# DEFOLIATION AND MORTALITY CAUSED BY WESTERN SPRUCE BUDWORM: VARIABILITY IN A DOUGLAS-FIR STAND

R. I. ALFARO, T. L. SHORE AND E. WEGWITZ
Agriculture Canada
Pacific Forest Research Centre
506 West Burnside Road
Victoria, B.C.
V8Z 1M5

## ABSTRACT

Variation in Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) defoliation and mortality caused by the western spruce budworm *(Choristoneura occidentalis* [Freeman]) was measured in sequential annual surveys of a stand near Pemberton, British Columbia. The implications of this variability in designing defoliation and mortality surveys is discussed.

## RÉSUMÉ

On a mesuré, au moyen de relevés annuels successifs, dans un peuplement prés de Pemberton, en Colombie-Britanique, les variations de la mortalité et de la défoliation causées par la tordeuse occidentale de l'épinette *(Choristoneura occidentalis* [Freeman]) chez le douglas taxifolié *(Pseudotsuga menziesii* [Mirb.] Franco). On discute de l'influence de ces variations sur la planification de relevés ultérieurs de la det de la mortalité.

## INTRODUCTION

The western spruce budworm *(Choristoneura occidentalis* [Freeman]) is a recurrent defoliator of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) and other coniferous trees, causing tree mortality, growth loss and stem deformities (Alfaro *et al.* 1982; Ferrell and Scharpf 1982; Van Sickle *et al.* 1983).

Budworm infestations are often extensive. The last epidemic in British Columbia (B.C.) reached a maximum area of 226 000 ha in 1976 (Harris *et al.* 1984). Although defoliation and mortality vary, both within and between stands, few measurements of this variability and its effect on sample size have been reported in western North America.

Intensive surveys were conducted by the late Mr. J. A. Baranyay, of this centre, to quantify defoliation in an infestation that started in 1970 and lasted until 1974 at Railroad Creek, 32 km northwest of Pemberton, B.C. The area was re-surveyed in 1981 to determine the extent and distribution of tree mortality. This paper reports and discusses the variability of defoliation and tree mortality caused by the budworm infestation in this stand.

Results from studies based on a 420-tree sample within the area covered by these surveys were reported by Alfaro *et al.* (1982), Van Sickle *et al.* (1983) and Alfaro *et al.* (1984). Annual defoliation records, maintained on these trees from 1970 to 1980, indicated that the latter year marked the return to normal foliage growth following the effects of defoliation (Alfaro *et al.* 1982).

## METHODS

Surveys were conducted each year from 1971 until 1973 in an area of approximately 54 ha of pure, 80-year-old Douglas-fir at Railroad Creek. The survey design consisted of 5.06 m radius ($80.4 m^2$) plots, spaced in a systematic grid every 43 m. The number of plots (number of trees in brackets) measured each year was 135 (470), 115 (378) and 122 (406) in 1971, 1972 and 1973, respectively. Data collected in each plot included tree species, diameter, height, mortality and crown class. The live crown was ocularly divided into 4 vertical levels and defoliation was estimated to the nearest 10% of the total foliage in each level. Defoliation for each tree was then calculated as the arithmetic mean of the four crown-level estimates. Average tree defoliation and associated variance were calculated using formulae for cluster sampling with unequal cluster size (Scheaffer *et al.* 1979).

To assess the relative efficiency of cluster *versus* single tree sampling, mean defoliation and variance were recalculated on a sample of one randomly selected tree out of each plot. Mean defoliation and variances were compared to those obtained using all plot trees.

In 1981, the area was re-surveyed by variable radius plot cruise (BAF 5) to determine the extent of basal area mortality. Tree data collected included species, crown class and mortality.

All four surveys followed a similar ground cruise design, but because plots were not permanently identified, location of the plot centers varied from year to year.

Since tree mortality caused by budworm was reported to be more intense on the smaller, suppressed and intermediate trees (Alfaro *et al.* 1982), the spatial distribution of these crown classes in the stand was studied by calculating the dispersion index: $I_D = S^2(n-1)/\bar{x}$ (Southwood 1978).

**TABLE 1.** Mean % defoliation (95% confidence interval in brackets) and sampling statistics obtained with single tree and cluster sampling in a Douglas-fir stand defoliated by the western spruce budworm.

