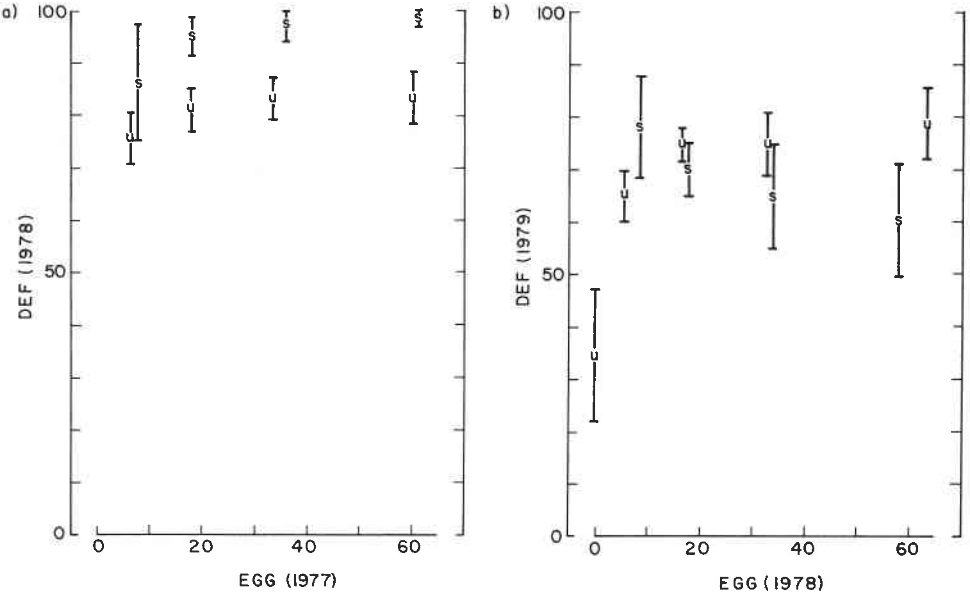


FIG. 5. Relationship between percent current defoliation, DEF, and the egg-mass-density class average (in number of new healthy egg-masses per $m^2$ of foliage) in the previous year. The letters *s* and *u* distinguish DEF values calculated respectively from sprayed and unsprayed forest blocks which were not sprayed in the previous year. The vertical bars show the DEF range of two standard errors about the mean. Sample sizes exceed 12 blocks.

Table II. Area sprayed and number of days in June and July when maximum temperature surpassed 70° and the amount of rainfall did not exceed 'trace'

| Year | ha × $10^6$ | Warm, dry days |
|---|---|---|
| 1975 | 0.94 | 67 |
| 1976 | 1.41 | 49 |
| 1977 | 0.37 | 59 |
| 1978 | 0.46 | 71 |
| 1979 | 1.13 | 67 |
| 1980 | 0.49 | 45 |

p. 39) suggest that insecticide was applied when the rapidly developing larvae reached their susceptible fourth instar although foliage had not developed enough to catch much of the spray cloud. They suggest that subsequent foliage growth may have "diluted" the insecticide concentration, thus reducing larval mortality. Third, Morris (1963, p. 191) suggests insecticides may break down more quickly or be less toxic in warmer temperatures.

We also checked for geographic influences on the effectiveness of spraying. In blocks unsprayed in consecutive years, we found that egg-mass densities for a given level of current defoliation were often larger in northwestern Maine than in southeastern Maine (Fleming *et al.* 1983). However, when we compared sprayed and unsprayed blocks of forest, we found no relation between the effectiveness of spraying and the geographical location of the block.

**Effect of insecticide treatment on hazard rating in its year of application**. The Maine Forest Service adopted the hazard rating system developed by Webb *et al.* (1956) to estimate the danger of further forest deterioration in the absence of spraying. A hazard rating is the sum of a site's individual ratings for egg-mass density, defoliation, and other measures of tree damage (cf. Trial and Thurston 1980, p. 72). Figure 6 shows the relationship between hazard ratings in successive years for blocks unsprayed in the initial year. The plots suggest that spraying has little immediate influence on block hazard ratings. Even if the sole effect of spraying were to save foliage in the year of application, some reduction of hazard rating in sprayed blocks of forest would be expected. If hazard rating accurately reflects the danger of further deterioration of the budworm–forest system, these results suggest that spraying does little to relieve such danger.

The areas which had a high hazard rating and which were selected for spraying did not have consistently higher egg-mass counts than those deleted. For example, although almost 50% of the high hazard area was deleted from the 1979 spray program (Trial and Thurston 1980, p. 25), the deletions were not due to low budworm densities (Trial and Thurston 1980, p. 37). Rather, the lack of significant differences at high initial hazards (Fig. 6) may be due to the fact that prior damage accounts for 58% of the range of the hazard index (Trial and Thurston 1980, p. 72). Since prior damage makes such a substantial contribution, and since spraying cannot reduce prior damage, this component obscures differences in hazard rating associated with spraying.

