FOREST MANAGEMENT NOTE

Northern Forestry Centre

Note 65

A SEQUENTIAL SAMPLING PLAN FOR CLASSIFICATION OF DAMAGE CAUSED BY SPRUCE GALL MIDGE (*MAYETIOLA PICEAE* [FELT])

INTRODUCTION

An outbreak of spruce gall midge *(Mayetiola piceae* [Felt]) was detected in northern Alberta and adjacent areas in the Northwest Territories in 1992 (Cerezke and Brandt 1993). Surveys in 1993 indicated that the infestation (Fig. 1) was widespread in white spruce, *Picea glauca* (Moench) Voss, stands, with 84% of surveyed sites infested and twig mortality as high as 81% of the total number of current-year shoots (Brandt 1994). Levels of damage decreased at most sites in 1994 (Brandt 1995), and by the spring of 1995 the outbreak had collapsed. The outbreak covered about 15 million ha at its peak in 1993. Other outbreaks were observed in the Yukon Territory in 1968 and 1969 (Tripp et al. 1970), in Connecticut in the early 1970s (Stephens 1985), and in New Brunswick and Nova Scotia in 1981 and 1982 (Magasi 1983). Typically, outbreaks have been localized and of short duration.

Spruce gall midges overwinter as larvae within cells in galled current-year shoots (Smith 1952). Pupation usually occurs from mid-May to early June, the adults emerging through conspicuous holes in the galls and mating shortly thereafter (Ives and Wong 1988). The fecundity of the females is unknown, but as many as 100 larvae have been noted per shoot. Eggs are laid at the base of the needles of developing shoots (Smith 1952). Upon hatching, the larvae immediately bore into the twig, and gall formation is stimulated. Galls become noticeable within 10 days and appear as a series of small, semiglobose swellings, which render the infested twig twice its normal diameter (Felt 1926). Galled twigs usually remain on branches for several years. Other than the work of Felt (1926) and Smith (1952), there is little information on this infrequent pest of white spruce.

Sequential sampling methods allow rapid classification of population densities and damage levels because they assess the adequacy of the sample as sampling units are examined. In contrast to fixed-size sampling plans, sequential sampling procedures typically reduce the sampling effort required to categorize populations in relation to particular objectives (Waters 1955). Sequential sampling plans have been developed to categorize pest damage for numerous insect pests (e.g., Stark 1952; Morris 1954; Ives and Prentice 1958; Kolodny-Hirsch 1986; Fleischer et al. 1991).

