Forest Health
Technology Enterprise Team

**TECHNOLOGY TRANSFER**

***Sampling Methods***

# Sampling Methods for Forest and Shade Tree Insects of North America, Volume 2

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**and Scott M. Salom**

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**Miscellaneous Insects**



**Piercing and Sucking Insects and Mites**

## Seed and Cone Insects



## Wood- and Bark-boring Insects

The genesis of this project came from an undergraduate classroom discussion around 12 years ago. A student in a shade tree pest management course taught at Virginia Tech asked if a compilation of sampling methods for estimating insect populations was available for reference. At that time no such resource existed for the average forester or arborist. Recognizing the need for an unambiguous and comprehensive tool, the original volume of Sampling Methods for Forest and Shade Tree Insects of North America was published by FHTET in 2001 (FHTET 2001-01). The information included in this publication was also made available online and can now be accessed at http://www.sampforestpest.ento.vt.edu/ (note this is a different URL from the one originally published in Vol. 1).

The responses to both the initial publication and website have been consistently positive. However, it was not long before we realized that the first volume probably did not cover all available publications that met our criteria of developing or describing sampling procedures to help make IPM assessments and decisions. In addition, many new publications became available after the publication of the first volume. As a result, a second volume has been produced that has nearly as many publications and summaries as the first volume. The updated website will incorporate all of the summaries from both volumes into one outlet.

The usefulness of this product is as important now as it was when it was first conceived. The use of the Internet has exploded since 2001 and the publishing industry has adapted to these changes. Many more federal publications are available online than previously. Most publishers provide all recent and often many older journal articles online. But if someone searching for this information is not associated with a research library, access to a specific journal article usually requires a steep fee.

Someone new to the field of estimating insect populations will greatly benefit from this resource that summarizes much of the sampling information available for both common and infrequent tree pests. In addition, many experienced natural resource professionals involved in making pest management decisions may benefit by reviewing the basic summaries that are provided here for some of the more complex sampling techniques. Furthermore, as noted in the preface to Volume 1, this compilation helps identify key forest pests for which sampling procedures for use in IPM are lacking and for which further resource is warranted.

Again, we are pleased to present the results of many years of effort and we hope that you find this compendium a useful tool for managing insect pest populations of forest and shade trees.

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Sampling to estimate forest insect pest populations or damage levels is essential in decision-making and efficacy evaluation of any forest pest management program. Prior to Fettig et al. (2001) and http://www.sampforestpest.ento.vt.edu/, a comprehensive presentation of sampling procedures for forest pests was not available. With the hardcopy compendium of summaries and the associated online database, sampling procedures were easier to find and understand and made more accessible for application in management situations.

The original publication required an exhaustive library search that yielded over 300 publications. Of these, 123 were considered appropriate for inclusion, using the criterion that the publication had to describe a sampling procedure that can be used directly or indirectly in pest management decision-making. In this second volume, using the same criterion, an additional 325 publications were identified and reviewed. From these, over 100 were selected for inclusion in this volume. Some of the articles generated a summary for more than one pest species, and some summaries contain content from more than one research article. All together, Volume II contains 115 summaries organized by feeding guild (Table 1). Sampling procedures for defoliating insects continues to dominate among the feeding guilds.

Table 1. The number of summaries within each category in Vol. 2

| Feeding group or guild | Number of summaries |
|---|---|
| Bud, shoot, root insects | 14 |
| Defoliating insects | 67 |
| Miscellaneous insects | 1 |
| Piercing and sucking insects and mites | 13 |
| Seed and cone insects | 7 |
| Wood- and bark-boring insects | 13 |

Each summary is formatted as in the original publication and includes: the citation, objective, abstract, sampling procedure (description of how to use it), notes (caveats), and references used in the summary. References beginning with an asterisk (*) were reviewed in the original publication and those beginning with a pound sign (#) were reviewed in this volume. We have included a more robust glossary section to help those unfamiliar with some of the biological and statistical terms.

No judgment was made on which sampling articles are the most appropriate to use for a particular pest. This compilation represents an archival record on what has been published previously in the literature and the user must decide how to use the techniques presented in each summary. Sometimes it may be appropriate for the user to consult the original article. If you do plan to use a particular procedure summarized here, we recommend that you read

the original article and verify that it suits your needs.

Reference

Fettig, C. J., J. G. Fidgen, Q. C. McClellan, and S. M. Salom. 2001. Sampling methods for forest and shade tree insects of North America. FHTET-2001-01. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team; 273 pp

# BUD, SHOOT, AND ROOT INSECTS

# Seedling Debarking Weevil

## *Hylobius congener* Dalla Torre, Shenkling, & Marshall

### Coleoptera: Curculionidae

Pendrel, B. A. 1990. Hazard from the seedling debarking weevil: a revised key to predicting damage on sites to be planted. Tech. Note 236. Forestry Canada, Maritimes Region; 4 p.

**Objective**

To revise a hazard key, originally published in 1987 (Pendrel 1987), for predicting damage by *H. congener* on 1-yr-old cuts to be planted.

**Abstract**

The seedling debarking weevil, *H. congener* Dalla Torre, Shenkling and Marshall, is a serious regeneration pest of newly planted seedlings on 1-yr-old clear cuts in the Maritime Provinces of Canada. Adult weevils girdle the main stem of planted seedlings, killing them quickly. A dichotomous key was devised that integrates variables such as percentage of ground cover and mineral soil, basal area of regenerating tree stems, and density of trapped adults. The key determines weevil hazard and aids management decision-making on one-year-old cuts as well as sites where the pre-harvest softwood content was ≥25% or in areas with a history of *H. congener* activity.

**Sampling Procedure**

Standardized pitfall traps, baits for *H. congener*, and instructions for their use are available from Research and Productivity Council (Fredericton, NB, Canada). Planting sites should be assessed 3–4 times in late May or early June. The first visit is necessary to evaluate the percent ground cover with feather moss, which provides hiding places for weevils, and exposed mineral soil, which discourages weevil activity. Using a meter stick, calculate the density of regenerating stems in $m^2$ plots as averaged from several plots in the site. Install at least three pitfall traps per site. Check traps daily for three days and average the number of trapped weevils for the site. Trapping can be discontinued after the first day if an average of two weevils is found in each trap. Trapping can be discontinued after the second day if the cumulative average number of weevils per trap is two. In both instances the minimum number of weevils needed to follow the key has been trapped. Otherwise, reference Table 1 to determine weevil hazard.

**Note**

The author did not provide details regarding the type of pitfall trap and bait used in this study.

This key was developed for sites in the Maritimes and so it should be, at least, used with caution in other geographic areas where this insect is a problem. The key should be used in the first spring following a harvest, which may not be operationally compatible with a spring planting. The key may be more suitable for use in conjunction with fall plantings.

**Table**

Table 1. Key to predicted damage from *Hylobius congener* in one-year-old cuts.

| | | | |
|---|---|---|---|
| 1 | a | GROUND COVER <10% FEATHER MOSS | 2 |
| | b | GROUND COVER >10% FEATHER MOSS | 4 |
| 2 | a | EXPOSED MINERAL SOIL <10% | 3 |
| | b | EXPOSED MINERAL SOIL >10% | 5 |
| 3 | a | REGENERATING STEMS <5/$M^2$ | 4 |
| | b | REGENERATING STEMS >5/$M^2$ | 5 |
| 4 | a | WEEVILS TRAPPED <0.3/NIGHT | 6 |
| | b | WEEVILS TRAPPED >0.3/NIGHT | 7 |
| 5 | a | WEEVILS TRAPPED <0.5/NIGHT | 6 |
| | b | WEEVILS TRAPPED >0.5/NIGHT | 7 |
| 6 | | **LOW HAZARD.** MORTALITY 0–5% | |
| 7 | | **MODERATE TO HIGH HAZARD.** MORTALITY >5% | |

# Black Vine Weevil

## *Otiorhynchus sulcatus* (F.)

### Coleoptera: Curculionidae

Reding, M. E.; Klein, M. G.; Brazee, R. D.; Krause, C. R. 2003. Research on black vine weevil and white grubs in ornamental nurseries in Ohio by USDA-ARS. Wooster, OH: US Department of Agriculture, Agricultural Research Service Extension Circular. 189: 89-93.

**Objective**

To develop effective traps for monitoring emerging adult *O. sulcatus*.

**Abstract**

The black vine weevil, *Otiorhynchus sulcatus* (F.), can be a serious pest of ornamental trees, especially those grown in containers or larger field-planted trees in nurseries. Larvae feed on the roots and girdle the main stem resulting in poor growth rates and mortality in extreme cases. Control measures against *O. sulcatus* are initiated when adults are first found, but they are often difficult to detect. Adult *O. sulcatus* rest in concealed locations during the day and are active at night.

Black vine weevil is a serious pest of trees in the genus *Taxus* (yews). The efficiency of three trap types was tested for capturing adult weevils in a typical but unsprayed field nursery of *Taxus*. Two of these traps were effective. The first trap is a 900 $cm^2$ x 2.54 cm thick board with 0.6 cm grooves cut into one face. Placed grooved-side down, adult *O. sulcatus* hide in the grooves during the day. The second is a pitfall trap made from two 500 ml plastic drinking cups. The former trap caught weevils earlier than the latter one. Moreover, foliage beating to dislodge adults was done concurrently with the placement of traps in the field. The board trap captured adults earlier than either the pitfall trap or the traditional means of detecting adults by beating foliage. However, the pitfall trap still captured adults several days before they were found by the beating method.

**Sampling Procedure**

Cut a 2.54 cm board into 30 X 30 cm squares. On one side of each 30 x 30 cm piece, cut a series of 0.6 cm grooves. No information was given as to their spacing and interested users should contact the authors for this information. Ten equally spaced grooves may be sufficient. Place traps grooved side down beneath the crown of randomly selected yews. This provides an attractive, convenient hiding place for adults.

The second trap consists of two 500 ml plastic drinking cups. The first cup is placed in a

hole beneath the crown of a randomly selected yew so that the lip of the cup is flush with ground level. Coat the inside rim of the second cup with grease to form an escape barrier and set the cup inside the first one.

Check traps regularly and initiate control measures when adult *O. sulcatus* are found.

**Notes**

These traps have not been used operationally and so they should be used with caution. The authors recommend further testing in commercial fields under normal management practices and with varying pest densities. No details were given as to the spatial deployment or number of traps needed to give reasonably accurate and precise information on weevil populations for management purposes.

# Cranberry White Grub

## *Phyllophaga anxia* (LeConte)

### Coleoptera: Scarabaeidae

Williamson, R. C. 2004. White grub (Coleoptera: Scarabaeidae) population density in relation to root damage to Fraser fir seedlings in transplant beds. Journal of Environmental Horticulture 22: 85–87.

**Objective**

To develop a damage threshold for *P. anxia* by relating larval density to root damage and seedling weight of Fraser fir, *Abies fraseri* (Pursh) Poir.

**Abstract**

White grubs (*Phyllophaga* spp.) is a widespread pest of the roots of many species of vascular plants. Larvae chew and girdle roots, impairing growth rates and easily killing plants. More specifically, cranberry white grub, *Phyllophaga anxia* (LeConte), is a pest of Christmas tree nursery stock in transplant beds.

Damage by second instar *P. anxia* on Fraser fir was investigated by experimentally manipulating densities of grubs and measuring the effect of increasing larval densities on root damage and plant weight. A density of approximately 31 larvae per $m^2$ (3–4 larvae per $ft^2$) resulted in significant root damage and a 50% reduction in seedling weight. Controls were recommended if the density of *P. anxia* larvae were at or above this threshold.

**Sampling Procedure**

Because this study manipulated grub densities experimentally, no details were given for a defined sample unit, the number of sample units to collect, or a specific procedure to collect them. The methodology of Ives and Warren (1965) for sampling white grubs (*Phyllophaga* spp.) could be used for this purpose. Briefly, remove all soil in a 30 by 30 cm surface area to the depth of 10 cm (a total volume of 9,000 $cm^3$) from the transplant bed. Pass portions of this soil sample one at a time through a screen to collect the grubs. Multiple samples of 9,000 $cm^3$ soil each should be taken from different areas of the transplant bed. Tally the cumulative number of white grubs found in all the soil samples and calculate the larval density per $m^2$ based on the total area sampled. Control is warranted if the density of white grubs averages 31 larvae or more per $m^2$ in a transplant bed.

**Notes**

Although *P. anxia* larvae were used specifically in this study, the author suggests that this threshold is useful for any *Phyllophaga* spp. larvae. Ives and Warren (1965) recommended including all white grubs found in the soil samples as the larvae are difficult to identify to species.

**Reference**

* Ives, W. G. H.; Warren, G. L. 1965.Sequential sampling for white grubs. Canadian Entomologist 97: 596-604.

# White Grubs

## *Phyllophaga* spp.

### Coleoptera: Scarabaeidae

Fowler, R. F.; Wilson, L. F. 1971. White grub populations, *Phyllophaga* spp., in relation to damaged red pine seedlings in Michigan and Wisconsin plantations (Coleoptera: Scarabaeidae). Michigan Entomologist 4: 23–28.

**Objective**

To predict seedling mortality of red pine, *Pinus resinosa* Soland., based on larval density of white grubs, predominantly comprised of *Phyllophaga* spp.

**Abstract**

White grubs (*Phyllophaga* spp.) are a widespread pest of the roots of many species of vascular plants. Larvae chew and girdle roots, impairing growth rates and easily killing young plants.

White grub populations were studied in red pine, *Pinus resinosa* Soland., plantations in national forests in the Great Lakes region. Root damage was accessed on seedlings and related to larval density using linear regression. Damage levels were positively related to larval density, particularly when separated by instar ($r^2 = 0.78$). This relationship is expressed in the following formula:

$$y = 0.94 + 2.30(1\text{-}e^{-0.03x})$$

where x = the feeding index and y = the damage index (modified from Johnston & Eaton 1939). The feeding index (FI) used in the above equation is $FI = [N1 + 2N_2 + 4N_3 + 8N_4]/n$ where $N_1$, $N_2$, etc. represent the number of larvae in instar 1, 2, 3, or 4, and n = the mean number of larvae sampled at the study site. The FI assumes that each instar eats twice as much as the previous instar. The damage index is defined as:

| Damage Score | Extent of injury to roots |
|---|---|
| 1 | No grub injury |
| 2 | ≤33% of fibrous roots damaged |
| 3 | 34–66% of fibrous roots damaged |
| 4 | 67–99% of fibrous roots damaged; some seedlings stripped of fibrous roots but some regrown root tips |
| 5 | 100% of fibrous roots destroyed or tap root severed above the fibrous roots |

The percentage of red pine seedlings damaged at the study site can also be predicted from the

feeding index using the equation $y = 5.34 + 65.41(1\text{-}e^{-0.04x})$, where x = the feeding index and y = the percentage of seedlings damaged. Finally, the damage index was positively related ($r^2 = 0.89$) to the percentage of damaged red pine seedlings and can be predicted using the equation $y = 1.08 + 0.03x$, where y = the damage index and x = the percentage of seedlings with damaged roots. This formula provides a reasonable damage estimate for *Phyllophaga* spp. larvae when >10% but <90% of the seedlings are damaged, without the need to actually score root damage on dug seedlings.

A threshold of 0.5 larvae per 0.09 $m^2$ or 0.03 $m^3$ soil has been suggested as a damage threshold for *Phyllophaga* spp. larvae, but the authors suggest this should be lowered. Based on their study, a density of 0.5 larvae per 0.03 $m^3$ would result in 16–34% seedling mortality in the subsequent growing season, including approximately 4% loss due to other mortality factors. A threshold of ≥0.25 larvae per 0.09 $m^2$ is suggested if seedling mortality should be ≤20%.

**Sampling Procedure**

Ideally damage estimates should be made before seedlings are planted or soon afterwards. Establish 4-5 parallel transects across the plantation. In the summer, sample larval densities by digging a 0.03 $m^3$ soil sample enclosed by a 30.5 x 30.5 cm metal quadrant. Take 4–6 soil samples evenly spaced along each transect. Sift each soil sample through a 0.64 cm mesh screen. Identify larvae to *Phyllophaga* spp. larvae and tally the number of each instar present. Calculate the mean density of larvae per 0.03 $m^3$ soil.

Calculate the Feeding Index (FI) using the equation $FI = [N1 + 2N_2 + 4N_3 + 8N_4]/n$ where $N_1$, $N_2$, etc. represent the number of larvae in instar 1, 2, 3, or 4, and n = the mean number of larvae sampled at the study site. Predict the percentage of damaged red pine seedlings using the equation $y = 5.34 + 65.41(1\text{-}e^{-0.04x})$, where x = the feeding index and y = the percentage of seedlings damaged. Predict the extent of larval damage using the equation $y = 0.96 + 2.07(1\text{-}e^{-2.92}x)$, where x = the damage index and y = the mean density of *Phyllophaga* spp. larvae per 0.03 $m^3$ soil. Consult Table 1 to relate the calculated damage index to the predicted extent of injury to seedling roots.

If seedlings are dug and examined for feeding injury, the damage index can be predicted using the equation $y = 1.08 + 0.03x$, where y = the damage index and x = the percentage of seedlings with damaged roots. Sample 20–90 seedlings near each location where the soil was sampled for *Phyllophaga* spp. larvae.

**Reference**

Johnston, H. R.; Eaton, C. B. 1939. White grubs in forest nurseries of the Carolinas. Rep. E-486. U.S. Department of Agriculture, Bureau of Entomology and Plant Quarantine; 9 p.

# White Pine Weevil on Spruce

## *Pissodes strobi* (Peck)

### Coleoptera: Curculionidae

Alfaro, R. I. 1995. A sequential sampling system for the white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae). Journal of the Entomological Society of British Columbia 92: 39–43.

Alfaro, R. I. 1998. White pine weevil, *Pissodes strobi*: risk factors, monitoring and management. Tech. Transfer Note No. 4. Victoria, B.C.: Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre; 4 p.

**Objective**

To describe a sequential sampling system for *P. strobi* damage in plantation-grown spruce and review risk factors for this pest.

**Abstract**

White pine weevil, *Pissodes strobi* (Peck), is an important pest of a number of spruces, *Picea* spp., and pines, *Pinus* spp., in North America. Larvae tunnel down through the terminal leader of host trees, destroying the apical dominance of the shoot. The resulting tree deformation reduces the commercial value of sawlogs and landscape trees. Stands of even-aged spruce trees, such as plantations or natural regeneration following a fire, are susceptible to attack when juvenile and are most susceptible when 10 and 30 years old. Attack by *P. strobi* typically does not kill older trees, but does reduce their growth rate.

A sequential sampling plan was developed to rapidly determine infestation levels of *P. strobi* in spruce. The method requires a maximum of 60 randomly selected spruce trees. All 60 trees must be sampled if the infestation ranges between 10–19%, but only 19 trees need be sampled sequentially to classify a stand as lightly infested. Infestations are considered light, moderate and severe if <10, 10–19, and ≥20% of the trees sampled have weevils. Young trees with accessible terminal leaders should be treated when warranted by pest pressure. Susceptibility of spruce stands to *P. strobi* can be minimized through careful selection of stand location, stand composition, and frequent monitoring when trees are young (≤30 years old).

**Sampling Procedure**

Sequential sampling plan (described in Alfaro 1995, 1998): Divide the stand into a grid (e.g., a 5 m X 5 m grid) with assigned X, Y coordinates. Randomly select 60 X, Y coordinate points from the grid; a random number generator would be useful for this. Do not duplicate numbers or replace them in the selection process. Number each coordinate point sequentially

from 1 to 60 in the order that they were selected.

Divide the list of coordinate points into 1–30 and 31–60. Beginning with 1–30, check the tree closest to the coordinate point in the stand for weevil damage. Move through the stand in an efficient manner and tally the number of trees with weevil damage; coordinant points do not need to be assessed sequentially. Plot the cumulative number of infested trees against the cumulative number of trees sampled using Fig. 1. If the slope of the plotted data crosses either decision line, then the stand can be classified as either lightly or severely infested without additional sampling. If the slope does not cross a decision line and remains in the moderate zone, continue sampling the second group of 31–60 coordinate points. After sampling the entire second group, continue plotting the cumulative tally of infested trees against the cumulative number of trees sampled in the same manner. The stand can then be classified as having a light, moderate, or severe infestation after sampling a maximum of 60 trees in this manner.

| Stand classification | Level of observed damage |
|---|---|
| Light | <10% |
| Moderate | Between 10 and 19% |
| Severe | ≥20% |

Risk factor evaluation (Alfaro1998): Known risk factors for *P. strobi* include even-aged stands of spruce, host species with long leaders, spruce stands between 10 and 30 years old, and thinned stands with reduced density. Sites that accumulate more than 785 degree days above 7.2°C over a year also encourage weevil attack. Dominant deciduous trees can shade plantings, reducing the risk of attack.

**Note**
This sampling plan was developed for spruce trees and may not be applicable for pines attacked by *P. strobi*.

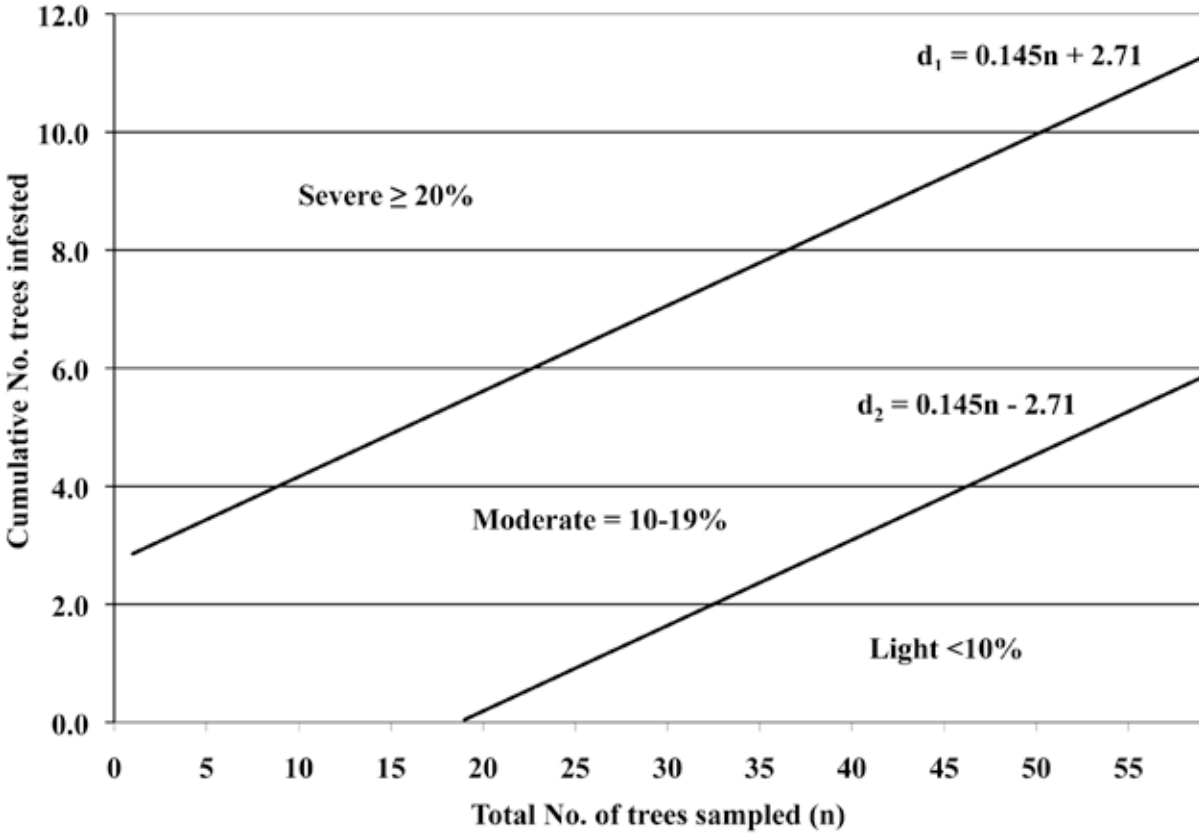


Figure 1. Parallel decision lines for a sequential sampling system for the white pine weevil, Pissodes strobi (Alfaro 1995).