Defoliation Year

| | 1971 | | 1972 | | 1973 | |
|---|---|---|---|---|---|---|
| | Single trees | Clusters | Single trees | Clusters | Single trees | Clusters |
| Mean Defoliation | 25.3(3.3) | 24.8(3.7) | 53.5(2.6) | 54.0(2.2) | 56.5(3.8) | 56.6(3.3) |
| Standard deviation | 18.5 | 20.8 | 13.7 | 11.5 | 20.5 | 17.7 |
| Sample Size | 122 | 122 | 108 | 108 | 112 | 112 |
| Avg. No. Trees per Cluster | - | 3.8 | - | 3.5 | - | 3.6 |

## RESULTS AND DISCUSSION

### Defoliation

Mean defoliation, as estimated by plot sampling, increased from 24.8% in 1971 to 54% in 1972 and 56.6% in 1973 (Table 1). Standard deviations for the same years, were 20.8, 11.5 and 17.7%. The coefficient of variation dropped from 83.9% in 1971 to 21.3% in 1972 and 31.3% in 1973.

Recalculation of the estimate, using one randomly selected tree from each plot, yielded mean defoliation estimates that were less than 1% different from those obtained using all plot trees. Standard deviation was lower in 1971 (18.5%) and higher in 1972 (13.7%) and 1973 (20.5%) in single tree sampling relative to plot sampling.

These results indicate that the original survey design which involved defoliation estimation of all trees in the plots was not justified and led to oversampling. Single tree sampling could have provided estimates of almost identical precision.

The increasing defoliation in the stand, from 1971 to 1972 and 1973, was reflected in the increasing frequency of plots with mean defoliation precentages in the 51-75% and 76-100% classes (Table 2). The spatial distribution of defoliation was highly variable in 1971 when defoliation was lower and the infestation was starting. Defoliation was more uniformly distributed across the stand in 1973 when 65.2% of the plots had mean defoliation of 51% or more (Table 2).

The variability obtained with single tree sampling can be discussed in the context of sample size determination. Two approaches are possible when determining the number of plots required to achieve a desired level of precision in the estimation of average stand defoliation. The first method, using formula (1) (Husch *et al.* 1972) calculates sample size by setting the error bound as a fixed proportion of the mean:

$$n = \frac{t^2\, cv^2}{(AE\,\%)^2} \qquad (1)$$

where t = Student's t value at the required confidence level
cv = coefficient of variation
AE% = allowable error as a percentage of the mean

Thus, in our case, the sample size (number of trees) required to be 95% confident that the estimated average defoliation was within 10% of the mean, was 204, 27 and 51 trees in 1971, 1972 and 1973, respectively. Since mean defoliation for these years was 25.3, 53.5 and 57.5%, these sample sizes theoretically would provide an error bound of 2.5%, 5.4% and 5.8% defoliation for each of the years. Estimation by eye of the defoliation of individual trees is an inexact method; individual estimates could at best be expected to come within 10% of the true value (Silver 1959). As a result, precision requirements related to the mean can be unrealistic when defoliation is light. This was the case in the 1971 estimate. A more realistic approach, discussed by MacLean and Ostaff (1983), consists of setting the error bound on the estimate as an absolute value, independent of the mean. Using formula (2) (Husch *et al.* 1972) to estimate mean defoliation in this stand to ± 10%, only 15, 9 and 18 trees would have been required in 1971, 1972 and 1973, respectively. This would have resulted in considerable savings in time and effort.

$$n = \frac{t^2 SD^2}{(AE)^2} \qquad (2)$$

where t = Student's t value at the required confidence level
SD = standard deviation
AE % = allowable error in the same units as the mean

Assuming the maximum standard deviation of 20% found in these defoliation surveys, the number of trees required to estimate mean defoliation to within absolute error bounds from 5 to 25% defoliation (i.e. using formula 2), is given in Fig. 1. Sixty one trees are required to estimate mean

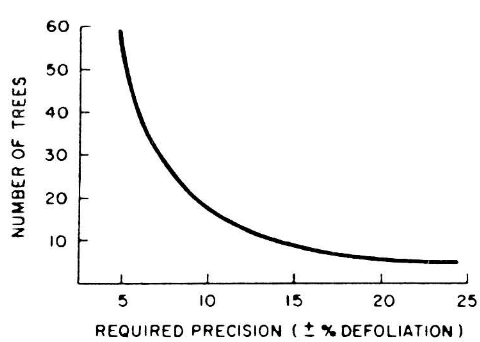


Fig. 1. Relationship between sample size and precision when defoliation standard deviation is 20% (maximum observed in this study).