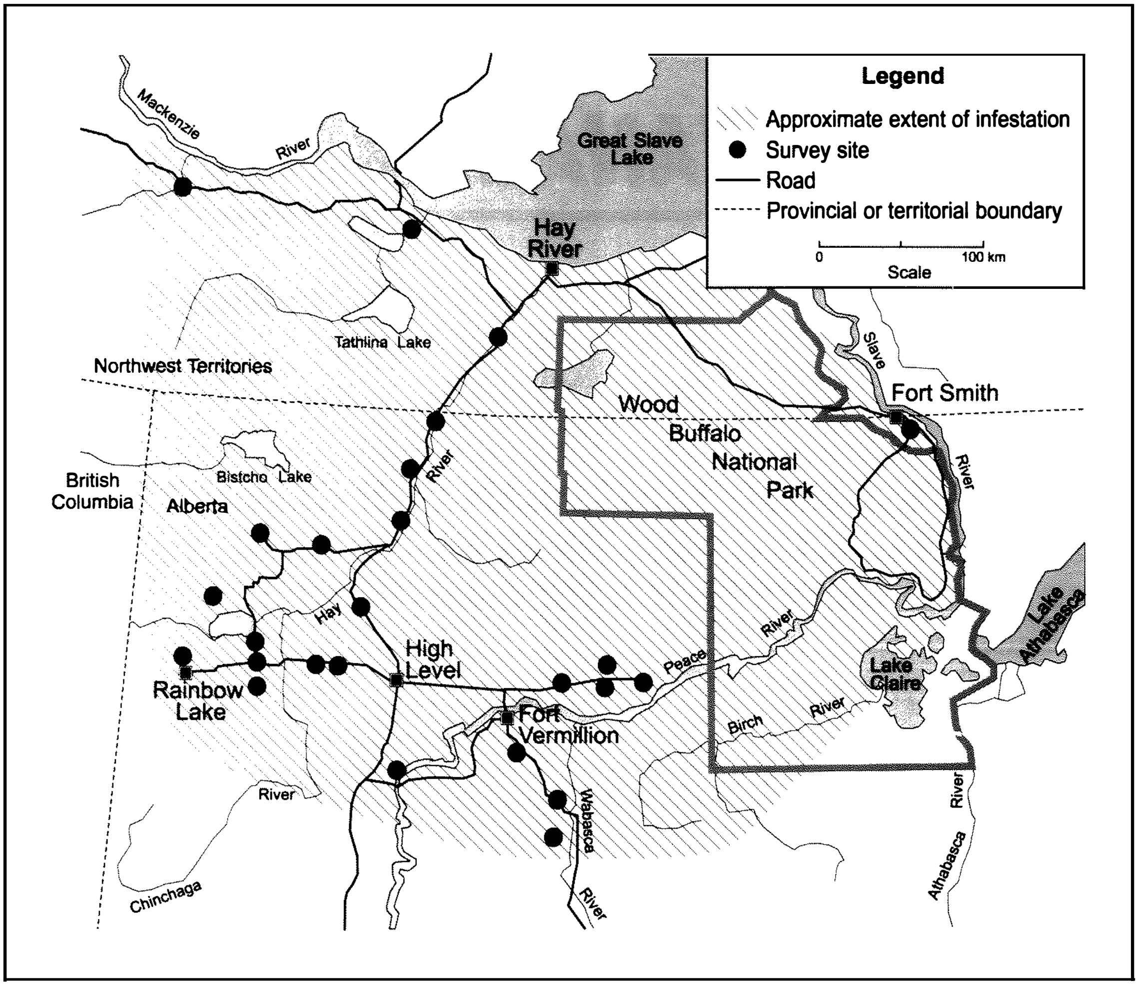

Figure 1. Extent of the spruce gall midge outbreak detected in 1992, and sites sampled in 1993 and 1994.

This note describes a sequential sampling plan for classification of damage caused by spruce gall midge populations.

MATERIALS AND METHODS

A grid with 10 × 10 km cells was overlaid on 1:250 000 scale topographic maps of the general area of infestation observed in 1992. Twenty-five cells were selected at random from the 205 road-accessible cells. One representative white spruce or white spruce–trembling aspen, *Populus tremuloides* Michx., stand was selected within each of the 25 cells. Within stands, three representative dominant or codominant white spruce trees were selected for sampling; the selected trees were located at least 100 m off the road to minimize any edge and road effects.

Sampling was conducted during a 2-week period in July 1993 and a similar period in July 1994. Tree crowns were stratified into upper, middle, and lower levels. The foliated portions of four branches were removed from each tree by means of pole pruners. One branch was removed from each crown level, and an additional branch was removed from a crown level selected at random. The branches were inspected for galled shoots in the laboratory. The number of galled current-year shoots was recorded, as was the total number of current-year shoots. These data were used to develop the sequential sampling plan for spruce gall midge according to the methods described by Oakland (1950).

Because of the sampling design, there was flexibility to pool the data in five ways and to test which group provided the best fit. The sample unit for each of the five groups consisted of an average of four branches per tree, four branches per tree, lower-crown branches only, mid-crown branches only, and upper-crown branches only. The mean (kp), variance (kpq), and dispersion parameter (k) of the negative binomial distribution were calculated for the sample unit in each group. For each group, goodness-of-fit to a negative binomial distribution, $(q - p)^{-k}$, was analyzed with a χ^2-statistic using an algorithm (Davies 1971). The expected frequencies were grouped if they were less than one (Cochran 1954; Pahl 1969).

SEQUENTIAL SAMPLING PLAN

The frequency distribution of galled current-year shoots was not significantly different from a negative binomial distribution when the average of four branches per tree was used as the sample unit ($\chi^2 = 12.575$, $df = 17$, $P = 0.764$). The negative binomial distribution is described by the mean $kp = 5.3333$, the variance $kpq = 83.0828$, and the dispersion parameter $k = 0.3007$. The distribution indicates aggregation of spruce gall midges on branches of white spruce trees because the variance is greater than the mean. The low value of k also indicates a high degree of aggregation: as k approaches zero, aggregation becomes extreme (Fisher et al. 1943), whereas a value of k approaching infinity (i.e., the Poisson distribution) would indicate no aggregation (Waters 1959). The cause of aggregation of spruce gall midge on white spruce branches is unknown; female spruce gall midges may be highly selective in choosing hosts for oviposition, they may be adapted to particular trees, or their dispersal ability may be limited.