**Figure 1 reprinted with permission from the author, granted April 6, 2009.**

# Pissodes Terminal Weevils

## White Pine Weevil, *Pissodes strobi* (Peck)
## Lodgepole Terminal Weevil, *Pissodes terminalis* Hopkins
## Coleoptera: Curculionidae

Fletcher, V. E. 1986. Development of sampling guidelines for estimating the proportion of weeviled trees on a plantation (plus errata). Forest Service Internal Rpt. PM-PB-18. Victoria, B.C.: British Columbia Ministry of Forests; 19 p.

**Objective**

To estimate the density of leaders damaged by *P. strobi* and *P. terminalis* at the 80 and 95% confidence levels in coastal plantations of Sitka spruce trees in British Columbia.

**Abstract**

White pine weevil, *Pissodes strobi* (Peck), is an important pest of a number of spruces, *Picea* spp., and pines, *Pinus* spp., in North America. Larvae tunnel down through the terminal leader of host trees, destroying the apical dominance of the shoot and destroying two years' growth. The resulting tree deformation reduces the commercial value of sawlogs and landscape trees. Stands of even-aged spruce trees, such as plantations or natural regeneration following a fire, are susceptible to attack when juvenile and are most susceptible between 10 and 30 years old. Attack by *P. strobi* typically does not kill older trees, but does reduce their growth rate. The related lodgepole terminal weevil, *Pissodes terminalis* Hopkins, produces similar damage in current-year growth.

Systematic sampling of trees in plantation rows provides an estimation of the percentage of trees attacked by *P. strobi* and *P. terminalis*. Systematic sampling offers the benefits of uniformly covering the plantation while detecting random and aggregated attacks. Sampling guidelines were developed for *Pissodes* spp. in Sitka spruce based on visual observation of terminal damage along set transects across a plantation. Managers can use this sampling scheme to determine the extent of an infestation before applying a residual insecticide in the spring when adults are feeding but before oviposition occurs, or to evaluate the efficacy of chemical application.

**Sampling Procedure**

Use Table 6 to determine the sample size (number of transects) needed given a required bound on the error of estimation and a set confidence interval of 80 or 95%. Twenty transects per plantation is a general recommended guideline. Determine a "transect interval" by dividing the total number of rows at the plantation by the number of transects required. If the plantation has 150 rows and 20 transects are desired, then the resulting transect interval is

8 after rounding up. Randomly choose a number between 1 and 8 as a starting row, such as 5. Set the first transect at row 5, the next at row 13, then rows 21, 29, etc.

Walk along transects and record the number of healthy trees and trees with Pissodes spp. damage on rows to either side. Ignore dead trees or damage from previous years. If little brush is present across the plantation, the observer can survey two rows on either side while walking down each transect. Transects may represent 1, 2, or 4 rows of trees, but a similar number of trees should be surveyed on each transect. Calculate the total number of trees with leader damage and the total number of trees observed from all transects. Estimate the average percentage of infested trees by dividing the cumulative number of trees observed with damage by the cumulative number of observed trees and multiplying by 100.

**Notes**

This is a preliminary sampling plan that should be used with the understanding that it could be improved with additional data. Furthermore, the plan was developed for spruce trees and may not be applicable for pines attacked by *P. strobi* or *P. terminalis.*

Table 6. Sample size calculations for estimating proportion of infested trees. Between transect variation ( $S^2 = 200$) estimated from previous field data.

| Bound on Error of Estimation | No. of Transects in Population | Average Transect Size (no. of trees) | No. of Transects Required (sample size) |
|---|---|---|---|
| | 80% Confidence Limits | | |
| 0.10 | 100 | 100 | 3 |
| 0.10 | 150 | 100 | 3 |
| 0.10 | 200 | 100 | 3 |
| 0.05 | 100 | 100 | 12 |
| 0.05 | 150 | 100 | 12 |
| 0.05 | 200 | 100 | 12 |
| | 95% Confidence Limits | | |
| 0.10 | 100 | 100 | 7 |
| 0.10 | 150 | 100 | 8 |
| 0.10 | 200 | 100 | 8 |
| 0.05 | 100 | 100 | 24 |
| 0.05 | 150 | 100 | 26 |
| 0.05 | 200 | 100 | 28 |

Table 6 was modified to reflect the changes made in the Errata for this publication.
**The table is reproduced with the permission of the Forest Establishment Officer, Ministry of Forests and Range, Victoria, BC, granted May 6, 2008.**

# Spruce Gall Midge

## *Mayetiola piceae* (Felt)

### Diptera: Cecidomyiidae

Brandt, J. P. 2000. A sequential sampling plan for classification of damage caused by spruce gall midge (*Mayetiola piceae* [Felt]). Forest Management Note 65. Edmonton, Alberta, Canada: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre; 7 p.

**Objective**

To develop a sequential sampling plan for classifying *M. piceae* damage on white spruce as light, moderate, or severe.

**Abstract**

The spruce gall midge, *Mayetiola piceae* (Felt), is a periodically severe pest of white spruce, *Picea glauca* (Moench) Voss, in Canada and the northern U.S. Larvae bore into new shoots, causing a noticeable gall in as little as 10 days. Damage by *M. piceae* is seen as reduced growth, deformation, and eventual mortality of twigs. Very little is known about *M. piceae*, except for work published by Felt (1926) and Smith (1952). A sequential sampling plan was devised to classify populations into categories based on the number of galled current-year shoots.

The type I and II errors for sequential sampling were set at 10% such that there was a 1 in 10 chance that the classification was inappropriate. Populations of *M. piceae* were classified as light, moderate and severe if the mean number of galled current-year shoots per branch was ≤3, 4 to 16, and ≥24, respectively. At least 28 uninfested trees must be sampled to classify a site as having light damage, but sites could be classified as having severe damage after sampling fewer trees.

**Sampling Procedure**

Sample white spruces when galls are visible on current-year shoots. Randomly select stands from the area of concern, as well as trees from the stands of concern and branches from sample trees. Select only dominant or co-dominant trees along a transect with a random start location. From each tree along the transect, remove one branch from each of the lower, middle, and upper crown. Also remove an additional branch from a crown level that is selected at random.

Average the number of galls among the four branches and reference Table I. If the cumulative number of galled current year shoots remains within the continue sampling bands, select

the next tree and sample four branches as described above. Add this total to the previous one and reference Table I. Stop sampling if the cumulative total is outside of the continue sampling bands and classify populations appropriately. If the cumulative total remains within the continue sampling band that delineates the light and moderate population levels after sampling 300 trees, classify populations as light-moderate. If the count remains within the continue sampling band that delineates the moderate and severe population levels after counting 2,000 galls, classify populations as moderate-severe.

**Note**

This plan was not validated with data from other areas of Canada or the USA and should be used with caution until it has been validated for other regions. Although sequential sampling can substantially save time and effort, the plan outlined here quickly becomes labor intensive when *M. piceae* populations fall between the light to moderate ranges.

**References**

Felt, E. P. 1926. A new spruce gall midge (Itonidae). Canadian Entomologist 58: 229-230.

Smith, C. C. 1952. The life-history and galls of a spruce gall midge, *Phytophaga piceae* Felt (Diptera: Cecidomyiidae). Canadian Entomologist 84: 272-275.

**Table**

Table I. Decision values of the *M. piceae* sequential sampling plan. Counts are the accumulation of the average number of galls pooled from a four-branch sample per tree.

| Number of trees sampled | <Value = light population | | In between values= moderate population | | | >Value= severe population |
|---|---|---|---|---|---|---|
| 5 | - | Continue Sampling | - | - | Continue Sampling | 468 |
| 10 | - | | - | - | | 568 |
| 15 | - | | - | - | | 669 |
| 20 | - | | - | - | | 769 |
| 25 | - | | - | - | | 870 |
| 30 | 8 | | 202 | 263 | | 970 |
| 35 | 26 | | 220 | 337 | | 1071 |
| 40 | 43 | | 237 | 437 | | 1171 |
| 45 | 61 | | 255 | 538 | | 1272 |
| 50 | 78 | | 272 | 638 | | 1372 |
| 55 | 96 | | 290 | 739 | | 1473 |
| 60 | 113 | | 307 | 839 | | 1573 |
| 65 | 131 | | 325 | 940 | | 1674 |
| 70 | 148 | | 342 | 1040 | | 1774 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 75 | 166 | | 360 | 1141 | | 1875 |
| 80 | 183 | | 377 | 1241 | | 1975 |
| 85 | 201 | | 395 | 1342 | | 2076 |
| 90 | 218 | | 412 | 1442 | | 2176 |
| 95 | 236 | | 430 | 1543 | | 2277 |
| 100 | 253 | | 447 | 1643 | | 2377 |
| 105 | 271 | | 465 | 1744 | | 2478 |
| 110 | 288 | | 482 | 1844 | | 2578 |
| 115 | 306 | | 500 | 1945 | | 2679 |
| 120 | 323 | | 517 | 2045 | | 2779 |
| 125 | 341 | | 535 | 2146 | | 2880 |
| 130 | 358 | | 552 | 2246 | | 2980 |
| 135 | 376 | | 570 | 2347 | | 3081 |
| 140 | 393 | | 587 | 2447 | | 3181 |
| 145 | 411 | | 605 | 2548 | | 3282 |
| 150 | 428 | | 622 | 2648 | | 3382 |
| 155 | 446 | Continue Sampling | 640 | 2749 | Continue Sampling | 3483 |
| 160 | 463 | | 657 | 2849 | | 3583 |
| 165 | 481 | | 675 | 2950 | | 3684 |
| 170 | 498 | | 692 | 3050 | | 3784 |
| 175 | 516 | | 710 | 3151 | | 3885 |
| 180 | 533 | | 727 | 3251 | | 3985 |
| 185 | 551 | | 745 | 3352 | | 4086 |
| 190 | 568 | | 762 | 3452 | | 4186 |
| 195 | 586 | | 780 | 3553 | | 4287 |
| 200 | 603 | | 797 | 3653 | | 4387 |
| 205 | 621 | | 815 | 3754 | | 4488 |
| 210 | 638 | | 832 | 3854 | | 4588 |
| 215 | 656 | | 850 | 3955 | | 4689 |
| 220 | 673 | | 867 | 4055 | | 4789 |
| 225 | 691 | | 885 | 4156 | | 4890 |
| 230 | 708 | | 902 | 4256 | | 4990 |
| 235 | 726 | | 920 | 4357 | | 5091 |
| 240 | 743 | | 937 | 4457 | | 5191 |
| 245 | 761 | | 955 | 4558 | | 5292 |
| 250 | 778 | | 972 | 4658 | | 5392 |
| 255 | 796 | | 990 | 4759 | | 5493 |
| 260 | 813 | | 1007 | 4859 | | 5593 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 265 | 831 | Continue Sampling | 1025 | 4960 | Continue Sampling | 5694 |
| 270 | 848 | | 1042 | 5060 | | 5794 |
| 275 | 866 | | 1060 | 5161 | | 5895 |
| 280 | 883 | | 1077 | 5261 | | 5995 |
| 285 | 901 | | 1095 | 5362 | | 6096 |
| 290 | 918 | | 1112 | 5462 | | 6196 |
| 295 | 936 | | 1130 | 5563 | | 6297 |
| 300 | 953 | | 1147 | 5663 | | 6397 |

Table generated from equations listed in Figure 2 of the original publication.

# Jeffrey Pine Needle Miner

## *Coleotechnites* sp.

### Lepidoptera: Gelechiidae

Unruh, T. R.; Luck, R. F. 1982. Comparison of two sampling methods for the Jeffrey pine needle miner, *Coleotechnites* sp. (Lepidoptera: Gelechiidae) in southern California. Canadian Entomologist 114: 605-615.

**Objective**

To propose a sampling plan for *Coleotechnites* sp.

**Abstract**

Jeffrey pine needle miner, *Coleotechnites* sp., is an aesthetic pest and stressor of Jeffrey pine, *Pinus jeffreyi* Grev. and Balf., in California. The caterpillars feed inside all needles older than the current year. Sporadic outbreaks may occur with severe defoliation and growth reduction. Often very little mortality is caused by this pest but secondary pests, such as the Jeffrey pine beetle, *Dendroctonus jeffreyi* Hopkins, and the California flatheaded borer, *Melanophia californica* Van Dyke, can attack and kill trees stressed by Jeffrey pine needle miner.

No information was previously available on intra- and inter-tree distribution of Jeffrey pine needle miner, therefore two sampling plans were developed for this pest. One plan was developed from the component of variance technique (Cochran 1963; Southwood 1978) and the other from the mean crowding relationship (Kuno 1976). The mean crowding technique was recommended over the component of variance technique because it requires no assumptions about the population distribution of the insect and because it also is easily adapted to sequential sampling techniques. Sampling 90 tips (1 tip per tree) or 30 tips (6 tips per tree) was found to give good estimates of population density at a site at the 10% level of precision. For integrated pest management of *Coleotechnites* sp., additional research is needed to relate population estimates to resulting levels of defoliation by this pest.

**Sampling Procedure**

The upper crown of *P. jeffreyi* contained more currently mined needles than either the middle or lower crown. The majority of current mines were found in fully-grown needles ≤4 years old. Refer to Table III to determine the number of trees to sample based on the number of tips sampled per tree. Randomly select 15- to 40-cm branch tips from the upper third of the live crown of *P. jeffreyi*. Trees should be between 6–10 m tall. Count the number of needles with current mines containing live Coleotechnites sp. larvae, pupae, or parasitoids. Average counts among trees if sampling 1 tip per tree. Average counts among tips if sampling >1 tip

per tree and then average the estimates among trees.

**Notes**

The 10% level of precision is usually intended for detailed studies where large sample sizes are required. The 25% level of precision is more appropriate for management purposes, and can be calculated by the following equation:

$$N = \left[ \frac{1}{n} \left[ \frac{\alpha + 1}{m} + \frac{\beta_1(\beta_2 - 1)}{\beta_2} \right] + \frac{\beta_1 - \beta_2}{\beta_2} \right] \Big/ D_0^2$$

where N = the number of trees required for a given value of precsion, n = sample size of tips per tree, m = mean, a = intercept, $b_1$ = the slope of the regression of mean on mean crowding for the composite population, $b_2$ = the slope of the mean on mean crowding for trees, and $D^2_0$ = (Var m)/$m^2$ (Kuno 1976). Change the value of the variable $D^2_0$ from 0.1 to 0.25, or any other desired level of precision. The other variables in this equation can be taken from Table III. See the original publication for additional information.

To be applicable over a larger geographic area and with larger and/or smaller trees, sampling additional stands/trees is necessary. Consequently, please use this plan with caution.

**References**

Cochran, W. G. 1963. Sampling techniques, 2nd ed. New York: John Wiley and Sons, 413 p.

Kuno, E. 1976. Multistage sampling for population estimation. Researches on Population Ecology 18: 39-56.

Southwood, T. R. E. 1978. Ecological methods with particular reference to the study of insect populations, 2nd ed. London: Chapman and Hall; 524 p

## Table

Table III. sizes necessary (number of trees at a rate of n tips per tree) to estimate the mean density of needles infested with the Jeffrey pine needle miner with 10% precision along with the parameters required for the mean crowding technique. Parameters for the mean crowding technique are derived from each plot (A), and from the plots pooled (B).

| | | | | | | | | n= | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plot | Mean | Mean crowding (m*) | Intercept (α) | $\beta_1$ | $\beta_2$ | $r^2$ | 1 | 2 | 3 | 6 | 15 | 30 |
| | | | | | **A** | | | | | | | | |
| Raw | Snow Valley | 32.8 | 53.2 | 5.28 | 1.45 | 1.13 | 0.957 | 65 | 47 | 41 | 35 | 31 | 30 |
| | Erwin Lake | 29.4 | 57.4 | -0.18 | 1.96 | 1.62 | 0.846 | 99 | 60 | 47 | 34 | 27 | 24 |
| | Big Bear City | 50.9 | 84.8 | 8.60 | 1.50 | 1.18 | 0.940 | 69 | 48 | 41 | 34 | 30 | 28 |
| | | | | | **B** | | | | | | | | |
| Raw | Snow Valley | 32.8 | - | 6.26 | 1.512 | 1.2302 | 0.86 | 74 | 49 | 41 | 32 | 27 | 25 |
| | Erwin Lake | 29.4 | - | 6.26 | 1.512 | 1.2302 | 0.86 | 77 | 50 | 41 | 33 | 26 | 24 |
| | Big Bear City | 50.9 | - | 6.26 | 1.512 | 1.2302 | 0.86 | 67 | 45 | 38 | 31 | 27 | 25 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

**Table III modified and reproduced with permission from the authors, granted April 2, 2009.**

# European Pine Shoot Moth

## *Rhyacionia buoliana* (Denis & Schiffermüller)

### Lepidoptera: Tortricidae

Gray, T. G.; Slessor, K. N.; Shepherd, R. F.; Grant, G. G.; Manville, J. F. 1984. European pine shoot moth, *Rhyacionia buoliana* (Lepidoptera: Tortricidae): identification of additional pheromone components resulting in an improved lure. Canadian Entomologist 116: 1525–1532.

**Objective**

To improve the pheromone lure for *R. buoliana* through the addition of other components.

**Abstract**

European pine shoot moth, *Rhyacionia buoliana* (Denis & Schiff.), has become an important pest of two- and three-needle pines (*Pinus* spp.) in the Pacific Northwest, the Lake States, the upper Midwest, and northeastern USA, as well as in southern Canada. Red pine (*Pinus resinosa* Ait.) is heavily damaged by *R. buoliana*, but other susceptible hosts include Scotch pine (*Pinus sylvestris* L.), lodgepole pine (*Pinus contorta* Dougl.), and ponderosa pine (*Pinus ponderosa* Laws.) This insect primarily infests terminal shoots causing severe deformation and reduced growth.

Pheromone trapping is an important tool in monitoring populations of *R. buoliana*. The sex pheromone of *R. buoliana* was identified as *E*-9-dodecenyl acetate, but commercial preparations of the lure did not attract the expected numbers of males in the field. Additional research has identified a 97:3 ratio of *E*-9-dodecenyl acetate:E-9-dodecenol as a stronger lure than either virgin females or *E*-9-dodecenyl acetate alone. Dodecanol (0.03% or more) inhibited male moths in the absence of dodecyl acetate but had no effect when both *E*-9-dodecenyl acetate and *E*-9-dodecenol were present. Dodecyl acetate masked this inhibition when present at concentrations of 0.3% or greater.

Lures embedded in polyvinyl chloride rods performed better than lures loaded in rubber septa, possibly due to varying release rates from the septa. In contrast, pheromone release from the rods was constant.

**Sampling Procedure**

Construct triangular traps from 2-liter milk cartons so that the interior surface measures 695 $cm^2$. Coat the interior surface with an adhesive material. Insert in each trap a 2.5 x 3 mm diameter lure of polyvinyl chloride rod (5% by weight) containing a 97:3 ratio of E-9-dode-

cenyl acetate:E-9-dodecenol embedded separately. Hang traps on Scotch pines 2–4 m above ground and 20 m apart. Orient traps with one edge directed to the ground. Leave traps in place 4–9 days before servicing.

# European Pine Shoot Moth

## *Rhyacionia buoliana* (Denis & Schiffermüller)

### Lepidoptera: Tortricidae

Regan, R. P.; De Angelis, J. D.; Gredler, G. 1991. Predicting seasonal flight of European pine shoot moth (Lepidoptera: Tortricidae) in western Oregon. Environmental Entomology 20: 1403–1406.

**Objective**

To predict seasonal flight of *R. buoliana* in Oregon using degree-day accumulations.

**Abstract**

European pine shoot moth, *Rhyacionia buoliana* (Denis & Schiff.), has become an important pest of two- and three-needle pines (*Pinus* spp.) in ornamental settings in the Pacific Northwest, the Lake States, the upper Midwest, and northeastern USA, as well as in southern Canada.

Red pine (*Pinus resinosa* Ait.) is heavily damaged by *R. buoliana*, but other susceptible hosts include Scotch pine (*Pinus sylvestris* L.), lodgepole pine (*Pinus contorta* Dougl.), and ponderosa pine (*Pinus ponderosa* Laws.) This insect primarily infests terminal shoots causing severe deformation and reduced growth.

Currently, chemical control of *R. buoliana* is directed towards the adults in early summer, preferably before mating occurs, or against newly hatched larvae. Adult activity can be predicted by estimating pupal densities, with first flight occurring when populations consist of approximately 20% larvae and 80% pupae (Antonelli and Campbell 1985), or based on phenological observations of needle development on host trees. However, degree-day accumulation offers a less time-consuming and less laborious method of predicting adult activity than population sampling. Likewise, it may be more practical for nurseries growing many different cultivars with differing phenologies.

Cumulative trap catch of adult male *R. buoliana* (Y) was related positively to degree-day accumulation above a base temperature of -2.2˚C (X) ($Y = -267.8 + 0.162X$; $r^2 = 0.965$; $P > 0.001$). Insecticide applications could be timed to coincide with adult activity, as predicted by degree-day accumulations. However, optimal timing of insecticide application against adult *R. buoliana* remains to be developed, as populations in western Oregon are currently insufficient for testing.

**Sampling Procedure**

Monitor emergence of male *R. buoliana* using Pherocon II pheromone traps (Trécé, Inc., Salinas, CA). Bait traps using a 97:3 blend of E-9-dodecenyl acetate and E-9-dodecenyl alcohol (1% active ingredient) embedded as a controlled-release formulation in polyvinyl-chloride. Hang traps in the canopies of Scotch pine, lodgepole pine, or mugo pine at 1.5–2 m above ground. Space traps at least 25 m apart. Check traps three times a week beginning the second week of May until the end of July. Replace lures 3–4 times during the flight period.

Starting January 1, monitor degree-day accumulations above the base temperature of -2.2˚C. Use the following model to predict the cumulative male moth trap catch:

$Y = -267.8 + 0.162X$

where Y = percent cumulative trap catch of male *R. buoliana* between 5 and 95% and X = number of degree-days above -2.2˚C. Reference the table below for the predicted degree-day accumulations for 10, 50, and 90% trap catch.

| % Cumulative trap catch | Accumulated degree-days |
|---|---|
| 10% | 1,712 |
| 50% | 1,958 |
| 90% | 2,205 |

Land managers can time insecticide applications to coincide with adult activity as predicted by degree-day accumulations. However, optimal timing of insecticide application against adult *R. buoliana* has not been determined.

**Notes**

This model was developed in western Oregon and should be used with caution in other regions. Insufficient densities of *R. buoliana* occur in western Oregon to determine the optimal timing of chemical control for this pest.

**Reference**

Antonelli, A. L.; Campbell, R. L. 1985. European pine shoot moth. Washington State University College of Agriculture Extension Bulletin 1011.

# Nantucket Pine Tip Moth

## *Rhyacionia frustrana* (Comstock)

### Lepidoptera: Tortricidae

Malinoski, M. K.; Paine, T. D. 1988. A degree-day model to predict Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), flights in southern California. Environmental Entomology 17: 75–79.

**Objective**

To develop a degree-day model for *R. frustrana* flight periods in order to improve the timing of treatment applications in southern California.

**Abstract**

Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a common pest of young loblolly, *Pinus taeda* L., shortleaf, *P. echinata* Mill., and Virginia, *P. virginiana* Mill., pine plantations in the eastern USA. In southern California it prefers Monterey pine, *P. radiata* D. Don, which is grown as Christmas trees. Larval feeding can cause shoot mortality and tree deformity, reductions in height and volume growth, and occasional tree mortality. Young larvae are very small and can be difficult to sample on the foliage. Larvae tunnel into shoots, where they are protected from insecticide sprays, before shoot injury becomes apparent. The aesthetic value of pines grown as Christmas trees is high enough that current control practices for *R. frustrana* include preventive sprays based on calendar date.