**Effect of insecticide treatment on egg-mass density and defoliation in the year after application**. The analysis in this section is based on blocks of forest which were sprayed in year $t$ and unsprayed in year $t+1$. The mean values for such blocks are designated by the letter $i$ in Figs. 2, 3, and 7 to indicate spraying occurred in the intial year (year $t$).

In Fig. 2, the mean egg-mass densities in year $t+1$ for blocks sprayed only in the initial ($i$) year differ little from the corresponding densities of initially unsprayed blocks ($u$, $s$). In contrast, Figs. 3 and 7 show that the second year ($t+1$) defoliation in blocks

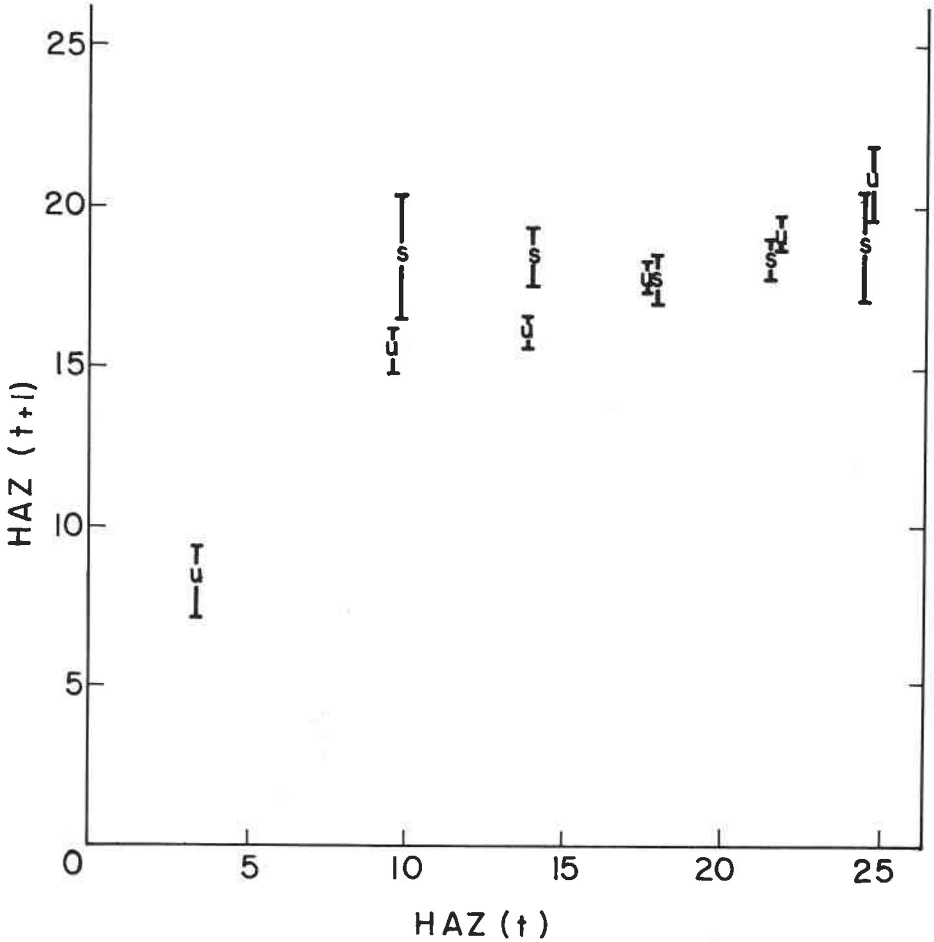


FIG. 6. Relationship between hazard ratings HAZ($t$) and HAZ($t+1$), in successive years for forest blocks unsprayed in year $t$. The letters $s$ and $u$ distinguish HAZ($t+1$) values calculated from blocks which were sprayed and unsprayed, respectively, in year $t+1$; the corresponding ± 2 standard error intervals about the means are shown. Sample sizes exceed 15 blocks.

sprayed only in the initial year ($i$) is often significantly less than that in initially unsprayed blocks ($u$, $s$). Together, Figs. 2, 3, and 7 suggest that spraying had its greatest impact on defoliation in the year following application.

The reasons for the delayed impact of spraying on defoliation are not obvious. The insecticides currently in use (Dylox, Orthene, and Sevin-4-oil) do not leave persistent residues (Rabeni *et al.* 1980). Although these insecticides reduce larval population densities immediately after application, fast larval development or poor spray timing can result in considerable foliage damage occurring before application. Under these circumstances spraying can do little to reduce current defoliation in the year of application. Furthermore, spraying may have little influence on egg-mass densities because moth dispersal may compensate for reductions in local budworm populations (cf. Miller 1979). In such cases, a large fraction of the egg-masses would have been laid by dispersing moths.