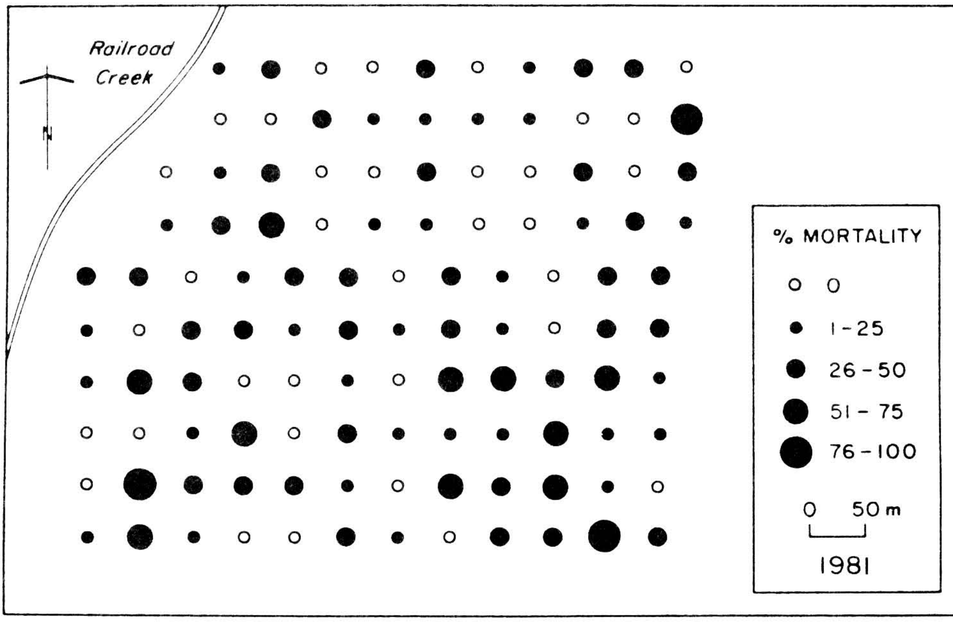


Fig. 2. Distribution of basal area mortality of Douglas-fir in plots surveyed in 1981, after the stand recovered from a western spruce budworm infestation that lasted from 1970 to 1974.

**TABLE 2.** Frequency distribution of the plots in five defoliation or basal area mortality classes.

| Defoliation or Mortality Class (%) | Defoliation | | | BA Mortality |
|---|---|---|---|---|
| | 1971 | 1972 | 1973 | 1981 |
| 0 | 1 ( 0.8)* | 0 ( 0.0) | 0 ( 0.0) | 35 (30.7) |
| 1-25 | 61 (49.6) | 3 ( 2.8) | 6 ( 5.3) | 32 (28.1) |
| 26-50 | 49 (39.8) | 32 (29.6) | 33 (29.5) | 34 (29.8) |
| 51-75 | 11 ( 9.0) | 69 (63.9) | 54 (48.2) | 10 ( 8.8) |
| 76-100 | 1 ( 0.8) | 4 ( 3.7) | 19 (17.0) | 3 ( 2.6) |
| Total | 123 (100) | 108 (100) | 112 (100) | 114 (100) |

*Percentages are given in brackets.

TABLE 3. Mean, standard deviation (S.D.) and coefficient of variation (C.V.) for basal area and basal area mortality in four surveys of a Douglas-fir stand defoliated by the western spruce budworm. Infestation lasted from 1970 to 1974.

| | 1971 | | | 1972 | | | 1973 | | | 1981 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | CV | Mean | SD | CV | Mean | SD | CV | Mean | SD | CV |
| | $m^2/ha$ | $m^2/ha$ | (%) | $m^2/ha$ | $m^2/ha$ | (%) | $m^2/ha$ | $m^2/ha$ | (%) | $m^2/ha$ | $m^2/ha$ | (%) |
| Alive | 46.9 | 31.2 | 66 | 38.0 | 24.5 | 64 | 46.1 | 36.0 | 78 | 24.0 | 12.5 | 52 |
| Dead | 0.4 | 2.4 | 600 | 0.0 | - | - | 0.2 | 1.2 | 620 | 7.8 | 7.9 | 102 |
| Total | 47.3 | 31.5 | 66 | 38.0 | 24.3 | 64 | 46.4 | 36.2 | 78 | 31.8 | 13.3 | 42 |

defoliation to ± 5% defoliation. The number of trees required is reduced to between 5 and 10 for precision levels of 15 to 25% defoliation.