A degree-day model (ºC) based on field data was developed to predict when early-instar *R. frustrana* would be feeding on Monterey pine foliage in Christmas tree plantations in southern California. This is when insecticide sprays are most effective in controlling *R. frustrana*. The model predicts that a mean total of 575 degree-days (575DD) accumulate between the capture of the first male in pheromone-baited traps and peak flight period. Lower and upper thresholds of 5.50º and 37.25ºC, respectively, are incorporated in the model to account for when development would cease due to lower and higher temperatures in California. Early instars are found feeding on foliage at 111DD after peak flight period, or at 686DD after the first moth is found in the pheromone-baited trap. Insecticide applications are most effective when applied at this time. Pheromone traps and degree-day monitoring should be conducted for each of the four flight periods of *R. frustrana* in southern California. Compared to current control practices for *R. frustrana*, using this model should reduce the number of insecticide sprays applied and identify when larvae are the most vulnerable to chemical control.

**Sampling Procedure**

Install delta traps baited with *R. frustrana* pheromone lures in early January. Hang traps on the outer canopy of Monterey pines 1.5–1.8 m above ground. Inspect traps daily for moth capture. Replace lures every 4 weeks. Four generations of *R. frustrana* occur in southern California and traps should be deployed prior to the start of each flight period. Replace traps as needed throughout the year.

Begin monitoring degree-day (ºC) accumulation at the start of each flight period, as indicated by when the first moth is found in the pheromone-baited traps. Do not include degree-days above the upper threshold of 37.25ºC or below the lower threshold of 5.50ºC. Expect peak flight to occur at 575DD after the capture of the first moth in the traps. Apply treatments against first instars 111DD after peak flight, or 686DD after the first moth is captured in the pheromone trap.

# Nantucket Pine Tip Moth

## *Rhyacionia frustrana* (Comstock)

### Lepidoptera: Tortricidae

Asaro, C.; Cameron, R. S.; Nowak, J. T.; Grosman, D. M.; Seckinger, J. O.; Berisford, C. W. 2004. Efficacy of wing versus delta traps for predicting infestation levels of four generations of the Nantucket pine tip moth in the southern United States. Environmental Entomology 33: 397-404.

**Objective**

To compare two different types of pheromone traps for efficient capture of *R. frustrana* and validate earlier models (Asaro and Berisford 2001) for predicting damage levels.

**Abstract**

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a common pest of young loblolly, *Pinus taeda* L., shortleaf, *P. echinata* Mill., and Virginia, *P. virginiana* Mill., pine plantations in the eastern USA. Larval feeding can cause shoot mortality and tree deformity, reductions in height and volume growth, increases in compression wood formation, and occasional tree mortality.

Two trap types (wing and delta traps) were evaluated in loblolly pine plantations in four southern states for efficacy in catching male *R. frustrana*. Wing traps were more useful at predicting tip moth density and tree damage than delta traps, especially for the first three tip moth generations ($r^2$ = 0.46 to 0.65). Average top whorl damage was related positively to average cumulative wing trap catch of the first ($y = 10.026 + 0.030x$; $r^2 = 0.53$), second ($y = 12.784 + 0.062x$; $r^2 = 0.44$) and third ($y = 11.747 + 0.217x$; $r^2 = 0.62$) generations. This trapping strategy validates the findings of Asaro and Berisford (2001) (see our review in this volume), who found that *R. frustrana* population density and percentage infested shoots was highly correlated with subsequent trap catch in the Georgia Piedmont. As such, the trapping strategy presented here should be useful for timing insecticide treatments when needed.

**Sampling Procedure**

Hang a Pherocon 1C wing trap (Trécé, Salinas, CA) 1–1.5 m high in the top whorl of four loblolly trees, or at the same height on steel conduit posts if trees are too short. Traps should be hung throughout the plantation, at least 30 m inside of the edge of the plantation and 60 m apart. Bait traps with rubber septa loaded with the two-component *R. frustrana* pheromone (Hill et al. 1981; Asaro et al. 2001). Replace baits monthly from January to mid-March/early April, the flight period of the first generation. Baits do not require replacement in subsequent

flight periods, which begin in May, June-July, and August. Traps should remain in place until the predicted spray date of the following generation. Refer to Fig. 3 to relate the average cumulative trap catch before the spray date for the first adult generation to the average percentage of shoots in the top whorl infested by the first brood generation.

**Notes**

The thresholds presented in Fig. 3 for low, moderate, and heavy damage levels are hypothetical and based on the experience and judgment of the authors. No damage categories have been established for *R. frustrana*, therefore use the levels presented here with caution.

**References**

Asaro, C.; Berisford, C. W. 2001. Predicting infestation levels of the Nantucket pine tip moth (Lepidoptera: Tortricidae) using pheromone traps. Environmental Entomology 30: 776-784.

Asaro, C.; Dalusky, M. J.; Berisford, C. W. 2001. Quantity and ratio of pheromone components among multiple generations of the Nantucket pine tip moth (Lepidoptera: Tortricidae) in Georgia and Virginia. Environmental Entomology 30: 1006-1011.

Hill, A. S.; Berisford, C. W.; Brady, U. E.; Roelofs, W. L. 1981. Nantucket pine tip moth, *Rhyacionia frustrana*: identification of two sex pheromone components. Journal of Chemical Ecology 7: 517-528.

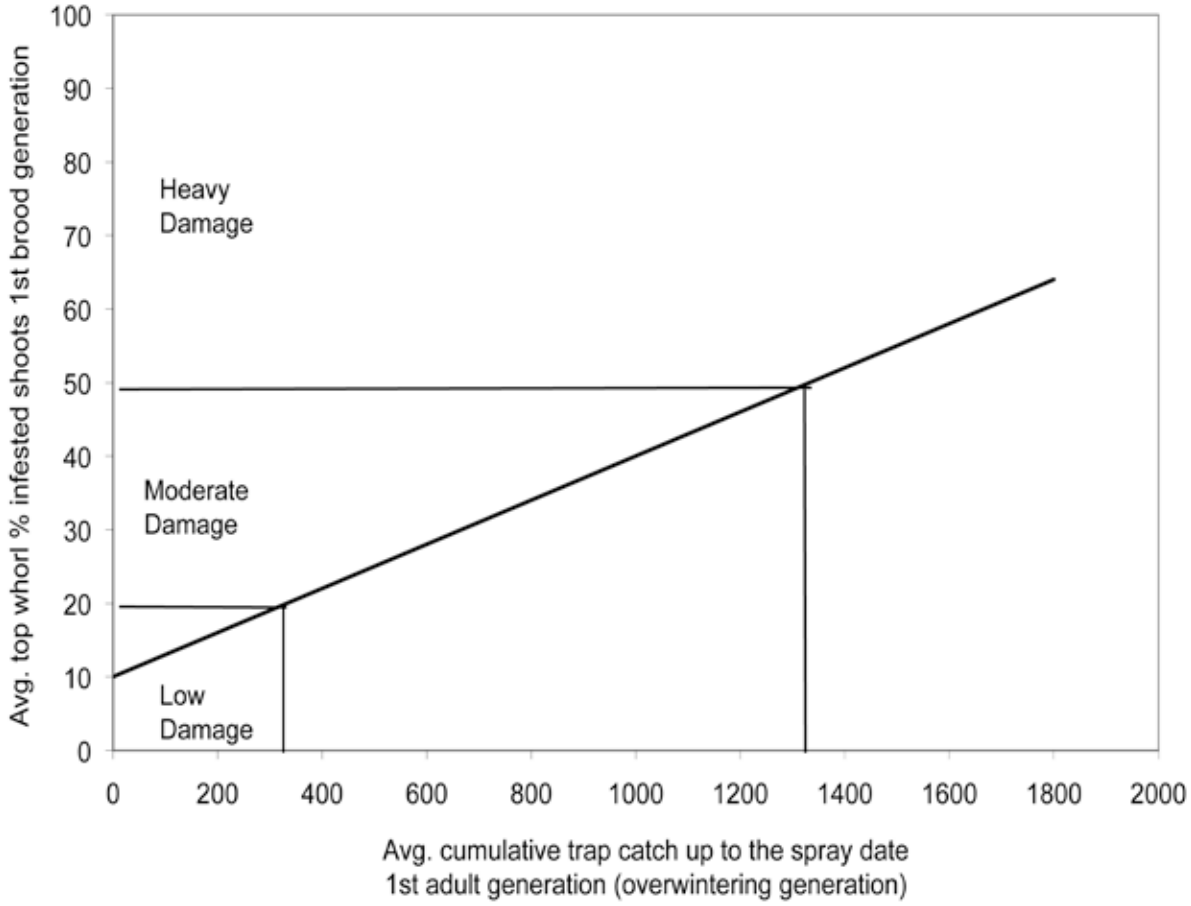


Fig 3. Diagrammatic illustration of how to use the wing trap regression model A to forecast subsequent damage levels (first generation brood) and make a decision regarding insecticide application. The cut-off values delineating low, moderate, and heavy damage are hypothetical and based on the experience and judgment of the authors.

**Figure 3 modified and reprinted with permission from Environmental Entomology, April 2, 2009.**

# Nantucket Pine Tip Moth

## *Rhyacionia frustrana* (Comstock)

### Lepidoptera: Tortricidae

Asaro, C.; Berisford, C. W. 2001. Predicting infestation levels of the Nantucket pine tip moth (Lepidoptera: Tortricidae) using pheromone traps. Environmental Entomology 30: 776-784.

**Objective**

To correlate trap catches of *R. frustrana* with population density and host damage in the Georgia Piedmont.

**Abstract**

Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a common pest of young loblolly, *Pinus taeda* L., shortleaf, *P. echinata* Mill., and Virginia, *P. virginiana* Mill., pine plantations in the eastern USA. Larval feeding can cause shoot mortality and tree deformity, reductions in height and volume growth, increases in compression wood formation, and occasional tree mortality. Research was conducted in the Georgia Piedmont over one to several years to correlate trap catch with population density and tree damage.

Hyperbolic curves best described the relationships between total trap catch and moth population density, and between trap catch and shoot damage, for one generation and the next. These relationships suggest that trap saturation may occur at very high densities of adult moths. However, relationships between trap catch of one generation to the density of subsequent generations and their damage had predictive values. Total trap catch of the first adult generation of *R. frustrana* was related positively to shoot damage produced by first generation brood ($y = 0.024x - 2.022$; $r^2 = 0.87$). Trap catch of the first generation was related positively to the density of the overwintering brood generation ($y = 2815.277x /(2.014 + x)$; $r^2 = 0.89$). Likewise, trap catch of the first generation was related positively to shoot damage caused by the overwintering brood generation ($y = 4660.129x /(61.730 + x)$; $r^2 = 0.82$). However, trap catch of the second generation gave only fair predictions of later population densities or host damage.

**Sampling Procedure**

Use Pherocon 1C wing traps (Trécé, Salinas, CA) with rubber septa loaded with *R. frustrana* pheromone. Select a 2-ha rectangular plot within a plantation. Set traps with one in each corner of the plot and one halfway along both of the two longest sides for a total of 6 traps per plot. Traps should be at least 30 m inside the edge of the plantation and apart from each

other. Replace baits weekly for maximum efficacy. Record the number of trapped males and empty traps or replace the bottoms every 3-5 days. Assume that a certain percentage of the total moths for a given emergence period will be trapped before the spray date. Spray dates for much of the southeastern USA can be predicted using degree-day accumulations (Fettig et al. 2000).

**Note**

The authors recommend use of this procedure with caution, as trap efficacy might be region-specific and validation may be required before widespread use is considered. While no damage threshold has been established for *R. frustrana*, the authors suggest that control is warranted when the cumulative trap catch within a plot exceeds 1,000 moths before the spray date, given that <40% infested shoots appears to limit host growth.

**Reference**

Fettig, C. J.; Dalusky, M. J.; Berisford, C. W. 2000. Nantucket pine tip moth phenology and timing of insecticide spray applications in seven southeastern states. Res. Pap. SRS-18. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station; 23 p.

# DEFOLIATING INSECTS

# Cottonwood Leaf Beetle

## *Chrysomela scripta* F.

### Coleoptera: Chrysomelidae

Fang, Y.; Hart, E. R. 2000. Effect of cottonwood leaf beetle (Coleoptera: Chrysomelidae) larval population levels on *Populus* terminal damage. Environmental Entomology 29: 43-48.

**Objective**

To relate density of *C. scripta* egg masses to defoliation levels on a hybrid poplar using a damage rating system.

**Abstract**

Cottonwood leaf beetle, *Chrysomela scripta* Fabricius, is an important pest of poplar and aspen, *Populus* spp., and willow, *Salix* spp., in North America. Larvae prefer to feed on young leaves and can produce significant defoliation. The second generation of *C. scripta* has fewer natural enemies and is less susceptible to abiotic factors, therefore it is more damaging than the first or third generations. Populus grown in plantations as a short-rotation woody crop is particularly susceptible to damage by *C. scripta* during the first 3 years when the trees produce abundant new growth. Reichenbacker et al. (1996) reported that approximately 75% defoliation in *Populus* reduced the above ground, root, and total biomass by approximately 33% after 2 years of defoliation.

A study was conducted on the relationship between larval density and resulting defoliation on the hybrid popular *Populus deltoides* Marsh. x *Populus nigra* L. var. 'Eugenei'in Iowa, U.S.A. For second-generation *C. scripta*, there was a significant relationship between the egg mass equivalent per actively growing terminal and the resulting defoliation on open trees ($R^2 = 0.8714$; $P = 0.0001$), as expressed by the equation $y = –0.91x^2 + 3.79x + 0.61$, where y = damage rating and x = egg mass equivalent per terminal. An egg mass equivalent was defined as an egg mass or a newly eclosed larval clutch. When the density of egg mass equivalents was >1 per leaf terminal, the expected level of defoliation was >75%. However, the relationship between beetle densities of <1 egg mass equivalent per terminal and expected level of defoliation was not as well defined.

Based on these data, the authors concluded that defoliation by *C. scripta* should reduce biomass by <33% over the first two years of plantation establishment as egg mass densities increase from 0 to 1 per terminal in each generation. In addition, the damage rating standard developed in this study offers a quick and reliable method of determining the defoliation level present in a stand comparable to measuring percent defoliation.

**Sampling Procedure**

Randomly sample actively growing leaf terminals of hybrid *Populus* spp. during peak oviposition by the second generation of *C. scripta*, in late June-early July in Iowa. An actively

growing terminal has new growth with leaves in good health and a leaf plastochron index (LPI) of 0–8. Briefly, designate the terminal, expanding leaf with a blade length nearest to 3 cm as LPI = 0. Designate the next leaf counted consecutively down the stem from apex to base as LPI = 1. Continue to number the leaves in this manner until a total of 8 leaves have been selected (as described in Fang et al. 2002). Examine each of these 8 leaves in the terminal and calculate the mean egg mass or newly eclosed larval clutch per terminal, referred to as the egg mass equivalent by the authors. Use the following equation to predict the expected damage rating from second-generation *C. scripta*:

$$y = -0.91x^2 + 3.79x + 0.61$$

where y = damage rating and x = egg mass equivalent per terminal. Relate the expected damaging rating to the leaf plastochron index using the following table:

| Damage Rating | Damage on Leaf Plastochron Index (LPI) |
|---|---|
| 0 | No feeding on LPI 0-8 |
| 1 | Light feeding, sample feeding only on LPI 0–8; <33% of LPI 0–8 consumed |
| 2 | Light to moderate feeding; 33–50% of LPI 0–8 consumed |
| 3 | Moderate to heavy feeding; approx. 50–75% of LPI 0–8 consumed; main leader intact |
| 4 | Heavy feeding; >75% of LPI 0–8 consumed; main leader and terminal bud heavily damaged |

In general, consider treating for *C. scripta* when the density of egg masses or larval clutches is >1 per leaf terminal, as the expected level of defoliation associated with this density is >75%.

**Notes**

The authors did not specify how many trees or how many terminals per tree should be sampled. Managers may want to review the economic injury level determined for second-generation *C. scripta* on 2-year old *Populus deltoides* Marsh. X *Populus nigra* L. var. 'Eugenei' (Fang et al. 2002), also included in this volume.

**References**

# Fang, Y.; Pedigo, L. P.; Colletti, J. P.; Hart, E. R. 2002. Economic injury level for second-generation cottonwood leaf beetle (Coleoptera: Chrysomelidae) in two-year-old Populus. Journal of Economic Entomology 95: 313-316.

Reichenbacker, R. R.; Schultz, R. C.; Hart, E. R. 1996. Artificial defoliation effect on Populus growth, biomass production, and total nonstructural carbohydrate concentration. Environmental Entomology 25: 632-642.

# Cottonwood Leaf Beetle

## *Chrysomela scripta* F.

### Coleoptera: Chrysomelidae

Fang, Y.; Pedigo, L. P.; Colletti, J. P.; Hart, E. R. 2002. Economic injury level for second-generation cottonwood leaf beetle (Coleoptera: Chrysomelidae) in two-year-old *Populus*. Journal of Economic Entomology 95: 313-316.

**Objective**

To develop an economic injury level (EIL) for the poplar hybrid, *Populus deltoides* Bartr. ex. Marsh x *Populus nigra* L. (*Populus* var. 'Eugenei'), based on the relationship between the density of *C. scripta* egg masses and subsequent defoliation by larvae.

**Abstract**

Cottonwood leaf beetle, *Chrysomela scripta* Fabricius, is an important pest of poplar in North America. Larvae prefer to feed on young cottonwood leaves, causing significant defoliation in the absence of insecticide use. The second generation of *C. scripta* has fewer natural enemies and is less susceptible to abiotic mortality factors, therefore it is more damaging than the first or third generations. *Populus* grown in plantations as a short-rotation woody crop is particularly susceptible to damage by *C. scripta* during the first 3 years, when the trees produce abundant new growth. Reichenbacker et al. (1996) reported that defoliation levels approaching 75% of Leaf Plastochron Index 0–8 of actively growing terminals in 2-year-old *Populus* reduced the above ground, root, and total biomass by approximately 33%.

Fang and Hart (2000) found that increasing numbers of egg masses per terminal shoot (X) was related positively to the percent defoliation (Y) ($Y = 68.13X + 6.31$, $r^2 = 0.89$) produced by second-generation *C. scripta* attacking 2-year-old poplars. This equation, along with the findings of Reichenbacker et al. (1996) and calculations of market value and management costs per hectare, was used to develop EIL values for second-generation *C. scripta* on hybrid poplar in central Iowa. Resulting EIL values varied from 0.2 to 0.9 egg masses per actively growing terminal shoot, depending on market value and management costs per hectare. Prior to this publication, no EIL existed for *C. scripta* and managers applied pesticides whenever they felt populations required control measures.

**Sampling Procedure**

Determine the market value per kg of the crop. The market value of *Populus* may differ depending on if the crop is grown for pulp or fuel biomass. Determine the management costs of the crop per hectare (cost of insecticide and the application method used). Use Table 1 to

determine the number of egg masses per actively growing terminal representing the EIL for second-generation *C. scripta* with regard to market value and management costs.

During peak oviposition by first generation females (late June-early July in central Iowa), randomly select 30 trees with actively growing terminals (Fang and Hart 2000). Actively growing terminals should have healthy new growth classified as 0¬–8 on the Leaf Plastrochron Index (LPI). For *Populus* spp., designate the terminal, expanding leaf with a blade length nearest to 3 cm as LPI = 0. Designate the next leaf counted consecutively down the stem from apex to base as LPI = 1. Continue to number the leaves in this manner until a total of 8 progressively older leaves have been selected. Determine the mean number of second-generation *C. scripta* egg masses per actively growing terminal (Fang and Hart 2000; see our review in this volume). Control measures are warranted if the average egg mass density per actively growing terminal exceeds the chosen EIL value from Table 1.

## Table

Table 1. Economic injury level (egg masses per actively growing terminal) for the cottonwood leaf beetle, second generation, in 2-yr-old *Populus* var. Eugenei.

| Market Value, $/kg | Management cost $/ha | | | | | |
|---|---|---|---|---|---|---|
| | 25 | 26 | 27 | 28 | 29 | 30 |
| 0.02 | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 |
| 0.03 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 |
| 0.04 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 |
| 0.05 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| 0.06 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| 0.07 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |



## Notes

The economic threshold was set as equal to the EIL in this study, therefore control measures should be applied as soon as the average egg mass density per actively growing terminal exceeds the chosen EIL value. The EIL values listed here were determined specifically for 2-year old *Populus* var. 'Eugenei' grown in Iowa. These EIL values may not be suitable for different species or hybrids of *Populus*, for different age classes, or for *Populus* var. 'Eugenei' grown in other regions. Further research is needed to determine EIL values for older stands of this hybrid and for other generations of *C. scripta*. Close monitoring of the *C. scripta* population is needed to ensure that only the second generation is sampled, and not the first or third generations.

**References**

# Fang, Y.; Hart, E. R. 2000. Effect of cottonwood leaf beetle (Coleoptera: Chrysomelidae) larval population levels on *Populus* terminal damage. Environmental Entomology 29: 43-46.

Reichenbacker, R. R.; Schultz, R. C.; Hart, E. R. 1996. Artificial defoliation effect on *Populus* growth, biomass production, and total nonstructural carbohydrate concentration. Environmental Entomology 25: 632-642.

# Elm Leaf Beetle

## *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller)

### Coleoptera: Chrysomelidae

Dahlsten, D. L.; Rowney, D. L.; Tait, S. M. 1994. Development of integrated pest management programs in urban forests: the elm leaf beetle (*Xanthogaleruca luteola* (Müller)) in California, USA. Forest Ecology and Management 65: 31-44.

**Objective**

To develop a pest management program for *P. luteola* in stands of urban elms based on degree-day accumulation above 11°C.

**Abstract**

Elm leaf beetle, *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller), is one of the most important pests of urban elms, *Ulmus* spp., in the U.S. and Canada. Larvae injure the host tree by skeletonizing leaves.

An integrated pest management program for *P. luteola*, based on degree-day (DD) accumulation above 11°C, was developed for urban English elms (*Ulmus procera* Salisb.) in northern and central California. The authors were unable to develop a model predicting defoliation damage at the end of the season based on peak egg densities present in the spring. Each generation of *P. luteola* varies in its potential to defoliate elms and should be monitored separately. Egg masses on English elms should be sampled around 275DD and 870DD for the first and second generations, respectively. Presence-absence sampling of egg masses on 30-cm branch terminals is sufficient to determine if populations of *P. luteola* warrant control measures. If the proportion of samples with first generation egg masses is >0.45, then the expected damage should be >40% and in the acceptable range with an error probability of 10%. If the proportion of samples with second generation egg is >0.30, then the expected damage should be >40% and in the acceptable range with an error probability of 10%. The damage threshold of 40% was based on experience with homeowners and tree managers. Suggested sample sizes for differently sized stands are presented, and foliar treatment, if warranted, can be based on degree-day accumulation as well. If control is warranted, apply treatments when early instar larvae peak, around 350DD (base 11°C) for the first generation and 1,100DD (base 11°C) for the second generation. While management decisions for *P. luteola* can be timed using degree-day accumulation, elms should still be sampled to confirm the presence of this pest before treatment.

**Sampling Procedure**

Beginning March 1, monitor degree-day accumulation above the threshold temperature of 11˚C. Adult *P. luteola* activity peaks at around 250DD. Sample *P. luteola* egg masses on elms around 275DD and 870DD for first and second generations, respectively. Refer to Table 3 to determine the appropriate number of trees to sample within each stand, based on the total number of trees within a stand. Randomly sample 30-cm branch terminals from the lower crown of each tree in all four cardinal directions. Examine each branch terminal for the presence of egg masses and tally the number of terminals with egg masses present. If the proportion of samples with first generation egg masses present is >0.45, then the expected damage should be >40% and in the acceptable range with an error probability of 10%. If the proportion of samples with second generation egg masses present is >0.30, then the expected damage should be >40% and in the acceptable range with an error probability of 10%.