The limits used to discriminate between light and moderate midge damage or between moderate and severe midge damage were set as follows. Light damage was represented by branches for which the mean number of galled current-year shoots per branch was less than or equal to three ($kp \leq 3$). This is the null hypothesis (H_0) for distinguishing between light and moderate damage. Moderate damage was represented by branches for which the mean number of galled current-year shoots per branch was between 4 and 16 ($4 \leq kp \leq 16$). This is the alternate hypothesis (H_1) for distinguishing between light and moderate damage or the null hypothesis for distinguishing between moderate and severe damage. Severe damage was represented by branches for which the mean number of galled current-year shoots per branch was greater than or equal to 24 ($kp \geq 24$). This is the alternate hypothesis for distinguishing between moderate and severe damage. These values represent, respectively, approximately up to 25% of the shoots damaged per branch, between 36% and 65% of the shoots damaged per branch, and more than 76% of the shoots damaged per branch (unpublished data). Twig mortality is the usual result of spruce gall midge attack. Although the effect on growth of this damage is unknown, it is not unreasonable to assume that the growth loss is similar to that caused by spruce budworm, (*Choristoneura fumifera* (Clem.), defoliation. The relationship between defoliation and growth loss is well established for spruce budworm (Kulman 1971; Gross 1985). White spruce growth may be reduced by 22% when trees are defoliated by more than 30% in any 1 year (Gross 1985). Damage levels set for spruce gall midge are about equal to damage levels commonly used for spruce budworm defoliation, with the light category being the lowest category visible by an observer in an aircraft (Allen et al. 1984), and the moderate and severe categories being similar to levels of budworm defoliation that result in reduced tree growth. Additional research is required to establish damage indices and an action threshold for implementation of control strategies.

The two sets of decision lines used to discriminate between light and moderate or between moderate and severe populations are illustrated for the sequential sampling plan in Figure 2. The probability of type I (α) and type II (β) errors under the null and alternate hypotheses are set at 0.10 for the plan. To implement the plan and categorize spruce gall midge damage, stands, trees, and branches must be selected at random. To produce a map of an outbreak showing damage levels at various sites, divide the general area of the infestation into equal-sized cells and select cells at random. Obtain a forest inventory listing of all stands in each cell, and select at least one stand per cell at random. Within stands, select dominant or codominant trees along a transect with a randomly selected start point and bearing. At each tree along the transect remove one branch from each of the lower, middle, and upper crown levels and an additional branch from a crown level selected at random. Count the number of galls per branch and calculate the average of the four branches. Plot the number of trees sampled and the