A possible cause of the delayed impact of spraying on defoliation is a result of this increase in the fraction of egg-masses laid by invading moths. Small starved female moths are particularly active dispersers and often emigrate after laying a disproportionately small

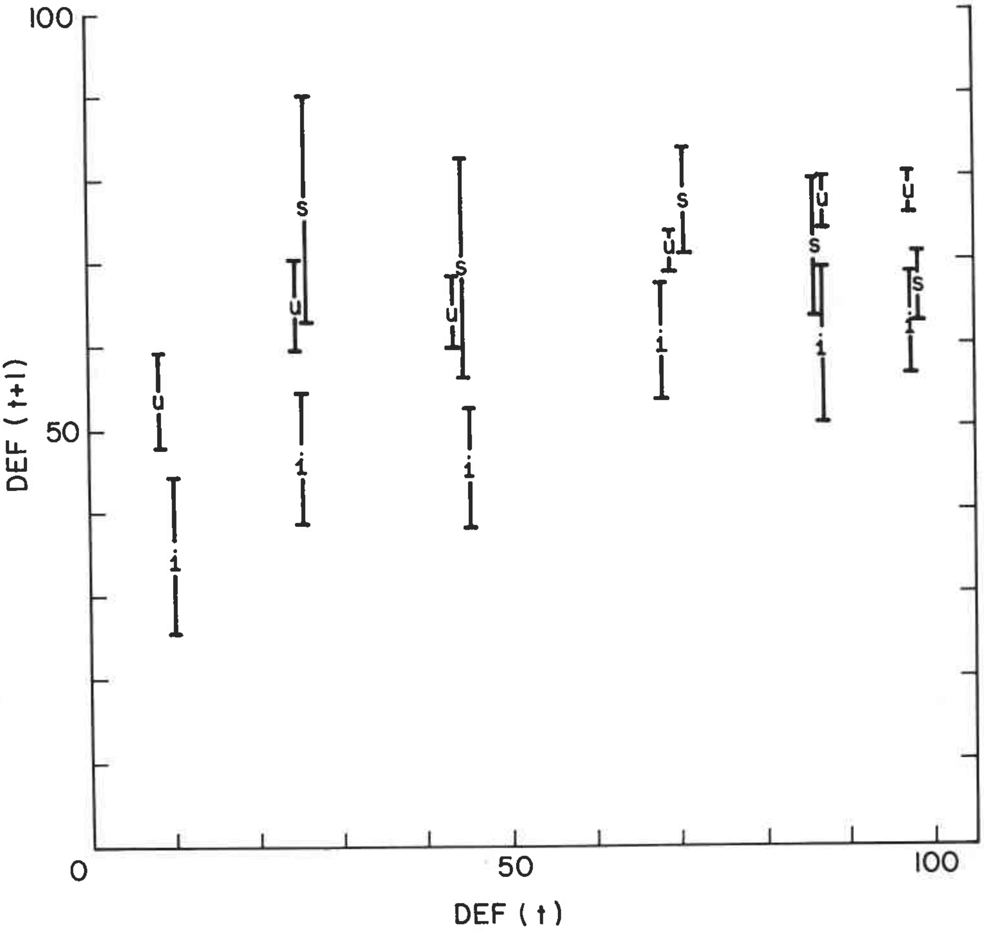


FIG. 7. Relationship between percent current defoliations, DEF($t$) and DEF($t+1$), in successive years. The letters $i$, $s$, and $u$ distinguish respectively histories of spraying only in the initial ($i$) and second ($s$) year, and of not spraying in either year ($u$). Vertical bars indicate the DEF($t+1$) range of two standard errors about the mean. Sample sizes exceed 12 blocks.

fraction of their egg complement (Greenbank *et al.* 1980, p. 14). Such females have reduced fecundity (Morris 1963, fig. 13.1), largely the result of laying fewer eggs per mass (Morris 1963, p. 84). Hence, while a substantial contribution by immigrant moths may maintain the egg-mass density, the actual egg density may be reduced. Fewer larvae would result and therefore presumably less defoliation in year $t+1$ for a given egg-mass density or defoliation level in the previous year. This provides a possible explanation for the low levels of defoliation observed in the second year (year $t+1$) in blocks sprayed only in year $t$ (Figs. 2, 7).