Consider applying foliar treatments if the proportion of samples with egg masses exceeds 0.45 or 0.30 for the first and second generation of *P. luteola*, respectively. If control is warranted, apply treatments when early instar larvae peak, around 350DD (base 11°C) for the first generation and 1,100DD (base 11°C) for the second generation.

**Notes**

This research was conducted in northern and central California and the degree-day accumulation correlated to oviposition and peak density of young larvae may not be valid in other areas. Use these recommendations with caution until validated in other regions.

Table

Table 3. Suggested sample size for elm leaf beetle egg clusters on English elm in different size stands[a]

| Total trees in stand | Trees Sampled | Samples per tree | Samples per segment | Total samples | Percentage of trees sampled |
|---|---|---|---|---|---|
| 3 | 3 | 40 | 5 | 120 | 100 |
| 4 | 4 | 32 | 4 | 128 | 100 |
| 5 | 5 | 32 | 4 | 160 | 100 |
| 6 | 6 | 24 | 3 | 144 | 100 |
| 7 | 6 | 24 | 3 | 144 | 86 |
| 8 | 7 | 24 | 3 | 168 | 88 |
| 9 | 8 | 16 | 2 | 128 | 89 |
| 10 | 8 | 16 | 2 | 128 | 80 |
| 11 | 8 | 16 | 2 | 128 | 73 |
| 12 | 8 | 16 | 2 | 128 | 67 |
| 13 | 8 | 16 | 2 | 128 | 62 |
| 14 | 8 | 16 | 2 | 128 | 57 |
| 15 | 8 | 16 | 2 | 128 | 53 |
| 16 | 9 | 16 | 2 | 144 | 56 |
| 17 | 9 | 16 | 2 | 144 | 53 |
| 18 | 9 | 16 | 2 | 144 | 50 |
| 19 | 9 | 16 | 2 | 144 | 47 |
| 20 | 9 | 16 | 2 | 144 | 45 |
| 21 | 9 | 16 | 2 | 144 | 43 |
| 22 | 10 | 16 | 2 | 160 | 45 |
| 23 | 10 | 16 | 2 | 160 | 43 |
| 24 | 10 | 16 | 2 | 160 | 42 |
| 25 | 10 | 16 | 2 | 160 | 40 |
| 26 | 10 | 16 | 2 | 160 | 38 |
| 27 | 10 | 16 | 2 | 160 | 37 |
| 28 | 10 | 16 | 2 | 160 | 36 |
| 29 | 10 | 16 | 2 | 160 | 34 |
| 30 | 10 | 16 | 2 | 160 | 33 |
| 40 | 12 | 16 | 2 | 192 | 30 |
| 50 | 15 | 16 | 2 | 240 | 30 |
| 60 | 15 | 16 | 2 | 240 | 25 |

[a]Criteria: (i) minimum of 128 branches; (ii) minimum of 25% of trees sampled; (iii) eight trees or more sampled if possible.

# Elm Leaf Beetle

## *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller)

### Coleoptera: Chrysomelidae

Dreistadt, S. H.; Dahlsten, D. L. 1989. Density-damage relationship and presence-absence sampling of elm leaf beetle (Coleoptera: Chrysomelidae) in northern California. Environmental Entomology 18: 849-853.

**Objective**

To develop a presence-absence sampling method for *P. luteola* in order to predict late season defoliation based on early season beetle density.

**Abstract**

The elm leaf beetle, *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller), is one of the most important pests of urban elms, *Ulmus* spp., in the U.S. and Canada. Larvae injure the host tree by skeletonizing leaves. A presence-absence sampling method was developed that could forecast late season defoliation of English elm, *Ulmus procera* Salisb., from the density of first generation eggs.

The proportion of 30 cm-long branch terminals (X) infested with at least one *P. luteola* egg was related positively to cumulative apparent damage (Y) of English elm ($Y = 0.97 + 17.42X$; $r^2 = 0.86$). The number of 30 cm-long branch terminals needed to estimate the proportion of terminals infested with at least one *P. luteola* egg at the 0.3 and 0.5 levels of fixed precision is given in Fig. 2. If the actual infestation level is 40% of terminals infested with at least one egg, then 20 and 4 branch terminals need to be sampled to meet the 0.3 and 0.5 levels of fixed precision, respectively.

**Sampling Procedure**

During the oviposition period of the first generation, randomly select 30-cm branch terminals from the lower third of the canopy on English elms. Take five inner and five outer samples from each aspect for a total of 40 branch samples per tree. Calculate the proportion of terminals infested with at least one *P. luteola* egg and compare to Fig. 2. If the proportion of samples infested exceeds the selected line representing the desired level of fixed precision, sampling can be stopped. Otherwise, continue sampling branch terminals and adjusting the proportion of terminals infested until the appropriate line is crossed. This proportion (X) can then be used in the equation, $Y = 0.97 + 17.42X$, to predict the cumulative apparent damage (Y) of English elm later in the season.

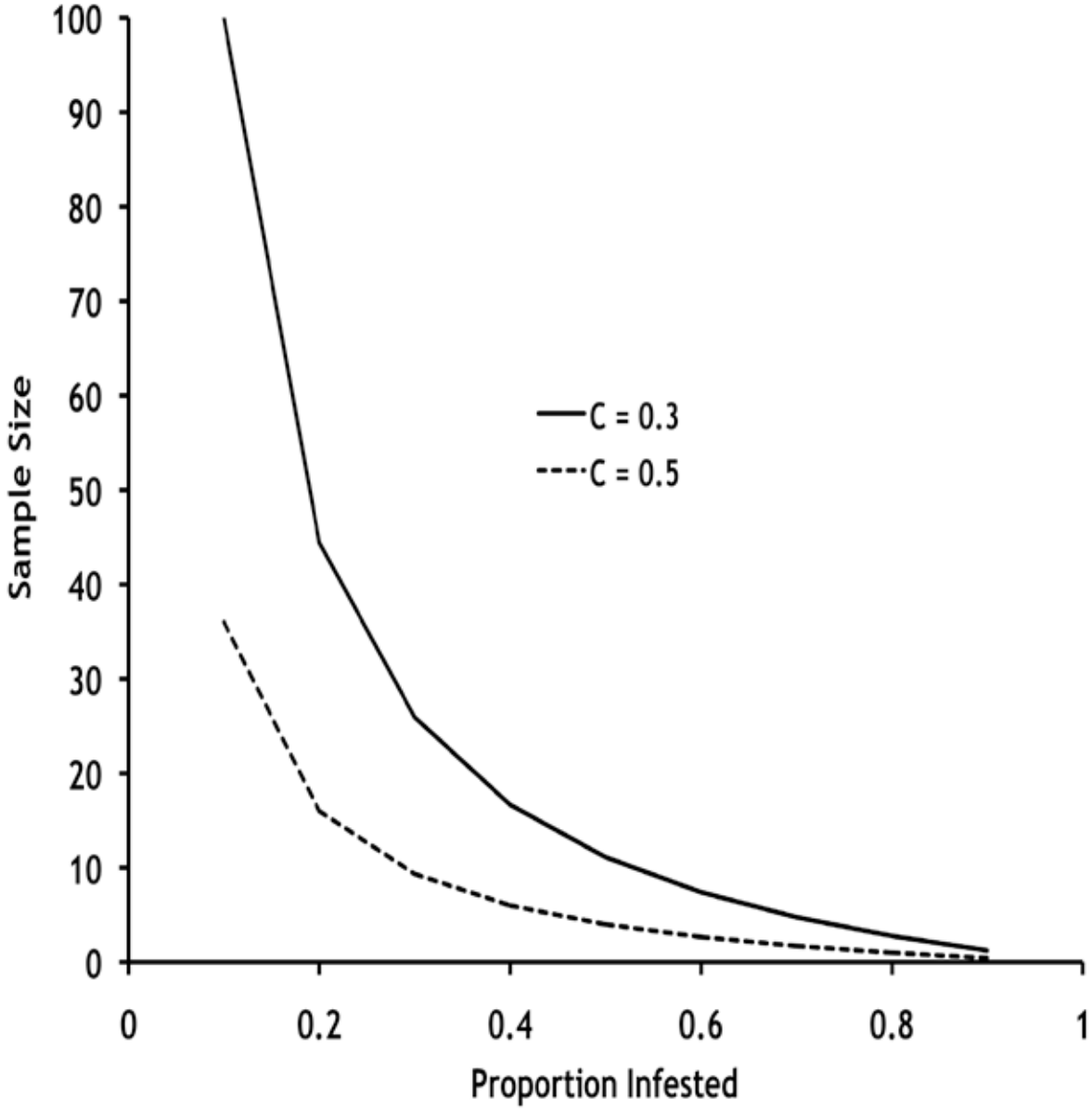


Fig. 2. Sample sizes needed at two levels of precision (C) to estimate the proportion of 30-cm branch terminals infested with eggs.

**Figure 2 modified and reproduced with permission from Environmental Entomology, granted April 2, 2009.**

**Notes**

The authors do not specify a minimum number of trees to sample, but sufficient trees should be sampled to get an average estimate of infestation levels before referencing Fig. 2. While no qualitative aesthetic injury has been set for *P. luteola*, >25% defoliation on English elm

was chosen as a goal in northern California. This sampling method was not as effective on Siberian elm, *Ulmus pumila* L., possibly because Siberian elms tend to abscise partially defoliated leaves and produce new foliage.

The line representing C = 0.1 in the original Fig. 2 was removed to reduce scaling effects. The line for this higher level of precision can be calculated with the formula:

$$n = \frac{}{}$$

where n = number of samples needed, Po = proportion samples uninfested, Pi = proportion samples infested, and C = desired level of precision of estimate. There may not be sufficient trees to sample in an area of concern if *P. luteola* densities are low and a higher level of precision of the estimate is needed (Fig. 2). A manager might run out of trees to sample before sampling should stop.

A later study (Dahlsten et al. 1998) presents action thresholds and a refined sampling technique for *P. luteola* (see our summary in this volume).

Reference

* Dahlsten, D. L.; Rowney, D. L.; Lawson, A. B. 1998. IPM helps control elm leaf beetle. California Agriculture 52: 17-23.

# Elm Leaf Beetle

## *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller)

### Coleoptera: Chrysomelidae

Dreistadt, S. H.; Dahlsten, D. L.; Rowney, D. L.; Tait, S. M.; Yokota, G. Y.; Copper, W. A. 1991. Treatment of destructive elm leaf beetle should be timed by temperature. California Agriculture 45: 23-25.

**Objective**

To develop optimal timing of insecticide applications for *P. luteola* based on accumulated degree-days.

**Abstract**

Elm leaf beetle, *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller), is one of the most important pests of urban elms, *Ulmus* spp., in the western USA and Canada. Larvae injure the host tree by skeletonizing leaves.

Management decisions for *P. luteola* in northern California can be timed using degree-day (DD) accumulation, although elms should still be sampled to confirm the presence of this pest. Eggs of *P. luteola* eclose between 370 and 600DD above the base temperature of 11°C, while densities of first and second instars peak around 700DD. Insecticide applications against larval *P. luteola* should be made around 700DD if larvae are present.

**Sampling Procedure**

Beginning March 1, monitor degree-day accumulation above the threshold temperature of 11˚C. Densities of first and second instars peak around 700DD in northern California. Insecticide applications should be made around this time if *P. luteola* populations are present. Temperature data are available from the University of California's Statewide IPM Project.

**Notes**

This research was conducted in northern California and the degree-day accumulation correlated to eclosion and peak density of young larvae may not be valid in other areas. Use these recommendations with caution until validated in other regions.

# Elm Leaf Beetle

## *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller)

### Coleoptera: Chrysomelidae

Lawson, A. B.; Dahlsten, D. L. 2003. Implementation of a citywide monitoring program to base treatment decisions on elm leaf beetle abundance. Journal of Arboriculture 29: 34-41.

**Objective**

To evaluate the operational feasibility of a monitoring program for *P. luteola* on urban elms.

**Abstract**

Elm leaf beetle, *Pyrrhalta* (=*Xanthogaleruca*) *luteola* (Müller), is one of the most important pests of urban elms, *Ulmus* spp., in the U.S.A. and Canada. English (*U. procera* Salisbury) and Siberian elms (*U. pumila* L.) are more susceptible to damage by *P. luteola* than other elms. Larvae injure the host tree by skeletonizing leaves. Dahlsten et al. (1994) developed a monitoring program that successfully predicted damage to elm from estimates of *P. luteola* egg mass density, but it had not been tested operationally. The program was evaluated in Sacramento, CA, from 1995 to 1999.

During the 5-year program, an average of only 11.3% of susceptible elms needed treatment, compared to the previous practice of treating all susceptible elms on a calendar basis. The monitoring program worked very well for the first and second generations of *P. luteola*, but not for the third generation. This was due mainly to low sample sizes and an inability to make accurate predictions of damage due to an extended oviposition period compared to the first two generations. Further research is needed to determine the threshold for the third generation.

The monitoring data fit the model of Dahlsten et al. (1994) well and thus were included in the model. The optimal damage threshold was subsequently raised to >27% of tips infested for the second generation. No increase in the damage threshold of the first generation was necessary. Managers may use a threshold of 30% elm branch tips infested with egg masses for both the first and second generations to simplify monitoring for this pest. Treatment decisions can be based on the mean infestation in a stand rather than from individual trees. Overall, the monitoring program in Sacramento reduced pesticide usage by 90% citywide with savings of approximately $62,000 per year. This monitoring program, with its adjusted damage thresholds, is useful for area-wide management of *P. luteola* in California.

**Sampling Procedure**

Select English elm, Siberian elm, and their hybrids for sampling. Sampling in Sacramento was reduced to 20% of the susceptible elm species at the end of the evaluation program. See our reviews of Dreistadt et al. (1991) and Dahlsten et al. (1994) in this volume for information on sampling *P. luteola,* including when to sample and the number of branch tips and percentage of trees to sample in an area. Briefly, monitor degree-day accumulation above the threshold temperature of 11°C beginning March 1 (Dreistadt et al. 1991). Densities of first and second instars peak around 700DD in northern California (Dreistadt et al. 1991), so begin looking for egg masses before then.

Take 16 branch terminals, each 30-cm long, from each tree using pole pruners. Take 2 branches from the inner canopy and 2 branches from the outer canopy in each cardinal direction. Note the presence of any egg masses on the samples. Consider treatment options when 30% of the sampled branch tips are infested with egg masses during the first or second generation of *P. luteola*. If a tree is found with an infestation near the treatment threshold, sample adjacent elms to delineate the area of infestation. Treatment decisions can be based on the mean infestation within a stand or on the mean infestation on individual trees.

**Notes**

English elm, Siberian elm, and their hybrids were included in this study. Caution should be used when implementing this monitoring program for other species of elm. A threshold of 20–30% infested branch tips can be used with caution for the third generation of *P. luteola,* but additional work is need to verify the appropriateness of this threshold.

**References**

# Dahlsten, D.L.; Rowney, D.L.; Tait, S.M. 1994. Development of integrated pest management programs in urban forests: the elm leaf beetle (*Xanthogaleruca luteola* (Müller)) in California, USA. Forest Ecology and Management 65: 31-44.

# Dreistadt, S. H.; Dahlsten, D. L.; Rowney, D. L.; Tait, S. M.; Yokota, G. Y.; Copper, W. A. 1991. Treatment of destructive elm leaf beetle should be timed by temperature. California Agriculture 45: 23-25.

# Balsam Fir Sawfly

## *Neodiprion abietis* (Harris)

### Hymenoptera: Diprionidae

Struble, G. R. 1959. Egg sampling reveals trend in white-fir sawfly abundance. Journal of Forestry 57: 510-511.

**Objective**

To develop a sampling procedure for the eggs of *N. abietis* as a means of predicting larval damage on true fir trees.

**Abstract**

Balsam fir sawfly (=white-fir sawfly), *Neodiprion abietis* (Harris), is a defoliator of white fir, *Abies concolor* (Gord. & Glend.) Lindl., and California red fir, *A. magnifica* A. Murr. Female *N. abietis* deposit eggs in slits cut into needles of true firs. Overwintering egg clutches hatch in June; larvae feed in June and July as gregarious colonies on last year's needles. The potential damage produced by larval *N. abietis* can be estimated by sampling egg clutches, which allows sufficient time to take control measures before larvae produce excessive defoliation.

**Sampling Procedure**

Divide selected sampling areas into four quadrants. In each quadrant, randomly select 25 trees and clip two twigs from each tree for a total of 200 twig samples from the sampling area. Clip branches that can be reached from the ground. Each clipping should be about 15.24 cm long with approximately 15 laterals. Keep clippings refrigerated until the number of clutches present can be tallied. A clutch of *N. abietis* eggs consists of all the eggs laid in the needles of one or more adjacent shoots on a twig, presumably laid by a single female. Sample trees between mid-May and early June, before larvae begin to hatch.

There is a direct correlation between the number of clutches observed and the level of defoliation produced by *N. abietis* larvae. Approximately 1,000 larvae are produced from a population of 20 clutches. A population of this size is likely to produce noticeable defoliation. More than 20 clutches per 200-twig sample from 100 trees indicates that control measures may be needed to limit defoliation in the sampling area.

**Note**

The author attributed a downward trend in the number of clutches observed over several years to a polyhedrosis virus attacking mature larvae.

# European Pine Sawfly

## *Neodiprion sertifer* (Geoffroy)

### Hymenoptera: Diprionidae

Lyytikäinen-Saarenmaa, P.; Anderbrant, O.; Löfqvist, J.; Hedenström, E.; Högberg, H.-E. 1999. Monitoring European pine sawfly population densities with pheromone traps in young pine plantations. Forest Ecology and Management 124: 113-121.

**Objective**

To monitor the density of *N. sertifer* in pine plantations using pheromone traps.

**Abstract**

European pine sawfly, *Neodiprion sertifer* (Geoffroy), was introduced into North America in 1925 and now occurs throughout the north-central and northeastern USA and Canada. This pest attacks two- and three-needle pines (*Pinus* spp.). Larval *N. sertifer* feed in gregarious colonies and prefer to consume older foliage. Severe defoliation results in reduced tree growth and damaged aesthetic value, but trees usually survive because the current-year foliage is rarely attacked. Pheromone trapping could be used to track population densities over years and provide a means of predicting outbreaks.

A study was conducted in Sweden to evaluate the use of pheromone traps in monitoring populations of *N. sertifer*. The pheromone diprionyl acetate, (2*S*,3*S*,7*S*)-3,7-dimethyl-2-pentadecyl acetate, was used in sticky traps at volumes of 1, 10 and 100 µg per trap. Traps loaded with 100 µg of diprionyl acetate caught the most males and this volume appeared optimal for monitoring *N. sertifer*. The best correlations between trap catches of male *N. sertifer* and larval density within the same or later generations were observed when the population was increasing, but not when declining to endemic levels. Because of the lack of strong correlations between male capture and larval density, annual pheromone trapping should be conducted in conjunction with other population surveys to monitor population trends. However, pheromone trapping still represents a method of predicting incipient outbreak densities with time to make management decisions for *N. sertifer*.

**Sampling Procedure**

Randomly select three host trees in the center of each trapping site. Selected trees should form a triangle, with 30–50 m between trees. Install 1 Lund-I sticky trap 2 m above ground in each selected tree (Anderbrandt et al. 1989). Bait each trap with 100 µg of diprionyl acetate loaded on a dental cotton roll. The pheromone should have a release rate of 2.5 µg per day over a 30 day period. Leave traps in place during the male flight period, generally

from early August to early October in Sweden. Reload the bait and replace the sticky bottom of each trap in September to ensure adequate coverage of the flight period. Trapping over successive years should provide trends in population levels allowing for the detection of outbreaks. Total trap catches that increase over multiple, consecutive years likely indicate an incipient outbreak of *N. sertifer*, but should be corroborated with data from surveys of eggs, larvae, or pupae.

**Notes**

This study was conducted in Sweden and the results may not be applicable in North America. Please use this trapping procedure with caution. A lure with a constant release rate would be preferable to dental cotton rolls, which dispense the pheromone at a decreasing rate with time.

**References**

Anderbrant, O.; Löfqvist, J.; Jönsson, J.; Marling, E. 1989. Effect of pheromone trap type, position, and colour on the catch of the pine sawfly *Neodiprion sertifer* (Geoffr.) (Hym. Diprionidae). Journal of Applied Entomology 107: 365-369.

# Yellowheaded Spruce Sawfly

## *Pikonema alaskensis* (Rohwer)

### Hymenoptera: Tenthredinidae

Morse, B. W.; Kulman, H. M. 1985. Monitoring damage by yellowheaded spruce sawflies with sawfly and parasitoid pheromones. Environmental Entomology 14:131-133.

**Objective**

To classify the population phase of *P. alaskensis* as either increasing or decreasing through pheromone trapping of the pest and its major parasitoid.

**Abstract**

Yellowheaded sawfly, *Pikonema alaskensis* (Rohwer), is an important native defoliator of spruce (*Picea* spp.) in Alaska, Canada, and the northeastern U.S., including the Lake States. Open grown spruces, such as those in ornamental plantings, plantations, and shelterbelts, are particularly susceptible to *P. alaskensis*. A single year of defoliation by *P. alaskensis* may result in growth loss, while defoliation over multiple years causes branch dieback, topkill, or tree mortality. Outbreaks may persist for 3 years, followed by population decline in the post-outbreak phase.

Pheromone traps can be used to monitor population densities of *P. alaskensis* and its parasitoid *Syndipnus rubiginosus* Walley (Hymenoptera: Ichneumonidae). Research conducted on white spruce [*Picea glauca* (Moench) Voss] in northern Minnesota showed that the population phase of *P. alaskensis* can be determined using the formula $\log(I) = 1.36 - 0.17 \log(S) - 0.25 \text{ Log}(P) + 0.13 \log (S*P) - 0.3 \log (Ht)$, where $I$ = a trend index based on defoliation, $S$ = the number of trapped *P. alaskensis*, $P$ = the number of trapped *S. rubiginosus*, $S*P$ = the interaction between $S$ and $P$, and $Ht$ = tree height. The *P. alaskensis* population is classified as increasing when $I > 1$ and decreasing when $I < 1$. Land managers can use this technique to monitor and plan control measures for populations of *P. alaskensis* approaching an outbreak phase of population growth.

**Sampling Procedure**

Use (Z)-10-nonadecenal and ethyl palmitoleate [ethyl (Z)-9-hexadecenoate] as lures for *P. alaskensis* and *S. rubiginosus*, respectively. Lures can be sandwiched separately between 16-mil polymeric films so that 1 $cm^2$ of film releases 0.67 mg/$cm^2$ sawfly pheromone or 0.62 mg/$cm^2$ parasitoid pheromone. Bait Pherocon II pheromone sticky traps (Trécé, Adair, OK) with 1 $cm^2$ of film of either the sawfly or parasitoid pheromone. Hang traps 1.5 m above ground in white spruce stands. Traps should be installed in early May for *P. alaskensis* and in early

June for *S. rubiginosus*. Remove both traps after one month. Sort trap contents and record the cumulative numbers of trapped male *P. alaskensis* and *S. rubiginosus*. After trapping has ended, determine the average tree height of the trees surrounding each trap.

Calculate the trend index for each group of trees surrounding each trap using the following formula:

$$\log(I) = 1.36 - 0.17 \log(S) - 0.25 \text{ Log}(P) + 0.13 \log (S*P) - 0.3 \log (Ht)$$

where $I$ = a trend index based on observed defoliation, $S$ = the number of trapped *P. alaskensis*, $P$ = the number of trapped *S. rubiginosus*, $S*P$ = the interaction between $S$ and $P$, and $Ht$ = tree height. Classify populations of *P. alaskensis* as increasing (pre-outbreak) if $I > 1$ or decreasing (post-outbreak) if $I < 1$. Consider implementing control measures if the population is increasing.

**Notes**

The authors presumably installed paired *P. alaskensis* and *S. rubiginosus* traps on the same tree within each plot but they did not specify how far apart trap trees should be separated nor did they recommend a specific number of traps to install in a stand. Clearly a sufficient number of traps must be installed throughout a stand to reduce variation among trap pairs and accurately classify *P. alaskensis* populations as increasing or decreasing. The model is applicable only to areas where *S. rubiginosus* occurs as a major parasitoid of *P. alaskensis*.