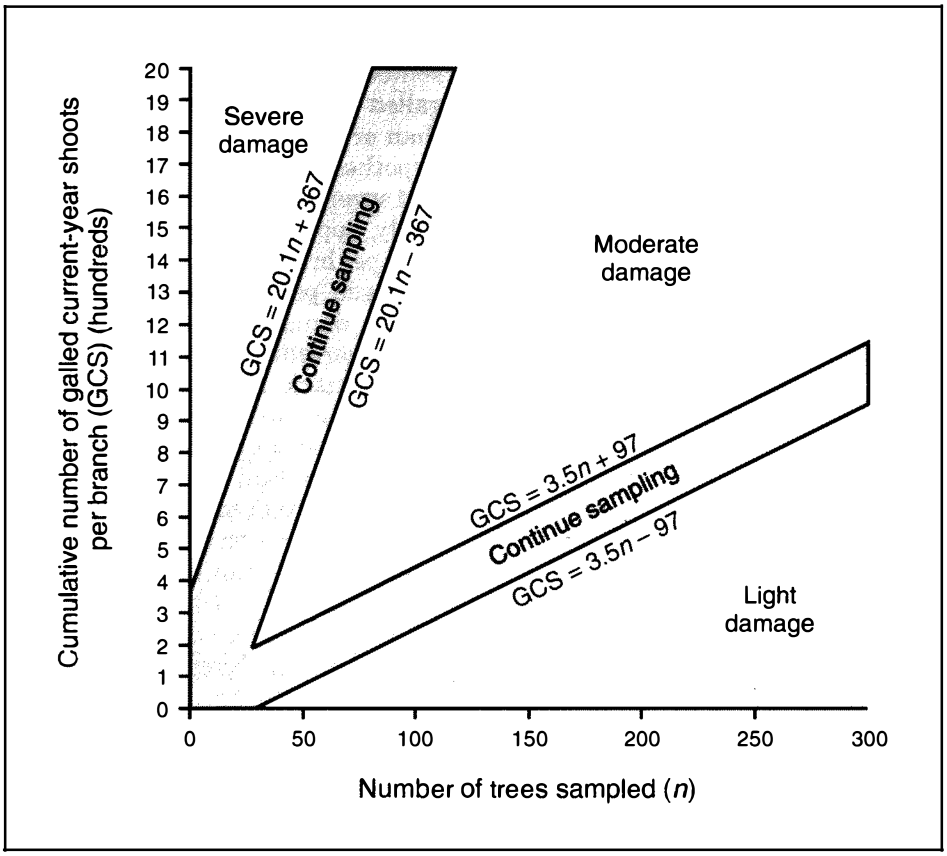

Figure 2. Decision lines of the sequential sampling plan to discriminate between light and moderate and between moderate and severe damage levels caused by spruce gall midge on white spruce trees.

cumulative mean number of galled current-year shoots on the graph of the sequential sampling plan (Fig. 2). Continue sampling trees along the transect until the damage has been classified into one of the damage classes of the sampling plan.

The sequential sampling plan minimizes the amount of effort required when sampling trees for the midge. For example, a minimum of 28 trees would have to be sampled to classify damage at a site if no galled current-year shoots were found on the branches. If 40 trees were sampled and the total number of galled current-year shoots was 300, then the damage level would be classified as moderate. In both of these examples there would be a 1 in 10 chance that the damage level would be classified incorrectly (e.g., in the first example, that the damage level was not light but rather moderate).

Obviously, if $3 < kp < 4$ or $16 < kp < 24$ (represented by the shaded areas in Fig. 2), the damage levels are not light, moderate, or severe but rather are intermediate. In this situation, the sampler should classify the damage as light-to-moderate or moderate-to-severe, respectively. Such a situation would be evident to the sampler from a plot of successive graph coordinates (x, y) of the number of trees sampled (x) and the cumulative number of galled current-year shoots (y). If the line drawn by connecting the coordinates runs parallel to the upper and lower decision lines of the two damage levels, then the sampler can assume an intermediate damage level.

Another feature of the sequential sampling plan is that class limits can be changed easily, which allows the user of the plan to adjust the decision lines to suit the user's needs. If more than 10 galled shoots per branch is unacceptable but fewer than 8 galled shoots per branch makes control uneconomical, then these values can be used to derive the new decision lines of the null and alternate hypotheses from a recalculation of the decision lines according to the parameters of the negative binomial distribution described above.

The operating characteristic curve (Fig. 3) and the mean sample number curve (Fig. 4) were also developed for the sequential sampling plan. The operating characteristic curve illustrates the probability of a correct decision, depending on the mean number of galled current-year shoots per branch (*kp*). Note that when $kp = 3$ or $kp = 4$ on the operating characteristic curve for light versus moderate damage levels, the probability of labeling the damage as light is 0.90 and 0.10, respectively and that these probabilities relate to the type I ($\alpha = 0.10$) and type II ($\beta = 0.10$) errors. The greatest uncertainty lies in the interval $3 < kp < 4$. In this range, sampling continues under the sequential sampling plan until the user is able to discriminate between light and moderate damage levels. The same can be demonstrated for the operating characteristic curve for moderate and severe damage levels.

The mean sample number curve illustrates the relationship between the mean number of trees sampled, $E(n)$ and the mean number of galled current-year shoots per branch (*kp*). As an example, suppose the sampler is attempting to discriminate between moderate and severe damage levels and the mean number of galled current-year shoots per branch is eight. In this situation the mean number of trees that would have to be sampled would be about 30.

SUMMARY

Galled current-year shoots caused by spruce gall midge displayed a negative binomial distribution described by the mean $kp = 5.3333$, the variance $kpq = 83.0828$, and the dispersion parameter $k = 0.3007$, according to data collected in 1993 and 1994 during an outbreak in Alberta and the