Thus far we have suggested that spraying in year $t$ reduces the larval population in year $t+1$ (compared with what it would have been without spraying in year $t$). With fewer defoliating larvae in year $t+1$ there is less competition for food. Under these circumstances both larval survival rates and moth fecundity are high (Morris 1963, p. 293). These high survival and fecundity rates plus moth dispersal could maintain egg mass density levels in the year following insecticide application as seen in Fig. 7.

## Conclusions

The reduction in mean defoliation associated with spraying differed considerably from year to year. While sprayed blocks often suffered less defoliation than unsprayed blocks with comparable egg-mass densities in the previous year, this relationship was reversed in 1978 (Fig. 5).

Insecticide applications were not as effective in reducing defoliation as expected. The maximum reduction in mean defoliation associated with insecticide application was about 20%; this was observed in heavily infested blocks (Fig. 7). Spraying also was associated with an approximately 50% reduction in the mean egg-mass densities in heavily infested blocks (Fig. 2). Spraying had little effect in reducing either defoliation or egg-mass densities in moderately infested blocks which were in poor condition because of heavy previous damage. Although spraying seemed to have a greater effect on mean defoliation in the year after application than in the year of application (Fig. 7), no such delayed impact on egg-mass densities was evident (Fig. 2).

Spraying had little effect on the reported Maine Forest Service hazard ratings. The Service uses this index to describe the danger of further forest deterioration in the absence of spraying (Trial and Thurston 1980). Again, these conclusions generally related to trends in the average value of the indicated variables and cannot be used to describe what would occur in a particular instance.

## Acknowledgments

We thank the Maine Forest Service for providing the data for this analysis and Henry Trial, Jr., the superviser of the data collection program, for guidance and assistance with the data. We also thank G. Mott, M. Devine, J. Connor, E. Hudes, D. C. Eidt, C. Miller, and M. Jones. This research was supported in part by a grant from the Eastern CANUSA Spruce Budworm Program of the U.S.D.A. Forest Service. All interpretations and conclusions are those of the authors and should not be taken as the view of the Maine Forest Service, of the U.S. Forest Service, or of any of the individuals who gave us assistance.

## References

Conover, W. J. 1980. Practical Nonparametric Statistics. Wiley, N.Y. 493 pp.

Fleming, R. A., C. A. Shoemaker, and J. R. Stedinger. 1983. Analysis of the regional dynamics of unsprayed spruce budworm (Lepidoptera: Tortricidae) populations. *Environ. Ent.* **12**: 707–713.

Greenbank, D. O., G. W. Schaefer, and R. C. Rainey. 1980. Spruce budworm (Lepidoptera: Tortricidae) moth flight and dispersal: New understanding from canopy observations, radar, and aircraft. *Mem. ent. Soc. Can.* 110. 49 pp.

Kleinschmidt, S., G. L. Baskerville, and D. S. Solomon. 1980. Foliage weight distribution in the upper crown of balsam fir. *U.S. For. Serv., For. Serv. Res. Pap.* NE-455. 7 pp.

McGill, R., J. W. Tuckey, and W. A. Larsen. 1978. Variations of box plots. *Am. Stat.* **32**: 12–16.

Miller, C. A. 1971. The spruce budworm in Eastern North America. *In* Proc. Tall Timbers Conference on Ecological Animal Control by Habitat Management, pp. 169–177.

——— 1977. The feeding impact of spruce budworm on balsam fir. *Can. J. For. Res.* **7**: 76–84.

——— 1979. An approach to measuring changes in the reproduction of spruce budworm (Lepidoptera: Tortricidae) field populations from survey data. *Can. Ent.* **111**: 309–316.

Morris, R. F. (Ed.) 1963. The dynamics of epidemic spruce budworm populations. *Mem. ent. Soc. Can.* 31. 332 pp.

Rabeni, C. F., K. E. Gibbs, and J. G. Stanley. 1980. Monitoring the effects of spruce budworm spraying on aquatic organisms. *Maine For. Rev.* **13**: 39–45.

Trial, H., Jr. 1980. A cartographic history of the spruce budworm in Quebec, Maine, and New Brunswick 1970-1978. *Maine For. Rev.* **13**: 3–7.

Trial, H., Jr. and A. S. Thurston. 1978. Spruce budworm in Maine: 1978. *Maine For. Serv. Ent. Div. Tech. Rep.* 8. 110 pp.

——— 1980. Spruce budworm in Maine: 1979. *Maine For. Serv. Ent. Div. Tech. Rep.* 14. 112 pp.

Webb, F. E., D. G. Cameron, and D. R. Macdonald. 1956. Studies of aerial spraying against the spruce budworm in New Brunswick V. Techniques for large-scale egg and defoliation ground surveys 1953–1955. *Interim Rep.* 1955-8, For. Biol. Lab., Fredericton, N.B. 24 pp.

(Received 19 January 1983; accepted 7 September 1983)