# Larch Sawfly

## *Pristiphora erichsonii* (Hartig)

### Hymenoptera: Tenthredinidae

Ives, W. G. H.; Prentice, R. M. 1958. A sequential sampling technique for surveys of the larch sawfly. Canadian Entomologist 90: 331-338.

**Objective**

To describe a sequential sampling procedure for the eggs of *P. erichsonii* useful for predicting the infestation level and corresponding expected percentage defoliation.

**Abstract**

Larch sawfly, *Pristiphora erichsonii* (Hartig), is a significant defoliator of larch, *Larix* spp., across its range in North America, including plantations and ornamental plantings. Larvae feed in gregarious colonies and consume entire needles. Trees may releaf following defoliation, but severe defoliation results in thin crowns, branch dieback, and growth loss. Repeated defoliation over consecutive years may cause tree mortality.

Female *P. erichsonii* lay eggs in small slits in the sides of new shoots, which often curl in a characteristic manner due to the injury. Even if shoots do not curl, the oviposition slits in new shoots are readily observable and are a means of estimating the density of *P. erichsonii*. A sequential sampling plan was developed for *P. erichsonii* eggs in larch stands in central Canada. The plan requires a minimum of 10 shoots and a maximum of 400 shoots to classify infestations as light, moderate, or severe. Light, moderate, and severe infestations correspond to <8, 12–22, and >28% of shoots used for oviposition and <20, 30–60, and >70% expected defoliation, respectively.

**Sampling Procedure**

Sample trees after oviposition has ended, usually in mid-August. Randomly select larch trees in each plot. Using pole pruners, sample two whole branches from the mid-crown of each tree. Starting at the apical tip, examine the current-year shoots on each branch in groups of 10 shoots. If the last group of shoots on the first branch does not equal 10, carry over to the second branch. Record the number of shoots in each group of 10 that show oviposition damage (i.e., curling and/or egg slits) as a cumulative tally. Reference Table 3 or Fig. 1 after processing each group of 10 shoots. Stop sampling when the cumulative tally falls out of either the light-moderate or moderate-severe bands in Table 3, or crosses one of the decision lines into the light, moderate, or severe areas of Fig. 1. If 400 shoots are examined without reaching a decision, and the cumulative count in Table 3 remains in the light-moderate band,

classify the infestation as light if the count is <39 but as moderate if >40. If the cumulative count remains in the moderate-severe band, classify the infestation as moderate if the count is <99 and severe if >100. Refer to Table 2 to determine the approximate expected percentage of defoliation corresponding to the infestation level and observed percentage of damaged shoots.

**Note**

Severe defoliation by *P. erichsonii* may result in decreased shoot production with changes in the relationship of pest density to expected defoliation.

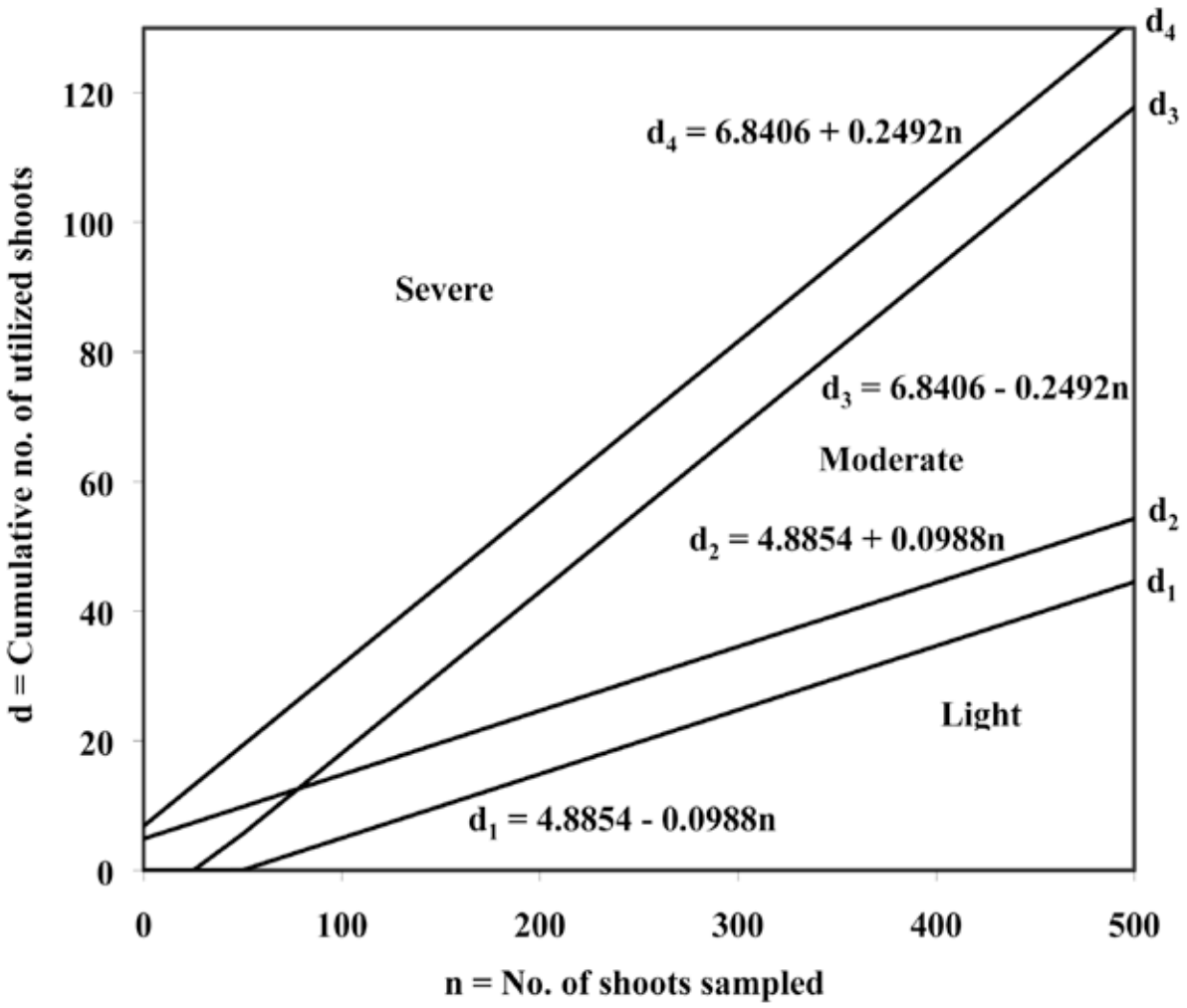


Fig. 1. Sequential graph for sampling larch sawfly populations.

Table 2. Larch sawfly infestation classes based on the proportion of shoots utilized for oviposition and the percentage of defoliation.

| Infestation class | Proportion of shoots utilized for oviposition | Approximate percentage of defoliation |
|---|---|---|
| Light | <0.08 | <20 |
| Moderate | 0.12–0.22 | 30–60 |
| Severe | >0.28 | >70 |

Table 3. Sequential table for use by field parties in classifying infestations. Sampling continues until the cumulative numer of shoots utilized for oviposition falls outside of either of the tow bands into one of the three zones.

| Number of shoots examined | Cumulative number of shoots utilized for oviposition | | | | | |
|---|---|---|---|---|---|---|
| | Light-moderate band | | | Moderate-severe band | | |
| 10 | LIGHT ZONE | – | MODERATE ZONE | –9 | SEVERE ZONE | |
| 20 | | – | | –11 | | |
| 30 | | – | | –14 | | |
| 40 | | – | | –16 | | |
| 50 | | 1– | | –19 | | |
| 60 | | 2– | | –21 | | |
| 70 | | 3– | | –24 | | |
| 80 | | 4–12 | | 14–26 | | |
| 90 | | 5–13 | | 16–29 | | |
| 100 | | 5–14 | | 19–31 | | |
| 110 | | 6–15 | | 21–34 | | |
| 120 | | 7–16 | | 24–36 | | |
| 130 | | 8–17 | | 26–39 | | |
| 140 | | 9–18 | | 29–41 | | |
| 150 | | 10–19 | | 31–44 | | |
| 160 | | 11–20 | | 34–46 | | |
| 170 | | 12–21 | | 36–49 | | |
| 180 | | 13–22 | | 39–51 | | |
| 190 | | 14–23 | | 41–54 | | |
| 200 | | 15–24 | | 43-56 | | |
| 210 | | 16–25 | | 46–59 | | |
| 220 | | 17–26 | | 48–61 | | |
| 230 | | 18–27 | | 51–64 | | |
| 240 | | 19–28 | | 53–66 | | |
| 250 | | 20–29 | | 56–69 | | |

| Number of shoots examined | Cumulative number of shoots utilized for oviposition | | | | |
|---|---|---|---|---|---|
| | | Light-moderate band | | Moderate-severe band | |
| 260 | LIGHT ZONE | 21–30 | MODRATE ZONE | 58–71 | SEVERE ZONE |
| 270 | | 22–31 | | 61–74 | |
| 280 | | 23–32 | | 63–76 | |
| 290 | | 24–33 | | 66–79 | |
| 300 | | 25–34 | | 69–81 | |
| 310 | | 26–35 | | 71–84 | |
| 320 | | 27–36 | | 73–86 | |
| 330 | | 28–37 | | 76–89 | |
| 340 | | 29–38 | | 78–91 | |
| 350 | | 30–39 | | 81–94 | |
| 360 | | 31–40 | | 83–96 | |
| 370 | | 32–41 | | 86–99 | |
| 380 | | 33–42 | | 89–101 | |
| 390 | | 34–43 | | 91–104 | |
| 400 | | 35–44 | | 93–106 | |

**Figure 1 and Tables 2 and 3 are reprinted as fair use under 17 USC § 107.**

# Fall Cankerworm

## *Alsophila pometaria* (Harris)

### Lepidoptera: Geometridae

Hébert, C.; St. Antoine, L. 1999. Oviposition trap to sample eggs of *Operophtera bruceata* (Lepidoptera: Geometridae) and other wingless geometrid species. Canadian Entomologist 131: 557-565.

**Objective**

To develop an oviposition trap for *A. pometaria* that could be used in large scale population monitoring.

**Abstract**

Fall cankerworm, *Alsophila pometaria* (Harris), is a significant defoliator of northern red oak, *Quercus rubra* L., and white oaks (*Quercus* spp.), maples (*Acer* spp.), elms (*Ulmus* spp.), hickories (*Carya* spp.), ashes (*Fraxinus* spp.) and *Prunus* spp. in Canada and the northern U.S. Fall cankerworm can cause a reduction in growth, mast production, and even tree mortality. In public areas, defoliation reduces the aesthetic value of infested trees.

A new egg sampling method for wingless geometrid moths that uses an oviposition trap has been refined from earlier work (Hébert & St. Antoine 1998), where females lay eggs on a polyurethane foam band covered by a Multi-Pher® plate. This trap was initially devised for monitoring populations of the Bruce spanworm, *Operophtera bruceata* (Hulst), but was also useful for surveying populations of *A. pometaria*. Density of *A. pometaria* eggs on oviposition traps was higher than adult females on sticky traps, and the oviposition traps were more effective in detecting low populations of *A. pometaria*. Moreover, oviposition traps did not become saturated at high population densities of *A. pometaria*, a phenomenon that occurred regularly with sticky bands used to trap adult females. Sub-sampling eggs on the polyurethane foam band is recommended when egg densities on the traps are high. This trap is also useful for monitoring populations of winter moth, *Operophtera brumata* (Linnaeus).

**Sampling Procedure**

The standard trap is a 1.2 m post of black ABS (acrylonitrile butadiene styrene) pipe, with a 10 x 31 cm band of polyurethane foam attached lengthwise around the top of the post. Each trap has a model I Multi Pher trap with a closed funnel placed on top of the post. Posts are sandblasted to ensure that the wingless females can climb to the oviposition strip. Trap placement and density will depend on the objective(s) of the sampling effort. Traps should be installed before the oviposition period of *A. pometaria* and collected after oviposition has

ceased. Examine collected foam strips and count the number of eggs laid on them with the aid of a light table. Sub-sampling the foam strips is often necessary to reduce effort when moth populations are high. Divide the foam strip into 30 pieces measuring 1 x 10 cm each. Randomly select and count the eggs on three pieces, which is the recommended sub-sample size.

**Notes**

Several wingless geometrids could lay eggs on the foam strips, causing a bias in estimation of the population of the targeted insect pest. An insecticidal strip in the Multi-Pher trap to trap adult females might help determine the relative contribution of eggs by species. The eggs of *A. pometaria* are black while those of *Operophtera bruceata* are orange.

**References**

* Hébert, C.; St. Antoine, L. 1998. The oviposition trap: a new technique for sampling eggs of the Bruce spanworm and similar species. Res. Notes 5. Canadian Forest Service, Laurentian Forestry Centre; 4 p.

# Eastern Hemlock Looper

## *Lambdina fiscellaria* (Guenée)

### Lepidoptera: Geometridae

Hébert, C.; St. Jobin, L.; Auger, M.; Dupont, A. 2003. Oviposition traps to survey eggs of *Lambdina fiscellaria* (Lepidoptera: Geometridae). Journal of Economic Entomology 96: 768-776.

**Objective**

To develop an oviposition trap for *L. fiscellaria* that could be used to monitor populations and detect outbreaks.

**Abstract**

Hemlock looper, *Lambdina fiscellaria* (Guenée), is an important native defoliator of balsam fir [*Abies balsamea* (L.) Mill.], hemlock (*Tsuga* spp.), and white spruce [*Picea glauca* (Moench) Voss] in eastern USA and Canada. Young larvae feed on a variety of hosts but have greater survival on young balsam fir needles. Older larvae feed indiscriminately. Periodical damage in balsam fir stands generally produces defoliation, growth reduction, and tree mortality. Outbreaks of *L. fiscellaria* build and subside quickly, but tree mortality can occur during the first year damage is found.

Egg density in a known volume of bark, epiphytic lichens, and moss or on 1-m branch samples has been used to monitor populations of *L. fiscellaria*, but these methods require an extraction process to remove and collect the eggs from the substrate (Otvos & Bryant 1972; Dobesberger 1989; Shore 1990). The use of an artificial substrate as an oviposition trap was explored for *L. fiscellaria* in Québec, Canada. White polyurethane foam, alone or in conjunction with a Luminoc® light trap (Comlab Inc., Québec City, Québec, Canada), was an attractive substrate for female *L. fiscellaria* and facilitated the determination of egg density without a time-consuming extraction process. Furthermore, these traps are not influenced by the presence of epiphytic lichens that occur in varying amounts on the 1-m branch samples and influence *L. fiscellaria* oviposition. The modified light-trap can detect increases in *L. fiscellaria* populations while populations are still at very low densities. The passive foam strips offer the advantage of being inexpensive and very easy to install.

**Sampling Procedure**

Modified light trap: Wrap white polyurethane foam around a drainage cylinder (10 cm diam. x 27.5 cm long). Cut two vertical rows of three 5-cm diameter holes through the foam and the cylinder wall. Place a 10 x 30 cm strip of white foam inside the cylinder. Modify the

housing of a Luminoc® light trap by cutting away part of the bottom section. Attach the drainage cylinder to the bottom of the modified light trap. Moths attracted to the light trap should be able to freely enter the drainage cylinder through the two vertical rows of holes. Hang light traps with attached cylinders on balsam fir branches 3–4 m above ground. Install traps in early August before the female flight period begins and operate through the oviposition period, removing the traps in mid-October. Light traps should run throughout the night. Replace the 6-V batteries after 2 weeks to ensure that traps remain operational.

Passive oviposition trap: Staple the top of a 20 x 45 cm strip of white polyurethane foam directly to a tree trunk at breast height. The 20 cm bottom edge should be free to allow females to oviposit on the underside of the foam strip. Install traps before the female flight period begins and leave in place through the oviposition period.

At the end of the trapping period, remove the white foam from either the modified light trap or from tree trunks and examine on a light table. Classify eggs as follows and tally the number of eggs in each state:

| **Egg state** | **Description** |
|---|---|
| Unhatched | Brown, intact |
| Hatched | Translucent chorion with hole at operculum |
| Parasitized | Black and intact, or mostly empty chorion with a dark spot and a hole at operculum |

Land managers can use these methods to monitor *L. fiscellaria* over multiple years and detect population changes before an outbreak. Eggs collected on the foam can be reared for study in the laboratory, unlike eggs that are extracted using hot water or bleach solutions.

**Notes**

The authors did not recommend a specific number of foam strips to use on each tree or the number of traps to install in each plot. Traps in this study were set on transect lines through plots with ≤40 m between traps.

**References**

* Dobesberger, E. J. 1989. A sequential decision plan for the management of the eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Lepidoptera: Geometridae), in Newfoundland. Canadian Journal of Forest Research 19: 911-916.

* Otvos, I. S.; Bryant, D. G. 1972. An extraction method for rapid sampling of eastern hemlock looper eggs, *Lambdina fiscellaria fiscellaria* (Lepidoptera: Geometridae). Canadian Entomologist 104: 1511-1514.

# Shore, T. L. 1990. Recommendations for sampling and extracting eggs of the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Lepidoptera: Geometridae). Journal of the Entomological Society of British Columbia 87: 30-35.

# Western Hemlock Looper

## *Lambdina fiscellaria lugubrosa* (Hulst)

### Lepidoptera: Geometridae

Evenden, M. L.; Borden, J. H.; Van Sickle, G. A.; Gries, G. 1995a. Development of a pheromone-based monitoring system for western hemlock looper (Lepidoptera: Geometridae): effect of pheromone dose, lure age, and trap type. Environmental Entomology 24: 923-932.

**Objective**

To evaluate appropriate type of trap, dose of pheromone, and lure longevity for *L. fiscellaria lugubrosa*.

**Abstract**

Western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is an important periodic defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and other conifers in the United States and Canada. Damage generally occurs in mature or senescing stands where defoliation results in growth reduction, top kill, and tree mortality.

A pheromone-based monitoring system could be established for *L. fiscellaria lugubrosa*, which is strongly attracted to the sex pheromone of eastern hemlock looper, Lambdina fiscellaria fiscellaria (Guenée). This pheromone, a 1:1 ratio of isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane, was tested at doses of 10, 100, 1,000, and 10,000 µg per trap. Trap saturation appeared to occur with the 1,000 and 10,000 µg doses, while traps baited with 1 or 10 µg were effective over the flight period of *L. fiscellaria lugubrosa*. Traps baited with 10 µg pheromone provide a better estimate of the size of the next generation and are therefore appropriate for a pheromone-based monitoring system (Evenden 1994, Evenden et al. 1995). Nonsticky Unitraps (Pherotech, Delta, BC) were recommended over sticky traps for monitoring *L. fiscellaria lugubrosa*. The inner surface of sticky traps, made from 2-liter milk cartons shaped into 3-sided traps and coated with adhesive on the interior, became saturated with as few as 100 moths. A pheromone-based monitoring system using 10 µg pheromone in Unitraps would allow managers to detect increasing populations of *L. fiscellaria lugubrosa* during the adult flight period in late summer instead of during egg surveys in October. The earlier detection would allow for additional time to make management decisions for this pest.

**Sampling Procedure**

Install Unitraps baited with rubber septa loaded with 10 µg of 1:1 ratio of isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane. Mount septa in the lid. Traps should be installed in trees 1–2 m above ground and at least 100 m apart from each other. Deploy traps

before the *L. fiscellaria lugubrosa* flight period, which begins in late July or early August, and leave in place through October. Check traps every 2–3 weeks. Solid-formulated cubes of dichlorovos placed in each trap will kill captured moths; replace dichlorovos each time traps are checked.

**References**

Evenden, M. L. 1994. Devleopment of a pheromone-based monitoring and detection technique for the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera: Geometridae). M.P.M. thesis, Simon Fraser University, Burnaby, BC, Canada.

Evenden, M. L.; Borden, J. H.; Van Sickle, G. A. 1995b. Predictive capabilities of a pheromone-based monitoring system for the western hemlock looper, (Lepidoptera: Geometridae). Environmental Entomology 24: 933-943.

# Western Hemlock Looper

## *Lambdina fiscellaria lugubrosa* (Hulst)

### Lepidoptera: Geometridae

Liang, Q.; Otvos, I. S.; Bradfield, G. E. 1997. Forest roadside sampling of larvae and adults of the western hemlock looper, *Lambdina fiscellaria lugubrosa*. Forest Ecology and Management 93: 45-53.

**Objectives**

To compare densities of *L. fiscellaria lugubrosa* along roads and within stands; to determine the optimum distance between adjacent sampling sites along roads.

**Abstract**

Western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is an important defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and other conifers in the United States and Canada. Periodical damage generally occurs in mature or senescing stands, where defoliation results in growth reduction, top kill, and tree mortality.

Research conducted in British Columbia suggests that *L. fiscellaria lugubrosa* populations can be surveyed along roads, which has the advantage of assessing large areas in less time compared to surveys conducted within stands. Pheromone trap captures and larval sampling were compared along roads and within stands in the Kamloops Forest Region. Larval densities along roads were positively related to those within stands ($r^2 = 0.97$; $P < 0.05$). Likewise, pheromone trap catches along roads were closely related to trap catches within stands ($r^2 = 0.88$; $P < 0.05$). These results suggest a means of predicting population trends using roadside sites, but additional research is required before population densities within stands can be predicted using roadside densities.

Spatial analysis of pheromone trap catches along roads in three Vancouver watersheds indicated that male moth captures remained similar when traps were placed less than 3 km apart along roads. In this region, pheromone traps should be placed at least 3 km apart along roads to reduce the number of necessary sampling sites and maximize sampling effort. However, spatial analysis of the data from the Kamloops site indicated that trap catches were similar when installed up to 7.25 km apart. At this location pheromone traps should be installed at least 7.25 km apart on roadways to maximize sampling effort. Clearly, the optimum distance between adjacent sampling points may vary among locations and should be validated for new areas as well as modified with new data when available.

**Sampling Procedure**

Larval sampling: Select sampling sites along roads at least 3 km apart. At each site, randomly select two western hemlock trees accessible from the road. Cut two 45-cm branch tips from the lower crown of each tree using pole pruners with an attached collection basket. Examine branch tips for larvae.

Adult trapping: Select sampling sites along roads at least 3 km apart. Place one Multi-trap baited with 200 µg of a 1:1 ratio of isomeric 5,11-dimethylheptadecane and 2,5- dimethylheptadecane (Pherotech,Vancouver, B.C.) at each sampling site. Hang traps in the tree canopy approximately 1.5 m above ground. Traps should be installed before adult emergence.

**Note**

The optimum distance between adjacent sampling sites may vary among regions. The recommended distance of 3 km between sites may not be appropriate outside of Vancouver, B.C

# Western Hemlock Looper

## *Lambdina fiscellaria lugubrosa* (Hulst)

### Lepidoptera: Geometridae

Liang, Q.; Otvos, I. S.; Bradfield, G. E. 1998. Pupal sampling of the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lep., Geometridae) using burlap traps. Journal of Applied Entomology 122: 85-88.

**Objectives**

To test the efficacy of three types of burlap traps in capturing pupating *L. fiscellaria lugubrosa* larvae; to validate trap capture as a predictor of population density.

**Abstract**

Western hemlock looper, Lambdina fiscellaria lugubrosa (Hulst), is an important defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and other conifers in the United States and Canada. Periodical damage generally occurs in mature or senescing stands, where defoliation results in growth reduction, top kill, and tree mortality.

Burlap bands are used to collect *L. fiscellaria lugubrosa* pupae, but trap catches have not been validated as an estimator of population densities. In 1993 and 1994, three types of burlap traps with different designs were tested in British Columbia to evaluate trap efficiency in capturing pupating larvae. Traps varied in the number of folds and type of pockets in the burlap material.