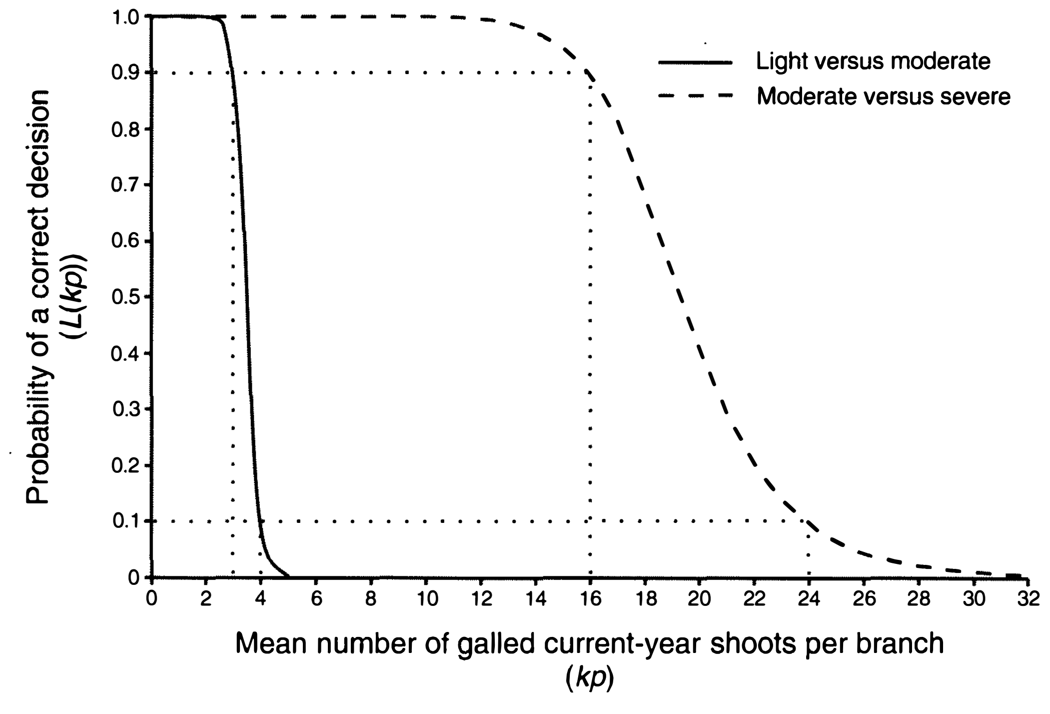

Figure 3. Operating characteristic curves for the spruce gall midge sequential sampling plan.

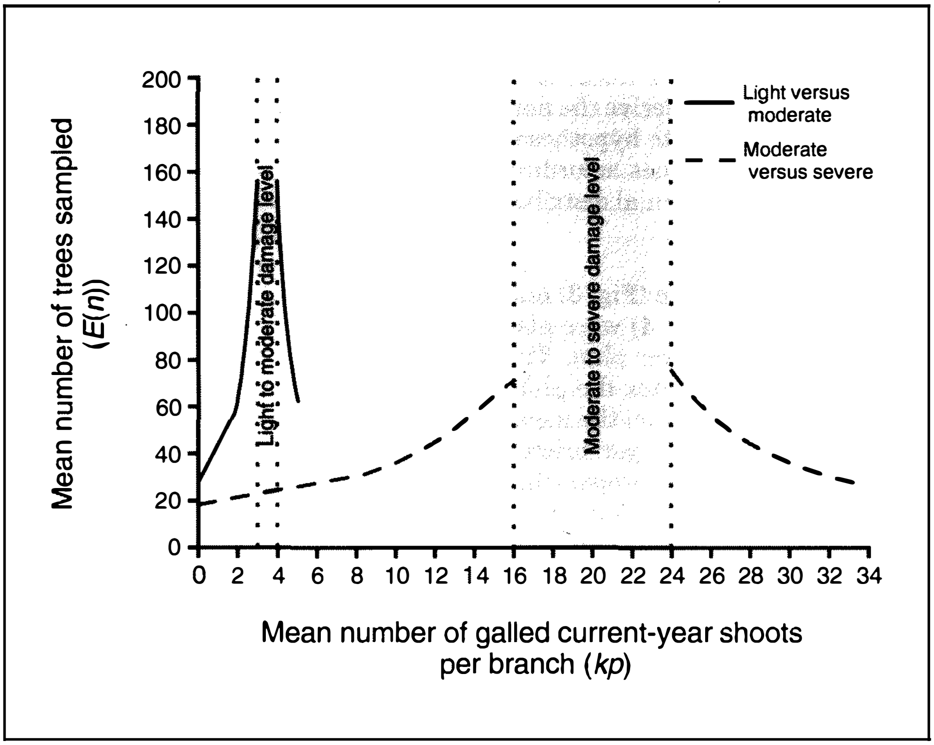

Figure 4. Mean sample number curves for the spruce gall midge sequential sampling plan.

Northwest Territories. This information was used to derive a sequential sampling plan for the classification of damage caused by spruce gall midge. The plan should prove useful to foresters and pest managers in their quest to make management decisions. Further work is required to develop damage indices and action thresholds for the implementation of control strategies.

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