Further studies in stands of different characteristics, using different plot sizes are necessary to derive sample curves of more general applicability. However, in the absence of these data, the curve in Fig. 1 can be used as a preliminary guide in the design of western spruce budworm defoliation surveys.

**Mortality**

Tree mortality during the three defoliation years covered by these surveys was less than 1% of the basal area per ha in each year; however mortality by 1981 averaged 7.8m²/ha (24.5% of the basal area per hectare) (Table 3). Mortality attributable to bark beetle or to other agents was low throughout the period (Alfaro *et al.* 1982); therefore, most mortality was attributable to budworm defoliation.

Plot to plot variation in basal area mortality was high in the 1981 survey but negligible in other years. About 30% of the plots had mortality levels in the 0, 1 to 25 and 26 to 50% basal area mortality classes, while 10 plots (8.8%) had basal area mortality between 51 and 75% and 3 plots (2.6%) had more than 75% of their basal area in dead trees (Table 2). Coefficient of variation for basal area mortality was 102% (Table 3). This variability resulted in error bound of 1.45 m²/ha or 18.5% in the estimation of the total dead basal area in the stand (7.8 m²/ha). To reduce that error to a fixed level of 1 m²/ha (12.8%), 240 plots would have been required.

Most mortality occurred among small, suppressed and intermediate trees (Alfaro *et al.* 1982). Using an index of dispersion to test the departure from randomness of the distribution of these trees (Southwood 1978) we concluded that trees of the suppressed and intermediate crown classes were distributed randomly in the stand. This random distribution of the smaller trees may explain the highly variable spatial distribution of mortality in the stand (Fig. 2). The uneven thinning effect resulting from such a mortality pattern may be silviculturally unacceptable.

In conclusion, assessment of the level of defoliation of a stand can be performed by a single-tree sampling scheme. This sampling could be done at the same time that other surveys are conducted in an infested stand. An optimum arrangement might be to estimate defoliation on one tree per plot on randomly selected plots during a mensurational survey aimed at assessing the stand volume at risk.

Since mortality occurs in the late stages of a budworm infestation and continues even after the population collapses, a different survey is required to determine the mortality level in the stand. Mortality surveys would be required to assess the total impact of an infestation and to enable management decisions such as early logging or site rehabilitation.


## ACKNOWLEDGEMENTS

The authors would like to acknowledge the contribution of the late J. A. Baranyay of this centre who conducted the 1971-73 surveys.


## REFERENCES


Alfaro, R. I., G. A. Van Sickle, A. J. Thomson and E. Wegwitz. 1982. Tree mortality and radial growth losses caused by the western spruce budworm in a Douglas-fir stand in British Columbia. Can. J. For. Res. 12:780-787.

Alfaro, R. I., A. J. Thomson and G. A. Van Sickle. 1984. Quantification of Douglas-fir growth losses caused by western spruce budworm defoliation using stem analysis. Can. J. For. Res. In Press.

Ferrell, G. T. and R. F. Scharpf. 1982. Stem volume losses in Grand firs top killed by western spruce budworm in Idaho. USDA For. Serv. Pacific Southwest For. and Range Exp. Sta. Res. Pap. PSW-164.

Harris, J. W. E., R. I. Alfaro, A. G. Dawson and R. G. Brown. 1985. The western spruce budworm in British Columbia 1909-1983. Agric. Can. Can. For. Serv. Inf. Rep. In Press.

Husch, B., C. I. Miller and T. W. Beers. 1972. Forest mensuration. Ronald Press Co. New York. 410 pp.

MacLean, D. A. and D. P. Ostaff. 1983. Sample size — precision relationships for use in estimating stand characteristics and spruce budworm caused tree mortality. Can. J. For. Res. 13:548-555.

Scheaffer, R. L., W. Mendenhall and L. Ott. 1979. Elementary Survey Sampling. Duxbury Press, Massachusetts. 278 pp.

Silver, G. T. 1959. Individual differences in estimating defoliation. Can. Dep. Agr. Res. Br. For. Bi. Div. Bi-mon. Prog. Rept. 15(3): 1-4.

Southwood, T. R. E. 1978. Ecological methods. John Wiley & Sons, New York. 524 pp.

Van Sickle, G. A., R. I. Alfaro, and A. J. Thomson. 1983. Douglas-fir height growth affected by western spruce budworm defoliation. Can. J. For. Res. 13:45-450.