Trap capture in a commercially available burlap trap folded once was related positively to *L. fiscellaria lugubrosa* population density. A pooled regression model based on data from three locations was developed to relate the number of pupae caught in a trap to the pupal counts recorded from a 30 cm x 40 cm area of bark on nearby trees:

$$\mathrm{Log}_e(y + 1) = 0.6199 \log_e(x + 1)$$

where x = the number of pupae per 100 $cm^2$ of burlap trap surface area and y = the pupal counts from a 30 cm x 40 cm area of bark of a nearby tree. This model showed a reasonable fit of $r^2 = 0.79$ (MSE = 0.0079, n = 90) for the pooled data, indicating that trap capture was a good estimator of actual population density.

**Sampling Procedure**

Traps are commercially available burlap bands (1-m wide) folded over once with the fold

located at the bottom of the trap and the opening oriented towards the canopy. Install burlap traps by wrapping once around the trunk at 1.3 m above ground. Study details, including plot characteristics and the pupal sampling procedure, are described in Liang (1997). Express pupal density as the number of pupae per 100 $cm^2$ of trap surface area. Use the following formula to estimate the actual population of *L. fiscellaria lugubrosa*:

$$\text{Log}_e(y + 1) = 0.6199\log_e(x + 1)$$

where x = the number of pupae captured in a burlap trap and y = the pupal counts from a 30 cm x 40 cm area of bark.

**Reference**

Liang, Q. 1997. Sampling methods and population prediction in *Lambdina fiscellaria lugubrosa*, in British Colombia. Ph.D. thesis, University of British Colombia, 176 pp.

# Western Hemlock Looper

## *Lambdina fiscellaria lugubrosa* (Hulst)

### Lepidoptera: Geometridae

Shepherd, R. F.; Gray, T. G. 1972. Solution separation and maximum likelihood density estimates of hemlock looper (Lepidoptera: Geometridae) eggs in moss. Canadian Entomologist 104: 751-754.

**Objective**

To describe an efficient method of processing *L. fiscellaria lugubrosa* eggs in moss samples and determining egg density.

**Abstract**

Western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is an important defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and other conifers in the USA and Canada. Periodical damage generally occurs in mature or senescing stands, where defoliation results in growth reduction, top kill, and tree mortality. Eggs are laid on moss, bark, and organic debris on the trunks and branches of trees and on the ground. Visual surveys of eggs in moss samples are tedious and often inaccurate as not all eggs are easily seen and empty chorions can be mistaken for viable eggs. A two-step separation technique using solutions of NaOH and NaCl was developed to process *L. fiscellaria lugubrosa* more efficiently. Eggs obtained in this manner can be used to determine egg density per unit of sampled moss or duff. Collected eggs can be reared if the NaOH soak is skipped. The entire process of soaking, rinsing, and separating a sample took an average of 15–20 minutes, not including time spent counting eggs on the filter paper.

The maximum likelihood method of sampling (MLM; Southwood 1966) can be used to determine the density of eggs in each moss sample. The MLM assumes that a constant proportion of eggs will be removed from the sample with each wash, but removing all eggs is not necessary. This method requires that each wash in the separation technique take exactly 2 minutes with the same amount of effort for each wash in each sample. This technique was evaluated with 35,464 $cm^2$ samples of moss and was considered to be efficient in estimating egg densities. Assuming a population of 200 eggs in each sample, 75% of the eggs must be collected by the three washes to obtain a coefficient of variation of ≤10%. This was exceeded in that the technique removed an average of >98% of the eggs in each sample.

**Sampling Procedure**

Collect 464.5 $cm^2$ samples of moss from the bark surface of hemlock trees. Soak each sam-

ple for one minute in separate containers filled with 0.5% NaOH solution. For each container, pour the contents onto a set of circular mesh screens, 20 cm wide, with the top and bottom screens having 1.00- and 0.354-mm mesh openings, respectively. Rinse the container with water and pour onto the mesh as well. Mix the moss on the upper screen continuously for exactly two minutes while irrigating the material with water from a hose at full tap pressure. Separate the two screens and wash the eggs and other fine debris off the bottom screen into a collection jar. Join the two screens again and wash the moss sample on the upper screen for exactly two minutes twice more, washing the eggs and other debris into the collection jar each time. Pour the contents of the collection jar onto a 12.4-cm disk of filter paper set in a Buchner vacuum funnel. Vacuum filtrate the contents, then count the number of eggs on the filter paper using a stereomicroscope.

Samples of moss or duff under trees require differential floatation to separate *L. fiscellaria lugubrosa* eggs from the very fine organic debris. After vacuum filtration, use a 15% NaCl solution to wash the eggs and fine material off the filter paper and into a 500-ml separatory funnel. Add enough 15% NaCl solution that the contents can mix easily and shake the funnel well. Intact eggs should float to the surface while empty chorions and other extraneous material sink to the bottom. Loosen the stopcock to remove this material from the funnel. The upper solution with intact eggs can be poured onto a 12.4-cm disk of filter paper set in a Buchner vacuum funnel. Rinse with additional NaCl solution and pour the rinsate onto the filter paper. Vacuum filtrate the contents, then count the number of eggs on the filter paper using a stereomicroscope. The NaCl solution can be reused for subsequent separations.

**Note**

Exposures of longer than one minute to the NaOH soak will dissolve the chorions and degrade the eggs, leading to inaccurate counts of egg densities.

**Reference**

Southwood, T. R. E. 1966. Ecological methods with particular reference to the study of insect populations. London: Methuen; 391 p.

# Western Hemlock Looper

## *Lambdina fiscellaria lugubrosa* (Hulst)

### Lepidoptera: Geometridae

Shore, T. L. 1990. Recommendations for sampling and extracting the eggs of the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Lepidoptera: Geometridae). Journal of the Entomological Society of British Columbia 87: 30-35.

**Objectives**

To compare methods of extracting eggs of *L. fiscellaria lugubrosa* from lichen and to determine the vertical distribution of eggs among crown levels on western hemlock.

**Abstract**

Western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is an important defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and other conifers in the United States and Canada. Periodical damage generally occurs in mature or senescing stands, where defoliation results in growth reduction, top kill, and tree mortality. In interior forests of British Columbia, females oviposit on lichens present on western hemlock branches (Thomson 1958).

The efficiency of extracting *L. fiscellaria lugubrosa* eggs from 100 g samples of lichen using a hot water wash was compared to a 2% chlorine bleach extraction. The hot water extraction removed more eggs from the lichen than the bleach extraction in removing eggs. However, the hot water extraction kills the eggs while the bleach extraction does not. The bleach extraction was preferable if eggs were to be reared to measure levels of fertility or identify any parasites present.

No differences in egg densities were found among the lower, mid-, or upper crowns of western hemlock. Lichen samples from the lower crown provide good estimates of egg density and are more accessible than samples from higher portions of the crown.

**Sampling Procedure**

Use pole pruners to sample lichen-covered branches randomly from the lower crowns of western hemlock. Remove the lichen from the branches and extract the eggs of *L. fiscellaria lugubrosa* using either the hot water or chlorine bleach extraction, depending on the research objectives.

Hot water extraction: Weigh the lichen sample. Place the lichen in a 2-liter plastic container

and cover completely with 100° C water. Agitate contents to loosen the eggs from the lichen. Strain the contents of the bucket through a 1000 micron sieve to remove the organic debris. Strain the water a second time through a 250 micron sieve to collect the eggs. Repeat the hot water extraction using the organic debris remaining in the first sieve. Finally, rinse the contents of the 250 micron sieve into a glass jar. Use vacuum filtration to extract the eggs from the rinsate onto filter paper. Count the number of eggs present using a dissecting microscope. Express egg density as the total number of eggs collected in the initial weight of the lichen sample (usually a 100 g sample). Refer to Table 1 to classify eggs as healthy, parasitized, infertile, or old using egg color.

Table 1. Color characteristics of western hemlock looper egg types removed from lichen by the bleach or hot water methods

| **Type of egg** | **Bleach method**[1] | **Hot water method** |
|---|---|---|
| Healthy | Brown | Bronze |
| Parasitized | Black | Black |
| Infertile | Green | Yellow |
| Old | Opaque | Opaque |

[1] From Ovtos and Bryant (1972).

**Table 1 reproduced with permission from the author, granted April 7, 2009.**

Chlorine bleach extraction: Weigh the lichen sample. Pull lichens apart and place in a 2-liter plastic container. Cover the lichen completely with a solution of 2% chlorine bleach. Agitate the container mechanically for 45 minutes at the lowest possible setting to loosen eggs from the lichen. Strain the contents of the bucket through a 1000 micron sieve to remove the organic debris. Strain the bleach solution a second time through a 250 micron sieve to collect the eggs. Repeat the bleach extraction using the organic debris remaining in the first sieve. Rinse the second sieve with tap water for 10 minutes to remove all traces of bleach. Finally, rinse the contents of the 250 micron sieve into a glass jar. Use vacuum filtration to extract the eggs from the rinsate onto filter paper. Count the number of eggs present using a dissecting microscope. Express egg density as the total number of eggs collected in the initial weight of the lichen sample (usually a 100 g sample). Eggs can be reared on moistened filter paper at 0°C for two months followed by 20°C until hatch to determine viability and parasitism, or refer to Table 1 to classify eggs as healthy, parasitized, infertile, or old using egg color.

## References

* Otvos, I. S.; Bryant, D. G. 1972. An extraction method for rapid sampling of eastern hemlock looper eggs, Lambdina fiscellaria fiscellaria (Lepidoptera: Geometridae). Canadian Entomologist 104: 1511-1514.

Thompson, M. G. 1958. Egg sampling for the western hemlock looper. Forestry Chronicle 34: 248-256.

# Bruce Spanworm *Operophtera bruceata* (Hulst)
# Winter Moth *Operophtera brumata* (L.)

## Lepidoptera: Geometridae

Fitzpatrick, S. M.; Troubridge, J. T.; Peterson, B. 1991. Distribution of European winter moth, Operophtera brumata (L.), and Bruce spanworm, *O. bruceata* (Hulst), in the lower Fraser Valley, British Columbia. Journal of the Entomological Society of British Columbia 88: 39-45.

### Objective

To present characters used to differentiate between male *O. bruceata* and *O. brumata* trapped in pheromone-baited traps.

### Abstract

Winter moth, *Operophtera brumata* (Linnaeus), is a significant defoliator of northern red oak, *Quercus rubra* L., maple (*Acer* spp.), and aspen (*Populus* spp.). It was introduced accidentally to Nova Scotia from Europe in 1930, and has expanded its range to include most of eastern Canada, portions of the northeastern US, and western Canada. It is a serious pest in commercial berry fields in British Columbia. Traps baited with the sex pheromone (Z,Z,Z)-1,3,6,9-nonadecatetraene were placed in a mixed coniferous/deciduous forest and in commercial raspberry and blueberry fields in the lower Fraser Valley of British Columbia. This pheromone is attractive to males of *O. brumata* and the related Bruce spanworm, *Operophtera bruceata* (Hulst), which is a defoliator of various hardwood trees in North America. The baited traps collected both *O. bruceata* and *O. brumata* as well as some individuals with intermediate characters, suggesting that hybridization does occur between the two species. Adult *O. bruceata* and *O. brumata* are similar morphologically and can be difficult to separate to species. The authors present external and genitalic characters useful in differentiating between male *O. bruceata* and *O. brumata*. Both species are pests and monitoring each population is of importance.

### Sampling Procedure

Use the external and genitalic characters given in Table 1 to separate male *O. bruceata* and *O. brumata* caught in pheromone-baited traps.

### Reference

Eidt, D. C.; Embree, D. G.; Smith, C. C. 1966. Distinguishing adults of the winter moth *Operophtera brumata* (L.), and Bruce spanworm *O. bruceata* (Hulst) (Lepidoptera: Geometridae). Canadian Entomologist 98: 258-261.

Table 1. Characters used to separate males of the Bruce spanworm, *Operophtera bruceata* (Hulst), from males of the European winter moth, *Operophtera brumata* (L.)

| Type of Character | Spanworm | Winter Moth |
|---|---|---|
| **External** | | |
| Wings | distinct lines and bands on dorsal surfaces | lines on dorsal forewing are obscure; often no lines on dorsal hindwing |
| Forewing | pale yellow-orange ventral costal margin[1] | yellow-orange color faint to absent |
| Hindwing* | dark dorsal discal dot | dot absent |
| Abdomen* | golden brown[2] | brown |
| **Genitalic[3]** | | |
| Uncus | narrow (<0.12 mm); nearly parallel-sided; not spatulate | wider (ca. 0.14 mm): slightly spatulate |
| Juxta | shallow medial notch at base; dorsal process wide (ca. 0.25 mm) at base | divided at base by a medial cleft; dorsal process narrowed (ca. 0.16 mm) at base |
| Saccus | long (ca. 0.63 mm); as long as or longer than width at base of valva | short (ca. 0.40 mm); shorter than width at base of valva |

* Previously unreported chracters
1, 2 True only of Bruce spanworms in B.C.
3 Genitalic characters are illustrated in Eidt et al. (1966).

**Table 1 reproduced with permission from the authors, granted April 6, 2009.**

# Bruce Spanworm, *Operophtera bruceata* (Hulst)
# Winter Moth, *Operophtera brumata* (L.)

### Lepidoptera: Geometridae

Pivnick, K. A.; Barton, D. L.; Millar, J. G.; Underhill, E. W. 1988. Improved pheromone trap exclusion of the Bruce spanworm *Operophtera bruceata* (Hulst) (Lepidoptera: Geometridae) when monitoring winter moth *Operophtera brumata* (L.) populations. Canadian Entomologist 120: 389-396.

**Objectives**

To improve the exclusion of *O. bruceata* from pheromone traps baited for *O. brumata* through the addition of an inhibitor for *O. bruceata*.

**Abstract**

Winter moth, *Operophtera brumata* (Linnaeus), is a significant defoliator of northern red oak, *Quercus rubra* L., in Nova Scotia where it was introduced accidentally in 1930. The range of *O. brumata* has expanded to include most of eastern Canada, portions of the northeastern US, and western Canada. Adults of *O. brumata* and the related Bruce spanworm, *Operophtera bruceata* (Hulst), are similar morphologically. *Operophtera bruceata* (Hulst), is a major defoliator of maple (*Acer* spp.), aspen (*Populus* spp.), and *Prunus* spp. throughout Canada. The sex pheromone of *O. brumata*, (*Z,Z,Z*)-1,3,6,9-nonadecatetraene (1,3*Z*,6*Z*,9*Z*-19:H), also attracts male *O. bruceata*. The two species are nearly identical in appearance and require examination of the genitalia for proper identification. Both species are pests and monitoring each population is of importance.

The addition of (*E,Z,Z*)-1,3,6,6-nonadecatetraene (1,3*E*,6*Z*,9*Z*-19:H) inhibits the attraction of *O. bruceata* to pheromone traps (Underhill et al. 1987). The discovery of the inhibitor 1,3*E*,6*Z*,9*Z*-19:H facilitates the identification and separation of *O. bruceata* and *O. brumata* populations, but traps baited with 1,3*Z*,6*Z*,9*Z*-19:H and 1,3*E*,6*Z*,9*Z*-19:H still capture a certain percentage of *O. bruceata*. Placement of the inhibitor inside the trap reduced capture of *O. bruceata* by 82% while placement of the inhibitor outside the trap reduced capture of *O. bruceata* by 97%. Contact with the inhibitor did reduce capture of *O. brumata*, signaling the need for careful placement of the inhibitor on the exterior of the trap. Research suggests that hybridization between *O. brumata* and *O. bruceata* does occur in areas where both species are present. The response of hybrid *O. brumata* x bruceata appears to be intermediate between the two species.

**Sampling Procedure**

Load 100 µg of a 1% solution of 1,3*Z*,6*Z*,9*Z*-19:H in hexane on rubber septa. Load 50 µg of a 1% solution of 1,3*E*,6*Z*,9*Z*-19:H in hexane on rubber septa. To each septum loaded with either the sex pheromone or the inhibitor, add 1–2 drops of both hexane and 10% butylated hydroxytoluene in acetone as an antioxidant. Place a septum loaded with 1,3*Z*,6*Z*,9*Z*-19:H inside each Hara trap, along with a trip of insecticide to kill attracted moths. Cover both ends of the trap, except for the entrance holes, with fiberglass mesh (1.5-mm mesh) to prevent predators from scavenging moths from the traps. Place 4 septa loaded with 1,3*E*,6*Z*,9*Z*-19:H on the exterior of each trap, with one septa placed above and one below the two entrance holes. Install traps about 1.5 m above ground and set at least 5 m apart in stands of host trees. Traps should be installed before the adult flight period in the fall.

**Notes**

Trapped moths can be identified to species using characteristics of the adult genitalia (Eidt et al. 1966; Fitzpatrick et al. 1991). Hybrid *O. brumata* x bruceata will be inhibited by 1,3*E*,6*Z*,9*Z*-19:H to a lesser extent than *O. bruceata*, but more so than *O. brumata*.

**References**

Eidt, D. C.; Embree, D. G.; Smith, C. C. 1966. Distinguishing adults of the winter moth, *Operophtera brumata* (L.), and Bruce spanworm, *Operophtera bruceata* (Hulst) (Lepidoptera: Geometridae). Canadian Entomologist 98: 258-261.

# Fitzpatrick, S. M.; Troubridge, J. T.; Peterson, B. 1991. Distribution of European winter moth, *Operophtera brumata* (L.), and Bruce spanworm, *O. bruceata* (Hulst), in the lower Fraser Valley, British Columbia. Journal of Entomological Society of British Columbia 88: 39-45.

# Underhill, E. W.; Millar, J. G.; Ring, R. A.; Wong, J. W.; Barton, D.; Giblin, M. 1987. Use of a sex attractant and an inhibitor for monitoring winter moth and Bruce spanworm populations. Journal of Chemical Ecology 13: 1319-1330.

# Bruce Spanworm, *Operophtera bruceata* (Hulst)
# Winter Moth, *Operophtera brumata* (L.)

### Lepidoptera: Geometridae

Underhill, E. W.; Millar, J. G.; Ring, R. A.; Wong, J. W.; Barton, D.; Giblin, M. 1987. Use of a sex attractant and an inhibitor for monitoring winter moth and Bruce spanworm populations. Journal of Chemical Ecology 13: 1319-1330.

**Objective**

To test the addition of an inhibitor in pheromone traps for differentiating populations of *O. bruceata* and *O. brumata*.

**Abstract**

The winter moth, *Operophtera brumata* (Linnaeus), is a significant defoliator of northern red oak, *Quercus rubra* L., in Nova Scotia where it was introduced accidentally in 1930. The range of *O. brumata* has expanded to include most of eastern Canada, portions of the northeastern US and even western Canada. Adults of *O. brumata* and the related Bruce spanworm, *Operophtera bruceata* (Hulst), are similar morphologically. *O. bruceata* (Hulst), is a major defoliator of maple (*Acer* spp.) and aspen (*Populus* spp.) stands throughout Canada.

The sex pheromone of *O. brumata*, (*Z,Z,Z*)-1,3,6,9-nonadecatetraene (1,3*Z*,6*Z*,9*Z*-19:H), also attracts male *O. bruceata*. The two species are nearly identical in appearance and require examination of the genitalia for proper identification. Both species are pests and monitoring each population is of importance. The pheromone (1,3*Z*,6*Z*,9*Z*-19:H) and several of its analogues were evaluated in the laboratory and in field trials for male response. Traps baited with (1,3*Z*,6*Z*,9*Z*-19:H) captured males of both species, but the addition of (*E,Z,Z*)-1,3,6,6-nonadecatetraene (1,3*E*,6*Z*,9*Z*-19:H), inhibited the attraction of *O. bruceata*. The analogue 1,3*E*,6*Z*,9*Z*-19:H alone was not attractive to either *O. brumata* or *O. bruceata*. The discovery of the inhibitor 1,3*E*,6*Z*,9*Z*-19:H facilitates the identification and separation of *O. bruceata* and *O. brumata* populations, but traps baited with 1,3*Z*,6*Z*,9*Z*-19:H and 1,3*E*,6*Z*,9*Z*-19:H still capture a low percentage of *O. bruceata*. Dissection of male genitalia is necessary to detect low densities of *O. bruceata* captured in traps with the inhibitor.

Hara traps (Hara Products Ltd., Swift Current, Saskatchewan) were preferred over Pherocon 1CP traps (Zoecon Corp., Palo Alto, CA) as trap saturation was a concern with the latter.

**Sampling Procedure**

Install Hara traps baited with 100 µg each of 1,3*Z*,6*Z*,9*Z*-19:H and 1,3*E*,6*Z*,9*Z*-19:H and

traps baited with 100 µg of 1,3*Z*,6*Z*,9*Z*-19:H alone at each site. Load compounds on rubber septa and include an insecticidal strip in each trap to kill captured males. Hang traps 1.0–1.5 m above ground on trees or poles. Traps should be set 10–15 m from each other.

In areas predominated by *O. bruceata*, fewer males should be captured in traps with the inhibitor than in traps without the inhibitor. Trap captures should not differ in areas predominated by *O. brumata*, thus significant differences in trap captures should signal the presence of *O. bruceata* at the site. Further research may refine this technique to where *O. bruceata* does not occur in traps with the inhibitor, but until then dissection of the genitalia is still necessary to detect low densities of *O. bruceata* in these traps. Dissection of males in traps baited with only 1,3*Z*,6*Z*,9*Z*-19:H is not necessary.

**Reference**

Eidt, D. C.; Embree, D. G.; Smith, C. C. 1966. Distinguishing adults of the winter moth, *Operophtera brumata* (L.), and Bruce spanworm, *Operophtera bruceata* (Hulst) (Lepidoptera: Geometridae). Canadian Entomologist 98: 258-261.

# Bruce Spanworm

## *Operophtera bruceata* (Hulst)

### Lepidoptera: Geometridae

Hébert, C.; St. Antoine, L. 1999. Oviposition trap to sample eggs of *Operophtera bruceata* (Lepidoptera: Geometridae) and other wingless geometrid species. Canadian Entomologist 131: 557-565.

**Objective**

To develop an oviposition trap for *O. bruceata* that could be used in large scale population monitoring.

**Abstract**

Bruce spanworm, *Operophtera bruceata* (Hulst), is a major defoliator of maple (*Acer* spp.) and aspen (*Populus* spp.) stands throughout Canada. Previous sampling methods for *O. bruceata* include the use of sticky bands placed on the bole of trees to sample the wingless female, but these are costly and laborious to maintain.

Adults of *O. bruceata* and the related winter moth, *Operophtera brumata* (Linnaeus), are similar morphologically. Standard trapping techniques using sticky bands that catch adults require tedious work because the genitalia must be examined in the laboratory to differentiate between the two species. However, winter moth eggs are significantly smaller than Bruce spanworm eggs and this characteristic could easily be used to differentiate between the species. A new egg sampling method using an oviposition trap has been refined from earlier work (Hébert & St. Antoine 1998), where *O. bruceata* lay eggs on a polyurethane foam band covered by a Multi-Pher® plate. An accurate method of sub-sampling eggs on the polyurethane foam band was tested statistically and is recommended when egg densities on the traps are high. Density of eggs from 3 randomly selected sub-samples (x) (1 x 10 cm each) was related positively to density of the entire foam strip (y) ($y = 6.7 + 10.5x$, mean $r^2 = 0.957$). This trap is also useful at monitoring populations of fall cankerworm, *Alsophila pometaria* (Harris).

**Sampling Procedure**

The standard trap is a 1.2 m post of black ABS (acrylonitrile butadiene styrene) pipe, with a 10 x 31 cm band of polyurethane foam attached lengthwise around the top of the post. Each trap has a model I Multi-Pher trap with a closed funnel placed on top of the post. Posts are sandblasted to ensure that the wingless females can climb to the oviposition strip. Trap placement and density will depend on the objective(s) of the sampling effort. Traps should

be installed before the oviposition period of *O. bruceata* and collected after oviposition has ceased. Examine collected foam strips and count the number of eggs laid on them with the aid of a light table. Sub-sampling the foam strips is often necessary to reduce effort when moth populations are high. Divide the foam strip into 30 pieces, measuring 1 x 10 cm each. Randomly select and count the eggs on three pieces, which is the recommended sub-sample size.

**Notes**

Several wingless geometrids could lay eggs on the foam strips, causing a bias in estimation of the population of the targeted insect pest. An insecticidal strip in the Multi-Pher trap to trap adult females might help determine the relative contribution of eggs by species. The authors also suggest using egg size to differentiate between *O. brumata* and *O. bruceata*, which has smaller eggs, but caution that this technique needs to be tested empirically with the oviposition trap (see Cuming 1961 and Brown 1962 regarding egg sizes of these two species).

**References**

Brown, C. E. 1962. The life history and dispersal of the Bruce spanworm, *Operophtera bruceata* (Hulst) (Lepidoptera: Geometridae). Canadian Entomologist 94: 1103-1107.

Cuming, F. G. 1961. The distribution, life history, and economic importance of the winter moth, *Operophtera brumata* (L.) (Lepidoptera:Geometridae) in Nova Scotia. Canadian Entomologist 93: 135-142.

* Hébert, C.; St. Antoine, L. 1998. The oviposition trap: a new technique for sampling eggs of the Bruce spanworm and similar species. Res. Notes 5. Canadian Forest Service, Laurentian Forestry Centre; 4 p.

# Winter Moth

### *Operophtera brumata* (L.)

### Lepidoptera: Geometridae

Hébert, C.; St. Antoine, L. 1999. Oviposition trap to sample eggs of *Operophtera bruceata* (Lepidoptera: Geometridae) and other wingless geometrid species. Canadian Entomologist 131: 557-565.

**Objective**

To develop an oviposition trap for *O. brumata* that could be used in large scale population monitoring.

**Abstract**

Winter moth, *Operophtera brumata* (Linnaeus), is a significant defoliator of northern red oak, *Quercus rubra* L., in Nova Scotia where it was introduced accidentally from Europe in 1930. The range of *O. brumata* has expanded to include most of eastern Canada, portions of the northeastern US and even western Canada. Although *O. brumata* is generally controlled by the parasitoids *Cyzenis albicans* (Faller) and *Agrypon flaveolatum* (Grav.) in its eastern range, populations of this pest may still reach epidemic levels and require sampling to determine if control measures are needed.

Adults of *O. brumata* and the related Bruce spanworm, *Operophtera bruceata* (Hulst), are similar morphologically. Standard trapping techniques using sticky bands that catch adults require tedious work because the genitalia must be examined in the laboratory to differentiate between the two species. However, winter moth eggs are significantly smaller than Bruce spanworm eggs and this characteristic could easily be used to differentiate between the species. A new egg sampling method using an oviposition trap has been refined from earlier work (Hébert & St. Antoine 1998), where *O. brumata* females lay eggs on a polyurethane foam band covered by a Multi-Pher® plate. Sub-sampling eggs on the polyurethane foam band is recommended when egg densities on the traps are high. Because *O. brumata* and O. bruceata have a similar life history and oviposition behavior as fall cankerworm, Alsophila pometaria (Harris), the authors suggest this trapping technique should work for all three geometrid species.

**Sampling Procedure**

The standard trap is a 1.2 m post of black ABS (acrylonitrile butadiene styrene) pipe, with a 10 x 31 cm band of polyurethane foam attached lengthwise around the top of the post. Each trap has a model I Multi-Pher trap with a closed funnel placed on top of the post. Posts are

sandblasted to ensure that the wingless females can climb to the oviposition strip. Trap placement and density will depend on the objective(s) of the sampling effort. Traps should be installed before the oviposition period of *O. brumata* and collected after oviposition has ceased. Examine collected foam strips and count the number of eggs laid on them with the aid of a light table. Sub-sampling the foam strips is often necessary to reduce effort when moth populations are high. Divide the foam strip into 30 pieces measuring 1 x 10 cm each. Randomly select and count the eggs on three pieces, which is the recommended sub-sample size.

**Notes**

Several wingless geometrids could lay eggs on the foam strips, causing a bias in estimation of the population of the targeted insect pest. An insecticidal strip in the Multi-Pher trap to trap adult females might help determine the relative contribution of eggs by species. The authors also suggest using egg size to differentiate between *O. brumata* and *O. bruceata*, which has smaller eggs, but caution that this technique needs to be tested empirically with the oviposition trap (see Cuming 1961 and Brown 1962 regarding egg sizes of these two species).

**References**

Brown, C. E. 1962. The life history and dispersal of the Bruce spanworm, *Operophtera bruceata* (Hulst) (Lepidoptera: Geometridae). Canadian Entomologist 94: 1103-1107.

Cuming, F. G. 1961. The distribution, life history, and economic importance of the winter moth, *Operophtera brumata* (L.) (Lepidoptera:Geometridae) in Nova Scotia. Canadian Entomologist 93: 135-142.

* Hébert, C.; St. Antoine, L. 1998. The oviposition trap: a new technique for sampling eggs of the Bruce spanworm and similar species. Res. Notes 5. Canadian Forest Service, Laurentian Forestry Centre; 4 p.

# Winter Moth

## *Operophtera brumata* (L.)

## Lepidoptera: Geometridae

Reeks, W. A. 1956. Sequential sampling for larvae of the winter moth, *Operophtera brumata* (Linn.) (Lepidoptera: Geometridae). Canadian Entomologist 88: 241-246.

### Objective

To develop a sequential sampling plan for fourth instars of *O. brumata*.

### Abstract

Winter moth, *Operophtera brumata* (L.), is a significant defoliator of northern red oak, *Quercus* rubra L., in Nova Scotia where it was introduced accidentally in 1930. The range of *O. brumata* has expanded to include most of eastern Canada, portions of the northeastern US and western Canada. Severe infestations result in thinned foliage, branch dieback, and tree mortality.

A sequential sampling plan was developed for fourth instar *O. brumata* on red oak, *Quercus rubra* L., in Nova Scotia. Twelve clusters of leaves randomly sampled from the live crown of eight trees each was shown to be an adequate sample size to predict defoliation by *O. brumata*. An additional two trees can be sampled if the cumulative tally of *O. brumata* larvae from eight trees remains in the "continue sampling" zones indicated in Table II. Light, moderate and severe infestations corresponded with approximate defoliation levels of 0–25%, 35–80% and 90–100% on individual trees, respectively.

### Sampling Procedure

Sample when fourth instar *O. brumata* are present, typically during the first two weeks of June in Nova Scotia. Randomly select eight red oaks within an area of concern. Remove 12 clusters of leaves from each tree from any part of the crown. A leaf cluster is defined as all the leaves on a current shoot. Examine the first cluster of leaves and tally the number of fourth instar *O. brumata* present. Reference Table II. If the tally falls within the light-moderate or moderate-severe zones, examine the next cluster of leaves for larvae and continue to reference Table II. Stop sampling when the cumulative count falls into a light, moderate, or severe zone. If all eight clusters are examined and the cumulative tally of larvae remains in the "continue sampling" columns, randomly select two more oaks and sample as above. Classify the infestation as "light-moderate" or "moderate-severe" as appropriate if no decision is reached after sampling 10 trees. Light, moderate and severe infestations correspond to approximate defoliation levels of 0–25%, 35–80% and 90–100% on a per tree basis, respectively.

**Notes**

This sequential plan may also be useful for fall cankerworm, *Alsophila pometaria* (Harris), which has a similar distribution and life history as *O. brumata*. Use this plan with caution for *A. pometaria* until it is validated for this species

Table II. Cumulative number of winter moth larvae per tree-sample (12 leaf clusters per tree-sample) for one to ten sample trees. Based on values for d as shown in text.

| Tree | Cumulative number of larvae per tree-sample | | | | |
|---|---|---|---|---|---|
| | | Light-moderate zone, continue sampling | | Moderate-severe zone, continue sampling | |
| 1 | Light Zone | 3–23 | Moderate Zone | 24–54 | Severe Zone |
| 2 | | 17–37 | | 63–93 | |
| 3 | | 30–51 | | 102–132 | |
| 4 | | 44–64 | | 141–171 | |
| 5 | | 57–78 | | 180–210 | |
| 6 | | 70–91 | | 219–248 | |
| 7 | | 84–105 | | 258–287 | |
| 8 | | 97–118 | | 297–325 | |
| 9 | | 111–132 | | 336–365 | |
| 10 | | 124–145 | | 375–404 | |

**Table II is reprinted as fair use under 17 USC § 107.**

# Forest Tent Caterpillar

### *Malacosoma disstria* (Hübner)

### Lepidoptera: Lasiocampidae

Schmidt, B. C.; Roland, J.; Wakarchuk, D. 2003. Evaluation of synthetic pheromones for monitoring forest tent caterpillar (Lepidoptera: Lasiocampidae) populations. Environmental Entomology 32: 214-219.

**Objective**

To develop a synthetic pheromone for use in detecting and monitoring populations of *M. disstria*.

**Abstract**

Forest tent caterpillar, *Malacosoma disstria* Hübner, is a major defoliator of hardwood forests, particularly trembling aspen, *Populus tremuloides* Michx., in the northern USA and Canada. Young larvae feed on developing buds, while later instars feed gregariously, often defoliating the tree completely. Defoliation causes growth loss, twig dieback, and tree mortality in cases of prolonged infestation.

Three blends of pheromones and 5 volumes of a specific tent caterpillar blend were tested on epidemic and endemic populations of *M. disstria*. A three component blend of (*Z,E*)-5,7-dodecadienal:(*Z,Z*)-5,7-dodecadienal:(*Z*)-7-dodecanal (100:1:10) was most attractive of the three blends tested. The highest volume of pheromone tested (390 µg) caught the most moths with fewest zero captures at a range of moth densities, though 100 µg per lure should be sufficient for use in a trapping program.

**Sampling Procedure**

Wing traps (Wing Trap I, Phero Tech Inc., Delta, B.C, Canada) are used to house the pheromone blend. Place a Flex Lure baited with 390 µg of (*Z,E*)-5,7-dodecadienal:(*Z,Z*)-5,7-dodecadienal:(*Z*)-7-dodecanal (100:1:10) pheromone into each trap. For more information regarding the manufacturing methods of these lures, consult Canadian patent #2,218,157 and US patent #5,750,129. Install traps in field just prior to moth flight. Lures are effective for approximately 28 days under field conditions, which is adequate to span the flight period of *M. disstria* in Alberta. Place traps approximately 1.5 to 2.0 m above ground and about 100 m apart along transects in aspen stands.

**Note**

Optimal trap density was not provided in this article. Users should consult the authors or Phero Tech Inc. regarding updates to this protocol.

# Gypsy Moth

***Lymantria dispar* (L.)**

**Lepidoptera: Lymantriidae**

Liebhold, A.; Twardus, D.; Buonaccorsi, J. 1991. Evaluation of the timed-walk method of estimating gypsy moth (Lepidoptera: Lymantriidae) egg mass densities. Journal of Economic Entomology 84: 1774-1781.

**Objective**

To compare the timed-walk method of estimating egg mass densities of *L. dispar* against estimates in fixed-radius plots.

**Abstract**

Gypsy moth, *Lymantria dispar* (L.) is an important defoliator of numerous hardwoods. Defoliation reduces tree growth and vigor, and, in combination with other stress factors, can cause excessive tree mortality. Populations are spreading from an initial accidental introduction at Medford, MA, around 1868, throughout northeastern USA and neighboring Canada.

Population monitoring of *L. dispar* would benefit from sampling methods requiring limited labor and time. Eggen and Abrahamson (1983) recommended using a timed-walk method of estimating egg mass densities, where all visible egg masses are tallied on a 5-minute walk through a plot. Egg mass densities are then predicted from the timed observations using linear regression. This technique has been criticized for several problems, including unspecified criteria for classifying population levels of *L. dispar*, unaddressed observer bias, and limited data collection for the development of the regression models used with this technique (Ravlin et al. 1987).

A study was conducted in the Mid-Atlantic region of the USA to compare the statistical feasibility of a timed-walk method (Eggen and Abrahamson 1983) against a sampling method using a fixed-radius plot (Wilson and Fontaine 1978). A single fixed-radius plot provided a more precise estimate of *L. dispar* egg mass densities than conducting ≤ four 5-min. walks when populations were at <1,500 egg masses per 0.40 hectare, which would encompass the thresholds for control decisions in most management programs for *L. dispar*. Both methods took ≈20 min. to conduct. The greater precision offered by using 0.01 ha fixed-radius plots offsets the effort needed to set up the plots and sample them.

**Sampling Procedure**

Use sequential sampling plans developed for estimating *L. dispar* egg mass densities in fixed-

radius plots with known precision levels (Fleischer et al. 1991, 1992; Kolodny-Hirsch 1986). If using timed walks to sample *L. dispar*, each observer should be calibrated to account for observational bias, spatial variation in egg mass densities, and differences in terrain across the landscape. This can be done by first estimating egg mass densities with a more precise fixed-radius or variable-radius plot sampling procedure, but the effort would be greater than simply using a fixed-radius plot in the first place.

**Note**

See the original publication for a complete description of the statistics used to compare the timed-walk and fixed-radius plot sampling methods.

**References**

Eggen, D.; Abrahamson, L. P. 1983. Estimating gypsy moth egg mass densities. Misc. Publ. No. 1, ESF 83-002. Albany, NY: State University of New York, College of Environmental Science and Forestry; 28 p.

* Fleischer, S. J.; Ravlin, F. W.; Reardon, R. C. 1991. Implementation of sequential sampling plans for gyspy moth (Lepidoptera: Lymantriidae) egg masses in eastern hardwood forests. Journal of Economic Entomology 84: 1100-1107.

* Fleischer, S. J.; Carter, J.; Reardon, R.; Ravlin, F. W. 1992. Sequential sampling plans for estimating gypsy moth egg mass density. NA-TP-07-92. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area; 12 p.

* Kolodny-Hirsch, D. M. 1986. Evaluation of methods for sampling gypsy moth (Lepidoptera: Lymantriidae) egg mass populations and development of sequential sampling plans. Environmental Entomology 15: 122-127.

Ravlin, F. W.; Bellinger, R. G.; Roberts, E. A. 1987. Gypsy moth management programs in the United States: status, evaluation and recommendations. Bulletin of Entomological Society of America 33: 90-98.

* Wilson, R. W. Jr.; Fontaine, G. A. 1978. Gypsy moth egg mass sampling with fixed and variable radius plots. Agric. Handb. 523. Washington, DC: U.S. Department of Agriculture; 46 p.

# Gypsy Moth

***Lymantria dispar* (L.)**

**Lepidoptera: Lymantriidae**

Sharov, A. A.; Liebhold, A. M.; Roberts, E. A. 1997. Methods for monitoring the spread of gypsy moth (Lepidoptera: Lymantriidae) populations in the Appalachian Mountains. Journal of Economic Entomology 90: 1259-1266.

**Objectives**

To compare variability of population boundaries of *L. dispar* in time and space as estimated from pheromone trap data and egg mass counts; to select the least variable threshold for use in monitoring population spread; to evaluate spread rates estimated from male moth trap catches; and to assess the relationship between accuracy and placement of pheromone traps.

**Abstract**

Gypsy moth, *Lymantria dispar* (L.) is an important defoliator of numerous hardwoods. Defoliation reduces tree growth and vigor, and, in combination with other stress factors, can cause extensive tree mortality. Populations are spreading from an initial accidental introduction at Medford, MA, around 1868, throughout northeastern USA and neighboring Canada. Population spread must be monitored to evaluate control strategies in gypsy moth management, including appropriate placement and timing of control measures, identification of areas for quarantine status, and targeting areas for treatment rather than broadcasting pesticides over widespread areas. Suppression or eradication of detected colonies ahead of the advancing front is an important tool in reducing the rate of spread. A model developed by Sharov and Liebhold (1997) predicts that control of isolated colonies will reduce the annual spread of *L. dispar* by 53%.

Historical pheromone trap data (1988-1995) and egg mass count data (1988-1991) from the Appalachian Mountains in northern Virginia and southern West Virginia were analyzed by the authors. Regression analysis of population boundaries in time and space, as measured by trap data and egg mass counts, was used to calculate spread rates from year to year. Sampling methods used to collect pheromone trap data and egg mass densities are described by Sharov and others (1995, 1996). Thresholds of 1, 3, 10, 30, 100, and 300 male moths per pheromone trap and 1, 3, 10, and 30 egg masses per 0.01 ha were evaluated. Correlograms for male moth trap catches were developed to analyze autocorrelation of spread rates in space, time, and among population thresholds. The effect of intertrap distance on population spread rate was estimated using a modified Tukey jackknife method (refer to original publication for greater detail of statistical analyses).

**Sampling Procedure**

Pheromone traps: A 2.5-km grid is an appropriate intertrap distance with a relatively high accuracy when estimating annual spread rates (SE = 13–21% of the annual spread rate). Intertrap distances can be maximized to 11-km, but the authors recommend increasing the distance to no more than 8 km in case traps are lost after deployment, thus creating gaps in the data. Increasing the intertrap distance from 2.5 to 7 km raised the mean standard error 3.9 times. Use a threshold of 10 male moths per trap for control decisions. Low trap catches (<3 males) likely result from wind-borne male migrants, while higher trap catches likely reflect reproduction by local colonies.

Egg mass surveys: Use a threshold of 10 egg masses per 0.01 ha, the least variable threshold tested, for control decisions.

**Notes**

Population boundaries are based on best-cell classification as described by Sharov et al. (1995, 1996). The authors also examined using defoliation maps as a means to estimate spread of *L. dispar*, but found that boundaries were highly variable and did not accurately reflect annual spread. The authors caution that the Appalachian Mountains represent a unique geographical area and their research may not accurately reflect population spread in other regions where gypsy moth is established.

**References**

Sharov, A. A., Roberts, E. A.; Liebhold, A. M.; Ravlin, F. W. 1995. Gypsy moth (Lepidoptera: Lymantriidae) spread in the central Appalachians: three methods for species boundary estimation. Environmental Entomology 24: 1529-1538.

Sharov, A. A.; Liebhold, A. M.; Roberts, E. A. 1996. Spread of gypsy moth (Lepidoptera: Lymantriidae) in the central Appalachians: comparison of population boundaries obtained from male moth capture, egg mass counts and defoliation records. Environmental Entomology 25: 783-792.

Sharov, A. A.; Liebhold, A. M. 1998. Model of slowing the spread of gypsy moth (Lepidoptera: Lymantriidae) with a barrier zone. Ecological Applications 8: 1170-1179.

# Douglas Fir Tussock Moth

***Orgyia pseudotsugata* (McDonnough)**

**Lepidoptera: Lymantriidae**

Dahlsten, D. L.; Rowney, D. L.; Copper, W. A.; Wenz, J. M. 1992. Comparison of artificial pupation shelters and other monitoring methods for endemic populations of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) (Lepidoptera: Lymantriidae). Canadian Entomologist 124: 359-369.

**Objective**

To predict larval populations of *O. pseudotsugata* on white fir in northern California from counts of cocoons or egg masses found in artificial pupation shelters.

**Abstract**

Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity.

Artificial pupation shelters as a means of monitoring populations of *O. pseudotsugata* in northern California were compared to sampling larval populations from three crown levels (as described in Dahlsten et al. 1985) and the use of pheromone traps. Cocoon numbers from the shelters were positively correlated with larval density in the same year in 1978 (r = 0.76) and 1979 (r = 0.71). Egg mass counts were not strongly correlated with larval density the following year (r = 0.55), but the positive correlation indicates that egg mass counts can be used to predict larval density. Furthermore, egg mass counts from artificial pupation shelters require less effort than sampling larval densities from three crown levels from multiple trees, and the shelters provide an earlier prediction of larval populations than foliage sampling allows. Artificial pupation shelters also offer an advantage over pheromone traps in that they do not require regular service and can be left in place without service until counts are made. Population increases detected from cocoon or egg mass counts the previous fall could be confirmed by sampling larval densities on foliage.

**Sampling Procedure**

Make pupation shelters from wood blocks 9 cm tall, 10 cm wide, and 4 cm deep (Fig. 1). Cut an opening 2.5 cm in diameter and approximately 4 cm deep on one side of the block, near

the bottom. Larvae will pupate inside this opening. Cut a 2.5 cm hole through the block near the top of the wide face. Hang the shelter on the tree using this hole.

Establish 0.4 ha plots containing white fir, *Abies concolor* (Gord. and Glend.) Lindl., within the area to be monitored. In each plot, install a pupation shelter on 10 white firs before larvae begin pupating in late July. Leave shelters in place until adults emerge if counting cocoons, or until egg-laying has ceased if counting egg masses. Using the artificial pupation shelters for multiple, consecutive years will allow land managers to monitor trends in *O. pseudotsugata* populations over time.

**Notes**

Paper cartons, as shown in Fig. 1, compared favorably to the wooden pupation shelters as a means of monitoring populations of *O. pseudotsugata*. However, the wooden shelters are more durable and can be left in place for several years. Cleaning the pupation shelters after taking counts will avoid the need to distinguish between old cocoons or egg masses from previous years and those from the current season.

The authors noted that using a larger number of plots within an area may reduce variation seen among plots, and installing more shelters per plot may improve the prediction of population trends when populations are very low. Further work is needed to correlate defoliation within plots to cocoon or egg mass counts.

**Reference**

Dahlsten, D. L.; Norick, N. X.; Wenz, J. M.; Williams, C. B.; Rowney, D. L. 1985. The dynamics of Douglas-fir tussock moth populations at low levels at chronically infested sites in California. In: Bevan, D.; Stokley, J. T., editors. Site characteristics and population dynamics of lepidopteran and hymenopteran forest pests: Proceedings of IUFRO Conference Subject Group S2.07.06; 1980 September 1–7; Dornoch, Scotland; p. 132–139.

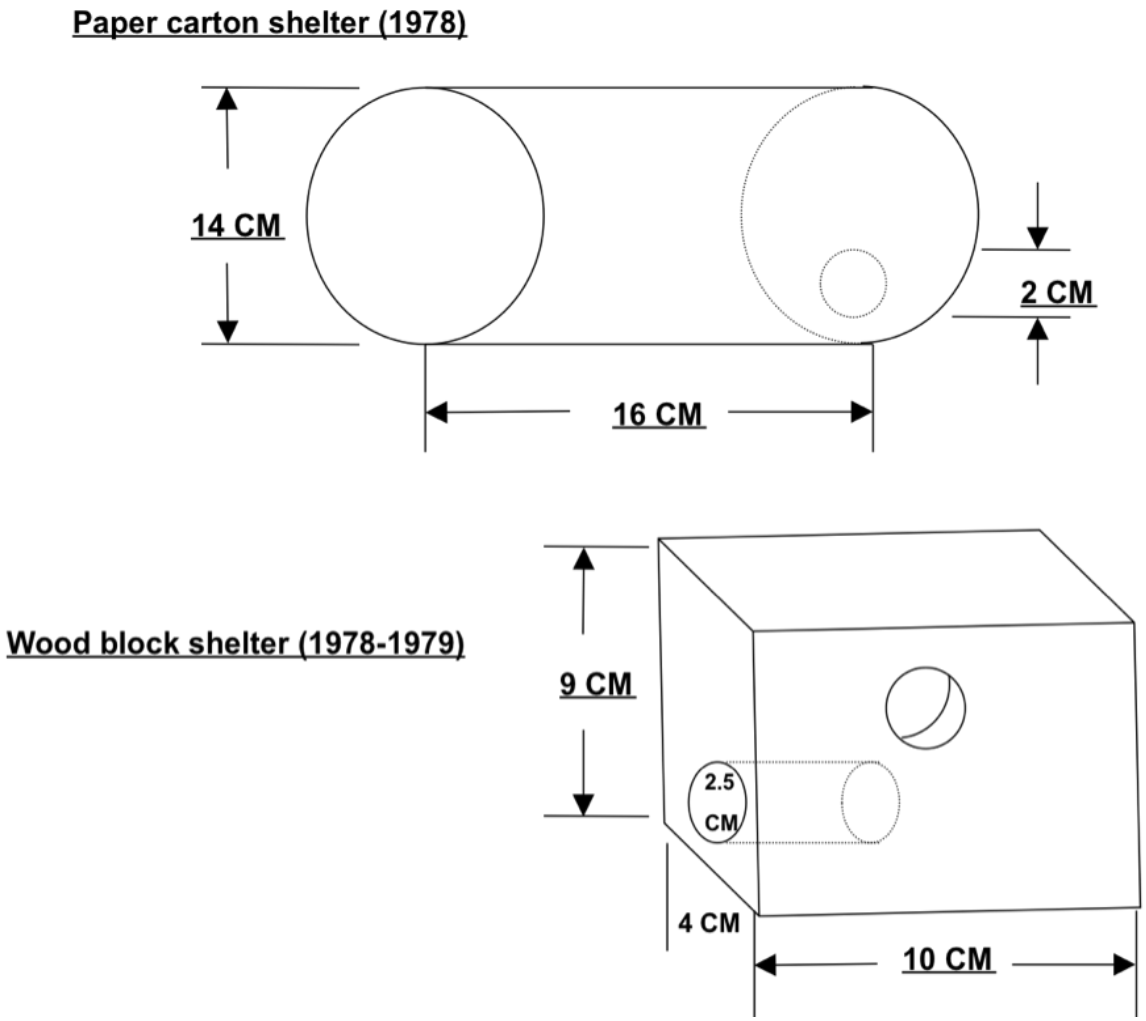


Figure 1. Artificial pupation shelters used for monitoring Douglas-fir tussock moth cocoons and egg masses in California, 1978 nad 1979. Refer to the text for more information regarding shelter design.

**Modified Figure 1 reprinted with permission from the authors, granted April 21, 2009.**

# Douglas Fir Tussock Moth

### *Orgyia pseudotsugata* (McDonnough)

### Lepidoptera: Lymantriidae

Daterman, G. E.; Wenz, J. M.; Sheehan, K. A. 2004. Early warning system for Douglas-fir tussock moth outbreaks in the western United States. Western Journal of Applied Forestry 19: 232-241.

**Objective**

To monitor increasing densities of *O. pseudotsugata* using a system of pheromone-baited traps in sentinel plots throughout the western USA.

**Abstract**

Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity.

Beginning in 1979, an Early Warning System established in the western USA has allowed the timely detection of increasing populations of *O. pseudotsugata* with pheromone-baited traps. Trapping in sentinel plots can detect increasing populations of *O. pseudotsugata* 1–3 years before defoliation is visible to aerial surveys. Each sentinel plot of host trees contains a line of 5 pheromone traps spaced at 22.9 m intervals. Traps are deployed annually from approximately late July to early November. Catches of ≥25 moths in each trap within a sentinel plot indicate increasing populations of *O. pseudotsugata* with the potential to produce visible defoliation within 1–3 years. Given the variation occurring among traps within plots and among plots, land managers can use the operational threshold of an average of 17 moths in each of the 5 traps installed in a sentinel plot. Populations exceeding this threshold require follow-up ground surveying for egg masses or larvae to delineate the infested area and confirm population levels. Based on trap catches from this early warning system, land managers can decide whether chemical control measures are necessary for *O. pseudotsugata* in the following spring with sufficient time to plan control operations over the winter months.

**Sampling Procedure**

Establish at least one sentinel plot per 1,214 ha. Plots should be spaced evenly throughout the area of concern and should reflect any previous defoliation. Consider establishing addi-

tional plots in areas with greater value or where management objectives may include applying control measures very quickly when populations exceed the threshold.

Traps consist of a 1.9-liter milk carton modified to a delta trap with an interior coated with an adhesive. Suspend a pellet of synthetic pheromone above the adhesive on a long pin. Refer to Daterman et al. (1979) for additional details regarding the pheromone traps used in the early warning system. Install traps each year in sentinel plots between late July and mid-August. Remove traps between mid-October and early November. Tally the number of moths in each trap.

Catches of ≥25 moths per trap signal increasing populations of *O. pseudotsugata* with the potential to produce visible defoliation in the next 1–3 years. However, mean moth catches will naturally vary among traps within a plot, among plots, and across regions. Operationally, land managers should consider control measures when trap catches average 17 moths per trap within a sentinel plot to account for a variation of ±30% trap catch. When *O. pseudotsugata* populations exceed this threshold, use ground surveys to pinpoint the location of the infestation and confirm rising populations by sampling egg masses or larvae. Survey egg masses, pupae, and/or cocoons in the fall of the year rising populations are detected or young larvae in the following spring. Surveys should be conducted in the 1- to 2-km area surrounding the plot where increasing populations were detected as pheromone traps may attract *O. pseudotsugata* migrating from other areas. Additional sentinel plots can be established in areas where rising populations are detected to confirm the population increase, but ground surveys are strongly encouraged so that control measures can be implemented as soon as possible if needed. Waiting until the end of the second year of rising populations to make management decisions may cost land managers the benefit of early warning in those cases where defoliation occurs within 1 year of initial warning.

**Reference**

Daterman, G. E.; Livingston, R. L.; Wenz, J. M.; Sower, L. L. 1979. How to use pheromone traps to determine outbreak potential. Douglas-fir Tussock Moth Handb. No. 546. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 11 p.

# Douglas Fir Tussock Moth

### *Orgyia pseudotsugata* (McDonnough)

### Lepidoptera: Lymantriidae

Mason, R. R.; Overton, W. S. 1983. Predicting size and change in nonoutbreak populations of the Douglas-fir tussock moth (Lepidoptera: Lymantriidae). Environmental Entomology 12: 799-803.

**Objective**

To predict future population trends of *O. pseudotsugata* populations from larval densities currently in a nonoutbreak phase.

**Abstract**

Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Large numbers of trees are often defoliated before direct control measures can be applied. Defoliation by *O. pseudotsugata* can be severe and cause tree mortality during the first year of an outbreak, and surviving trees often exhibit growth loss and top kill.

Data collected from 11 generations of *O. pseudotsugata* from four widely separated populations in western USA were used to develop equations for predicting changes in nonoutbreak populations. The density of larvae surviving to late instars (X) in a given generation was a good predictor of the early larval density in the subsequent generation (Y), expressed as $\log Y = 0.950 + 0.963 \log X$ ($r^2 = 0.85$). Furthermore, densities of early and late instars can be used to detect increasing population densities in advance of an actual outbreak. High densities of surviving larvae are necessary for population increase in *O. pseudotsugata,* but population decline may be related to mortality in a different life stage than larvae. Overall, these procedures provide valuable information needed for management decisions with time to plan control operations in advance.

**Sampling Procedure**

Initiate sampling of early larvae (instars 1 and 2) when the density *O. pseudotsugata* appears to be approaching an outbreak phase but still fewer than 20 early larvae are present per 0.65 $m^2$ of branch foliage. Sample larvae in midcrown foliage using the methods of Mason (1970, 1977, 1979). Express larval densities as the mean number of larvae per 0.65 $m^2$ of branch foliage. Sample lower crown foliage if densities are below 1 larva per 0.65 $m^2$ of branch foliage. Return to plots and sample late larvae (instars 5 and 6) when present.

**Use the following equation to predict the general population density of early instars in the subsequent generation:**

$$\log Y = 0.950 + 0.963 \log X$$

where Y = the density of early instars in a given generation and X = the density of late instars in the previous generation.

**Use the following equation to predict changes in the size of the subsequent generation:**

$$Y = —0.214 + 13.825X$$

where Y = the trend index (I) and X = larval survival (S), or the proportion of larvae in a single generation surviving to late instars. The trend index, I, is the ratio of early instar densities in two successive generations ($I = N_{t+1}/N_t$ where $N_t$ = the density of early instars in a given generation and $N_{t+1}$ = the density of surviving late instars in the following generation). Populations are classified as increasing when $I > 1.0$, but this regression model does not adequately represent declining populations where $I < 1.0$.

Larval survival (S) is defined as $S = N_s / N_t$, where $N_s$ = the density of surviving late instars in the same generation as $N_t$. Larval survival can be used to detect declining or static populations not represented by the trend index in the above model. A larval survival rate of >0.2 generally signals a rapidly increasing population whereas a rate of <0.2 indicates that the population will remain static or decline.

**Notes**

These procedures were developed from data collected from low-density populations of *O. pseudotsugata* that had not erupted into an outbreak recently or were only in the very beginning of an outbreak phase. The equations may not be valid for larval densities during an outbreak or in a post-outbreak decline.

**References**

* Mason, R. R. 1970. Development of sampling methods for the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* (Lepidoptera: Lymantriidae). Canadian Entomologist 102: 836-845.

* Mason, R. R. 1977. Sampling low-density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower tree crown. Res. Pap. PNW-216. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 8 p.

* Mason, R. R. 1979. How to sample Douglas-fir tussock moth larvae. Agric. Handb. 547. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 15 p.

# Douglas Fir Tussock Moth, *Orgyia pseudotsugata* (McDonnough) Western Spruce Budworm, *Choristoneura occidentalis* (Freeman)

## Lepidoptera: Lymantriidae

Mason, R. R.; Paul, H. G. 1994. Monitoring larval populations of the Douglas-fir tussock moth and the western spruce budworm on permanent plots: sampling methods and statistical properties of data. Gen. Tech. Rep. PNW-GTR-333. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 23 p.

### Objective

To describe sampling methods for determining larval densities of *O. pseudotsugata* and *C. occidentalis*.

### Abstract

Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity. Western spruce budworm, *Choristoneura occidentalis* Freeman, also attacks Englemann spruce, *Picea englemannii* Parry ex. Englem., and larch, *Larix occidentalis* Nutt., in addition to Douglas-fir and true firs in western North America. Infestation of *C. occidentalis* in mature stands can result in growth loss, top kill, and occasional tree mortality.

This work is an extensive summary of earlier published studies and is derived from research conducted in eastern Oregon and Washington. The authors demonstrate that permanent plots in a geographical monitoring unit offer a statistically reliable tool for monitoring densities of *O. pseudotsugata* and *C. occidentalis*. Typically, larval population densities are estimated by sampling a number of tree clusters in a small area and a number of small areas in a stand. The mid-crown of Douglas-fir <15 m tall is the preferred region for sampling branches. Traditionally three 45-cm branch tips are sampled per tree on each of 20 to 50 trees in a plot, depending on larval densities (low and high populations requiring a larger number of samples). Sampling should be timed to coincide with presence of first and second instars of *O. pseudotsugata* and nominal fourth instars of *C. occidentalis*. Alternatively, branches in the lower crown can be sampled and the resulting estimates of larval density per sampling unit converted to mid-crown density per m2 using a corrective equation. Equations are presented to estimate the number of plots needed given the size of the area of concern. Roughly 50 plots would be needed to estimate tussock moth density at the size of a state or Canadian province. Sampling methods must be consistent across regions and time to build a meaningful database monitoring population trends.

**Sampling Procedure**

Permanent sample plots are generally about 2 ha in size. Plots should be selected to adequately reflect the larger monitoring unit, whether the unit is a ranger district or a national forest. Each sample plot should contain a cluster of Douglas-fir and true fir trees. Trees should have canopies accessible from the ground. Randomly select trees to reflect the species composition within plots. Plots should be sampled annually to monitor population trends over time and regions.

Begin sampling after budburst when new shoots are ≤4–6 cm long. Sample the same instars each year. Typically early instars (i.e., first and second instars) are preferred for *O. pseudotsugata*, while nominal fourth instars (i.e., instars III, IV, and V) are preferred for *C. occidentalis*. Sample three 45-cm branch tips from the lower crown of each tree using a beat sheet and a beat stick. Be aware that *C. occidentalis* larvae on webbed shoots may require more vigorous beating to dislodge them than *O. pseudotsugata* larve. Sampling 20–50 trees in a plot provides a density estimate with a standard error of <20% of the mean at the 68% probability level. Lower pest densities require a larger sample size than higher pest densities at the same precision level. Examine arthropods dislodged onto the beat sheet and record the number of *O. pseudotsugata* and *C. occidentalis* larvae found separately for each 3-branch sample.

Calculate the mean number of larvae for each species per sampling unit, $\bar{y}$, using the following formula:

$$\overline{M} = \frac{1}{n}\sum_{i=1}^{n} M_i$$

where $y_i$ = the number of larvae in the sampling unit of the *i*th tree and *m* = the number of trees sampled per plot. Sample variance among the 3-branch sampling units, $V(y)$, can be calculated for each cluster of trees using the following formula, with $y_i$ and *m* described as above:

$$V(M) = \frac{1}{n-1}\sum_{i=1}^{n}\left(M_i - \overline{M}\right)^2$$

Calculate the mean population density for a monitoring unit ($M$) using the following equation:

$$\overline{M} = \frac{1}{n}\sum_{i=1}^{n} M_i$$

where $M_i$ = the larval density in the ith sampling plot of the unit and $n$ = the number of plots per unit. The interplot variance, $V(M)$, can be calculated among the sampling plots using the following formula, with M*i* and $n$ described as above:

$$V(M) = \frac{1}{n-1}\sum_{i=1}^{n}\left(M_i - \overline{M}\right)^2$$

Calculate the appropriate number of permanent sampling plots required by solving for inter-plot variance ($V$) in the following equation:

$$V(M) = a\,\overline{M}^{b}$$

where $a$ and $b$ = parameters reflecting the spatial variation of larval populations and  = the population mean. Substitute the value of $V$ in the following equation:

$$n = \frac{t^2 V(M)}{E^2}$$

where $t$ = Student's $t$ for a specified confidence probability and E = the desired standard error of estimate to determine the number of permanent plots required within a monitoring unit. Both *O. pseudotsugata* and *C. occidentalis* larvae can be monitored simultaneously on the same plots within a management unit. District-sized, forest-sized, and province-sized units will generally need 15–20, 25–30, and 50–60 units, respectively. These numbers of plots should be sufficient for a precision of estimate of 20 percent of the mean and a confidence level of 68%.

Larval densities estimated from the lower crown should be converted to a standard abundance index in the mid-crown ($M$) using the following equation:

$$SA = \sum PD_i / n$$

where 3.1 = the average number of 3-branch sampling units per $m^2$, $\bar{y}$ = the mean density of larvae per sampling unit, and R = the correction factor, which is a ratio of mid-crown to lower crown density of larvae. Substitute 2.0 as R for early instar *O. pseudotsugata* and 2.23 for nominal fourth instar *C. occidentalis* to convert estimates of lower crown density per sampling unit to mid-crown density per m2.

**Notes**

Often early instar *O. pseudotsugata* and nominal fourth instar *C. occidentalis* can be sampled together at the same time, but not always. The two species should be sampled separately if *C. occidentalis* larvae become active in the spring weeks before *O. pseudotsugata* due to cool spring weather.

Refer to the original publication for greater details regarding the calculations summarized here and additional information about monitoring permanent plots for *O. pseudotsugata* and *C. occidentalis* larvae.

# Douglas Fir Tussock Moth

### *Orgyia pseudotsugata* (McDonnough)

### Lepidoptera: Lymantriidae

Mason, R. R.; Wickman, B. E. 1991. Integrated pest management of the Douglas-fir tussock moth. Forest Ecology and Management 39: 119-130.

**Objective**

To review the integrated pest management practices for *O. pseudotsugata* populations.

**Abstract**

Douglas-fir tussock moth, Orgyia pseudotsugata (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity.

**Sampling Procedure**

Much of the information included in this review paper is summarized as individual research articles in Sampling Methods for Forest and Shade Tree Insects of North America, Vol. 1, or presented elsewhere. However, those unfamiliar with *O. pseudotsugata* may find this paper an informative source of management practices. Table 1, describing the phases of *O. pseudotsugata* densities, may be of particular interest to land managers.

**Notes**

Larvae of *O. pseudotsugata* can be sampled following the methods of Mason 1969, 1970, 1978, 1979, and 1987; or Shepherd et al. 1985.

**References**

* Mason, R. R. 1969. Sequential sampling of Douglas-fir tussock moth populations. Res. Note PNW-102. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 11 p.

* Mason, R. R. 1970. Development of sampling methods for the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* (Lepidoptera: Lymantriidae). Canadian Entomologist 102: 836-845.

* Mason, R. R. 1977. Sampling low-density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower tree crown. Res. Pap. PNW-216. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 8 p.

* Mason, R. R. 1978. Detecting suboutbreak populations of the Douglas-fir tussock moth by sequential sampling of early larvae in the lower tree crown. Res. Pap. PNW-238. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 9 p.

* Mason, R. R. 1987. Frequency sampling to predict densities in sparse populations of the Douglas-fir tussock moth. Forest Science 33: 145-156.

* Shepherd, R. R. 1985. Pest management of Douglas-fir tussock moth: estimating larval density by sequential sampling. Canadian Entomologist 117: 1111-1115.

Table 1. Description of typical phases of an outbreak of the Dougls-fir tussock moth.

| Phase | Density of small larvae (No./$m^2$ foliage) | Description |
|---|---|---|
| 0 | <3 | Low density. No visible defoliation. Caterpillars uncommon, egg-masses rare. |
| I (Release) | 30 > 3 | Sub-outbreak density. Usually little or no visible defoliation. May be some light feeding in tops of crowns late in season. Caterpillars common. New egg-masses large, outnumber old masses. |
| II (Peak) | >30 | Outbreak density. Defoliation visible on most host trees, especialy severe in upper crowns. Caterpillars abundant all season. New egg-masses, also abundant, outnumber old masses. |
| III (Decline) | >30 | Outbreak density. Defoliation repeated on all trees. Caterpillars abundant early in season, but numbers decline sharply before pupation. New egg-masses scarce and smaller than usual. |
| IV (Postdecline) | <3 | No new defoliation. Caterpillars scarce. New egg-masses rare. |

# Douglas Fir Tussock Moth

### *Orgyia pseudotsugata* (McDonnough)

### Lepidoptera: Lymantriidae

Mason, R. R.; Scott, D. W.; Paul, H. G. 1993. Forecasting outbreaks of the Douglas-fir tussock moth from lower crown cocoon samples. Research Pap. PNW-RP-460. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 12 p.

**Objective**

To determine whether suboutbreak populations of *O. pseudotsugata* will develop into a damaging outbreak the following season, based on the cocoon density present in the lower crown.

**Abstract**

Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, Abies spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity.

Research conducted throughout the Pacific Northwest indicates that, when *O. pseudotsugata* populations are in a suboutbreak phase, the density of cocoons in the lower crown is a good estimator of midcrown larval density the following year. This relationship between the number of cocoons per 0.65 $m^2$ of branch area in the lower crown (X) and the number of small larvae per 0.65 $m^2$ of branch area in the midcrown (Y) is expressed by the equation $Y = 1.70 + 55.14X$ ($R^2 = 0.66$). In general, each cocoon sampled from the lower crown in the fall represents 55–65 larvae in the midcrown the following spring. Furthermore, the density of sampled cocoons is related to the level of expected defoliation the following spring. Land managers using this technique to forecast larval densities can decide whether the application of suppression tactics is necessary the following spring with sufficient time to plan operations over the winter months.

**Sampling Procedure**

Determine the number of plots necessary to estimate cocoon densities at the desired level of precision, assuming 50 host trees are sampled in each plot (Table 3). Several plots of 50 trees each should be sampled to forecast larval densities the following year. Selected stands should have had increasing populations of *O. pseudotsugata* over the past several years but no defoliation should be apparent.

Sample cocoons in the fall, after moths have emerged and laid eggs. Randomly select 50 trees in each plot and cut three 45 cm terminal branches from the lower crown of each tree. Examine the underside of each branch sample for the presence or absence of *O. pseudotsugata* cocoons. Tally the number of 3-branch sample units with at least one cocoon present on a branch. Calculate the proportion of infested trees (*p*) using the equation p = r/n, where r = the total number of sampled trees with at least one cocoon present and n = the total number of trees sampled.

Convert the proportion of infested trees (*p*) into the number of cocoons per 0.65 $m^2$ (1000 $inch^2$) of branch area (X) using the equation X = -2 ln(1-p) (Mason 1977). Alternatively, determine the total number of cocoons per 0.65 m2 of branch area (X) using the following equation:

$$X = \frac{2\sum_{i=1}^{n} y_i}{n}$$

where $y_i$ = the number of cocoons on the *i*th sample unit and *n* = the number of sample trees.

Calculate the number of small larvae per 0.65 $m^2$ of branch area in the midcrown (Y) expected next year from the number of cocoons per 0.65 m2 of branch area in the lower crown (X) using the equation Y = 1.70 + 55.14X. Consult Table 4 to review the level of expected defoliation associated with the predicted density of young larvae the next year. The regression equation Y = 1.70 + 55.14X was developed from a dataset containing some very high densities of larvae from several geographic locations, so the model may overestimate subsequent larval densities more frequently than it underestimates populations.

**Notes**

This sampling method was developed using data from *O. pseudotsugata* populations that have been increasing in recent years but have not yet produced visible defoliation. The relationship between densities of cocoons and small larvae is less definable in outbreak conditions, when defoliation is visible on most trees, due to increasing variability produced by density-dependent mortality factors.

**Reference**

* Mason, R. R. 1977. Sampling low density populations of the Douglas-fir tussock moth by frequency of occurrence in the lower crown. Res. Pap. PNW-216. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 8 p.

Table 3. Number of plots required to estimate cocoon densities at different levels of precision when sampling 50 trees per plot[a]

| | Standard error as percent of the mean | | | | | |
|---|---|---|---|---|---|---|
| Mean cocoon density | 10 | 20 | 30 | 40 | 50 | 60 |
| *No./1000 in²* | | | | | | |
| 0.20 | 81 | 20 | 9 | 5 | 3 | 2 |
| 0.40 | 64 | 16 | 7 | 4 | 3 | 2 |
| 0.60 | 55 | 14 | 6 | 3 | 2 | 2 |
| 0.80 | 50 | 12 | 6 | 3 | 2 | 1 |
| 1.00 | 46 | 11 | 5 | 3 | 2 | 1 |
| 1.20 | 43 | 11 | 5 | 3 | 2 | 1 |
| 1.40 | 41 | 10 | 5 | 3 | 2 | 1 |

aSample size, n, was calculated by solving the equation $n = s_2/s^2x$ where $s^2$ is between-plot variance and sx the desired standard error

Table 4. Relation of estimated cocoon densities in pre-outbreak populations of the Douglas-fir tussock moth to predicted larval densities and status in the next generation.

| Range of cocoon densities in the lower crown | Predicted larval densities in the midcrown | Predicted population status |
|---|---|---|
| *No./1000 square inches* | | |
| <0.01 | <2.0 | Low density; no defoliation |
| 0.01–0.30 | 2.0–20.0 | Sub-outbreak; little or no visible defoliation |
| 0.31–0.70 | 21.0–40.0 | Moderate oubreak; defoliation visible on most trees |
| >0.70 | >40.0 | Severe outbreak; defoliation intense in upper crowns of many host trees with some trees completely defoliated |

# Douglas Fir Tussock Moth

***Orgyia pseudotsugata* (McDonnough)**

**Lepidoptera: Lymantriidae**

Shepherd, R. F.; Otvos, I. S. 1986. Pest management of Douglas-fir tussock moth: procedures for insect monitoring, problem evaluation and control actions. Research Rpt. BC-X-270. Victoria, B.C.: Canadian Forestry Service, Pacific Forestry Centre; 14 p.

**Objective**

To review the integrated pest management practices for *O. pseudotsugata* populations in British Columbia.

**Abstract**

Douglas-fir tussock moth, *Orgyia pseudotsugat*a (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menzies*i (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity.

**Sampling Procedure**

Much of the information included in this thorough guide has been presented as individual research articles in Sampling Methods for Forest and Shade Tree Insects of North America, Vol. 1, or the current volume. However, those unfamiliar with *O. pseudotsugata* may find this publication to be an informative source of management practices in British Columbia. The authors have described the identification of susceptible and infested stands; the detection and monitoring of *O. pseudotsugata* populations at low and increasing densities; the evaluation of the need for control measures; and available control options. The timeline, presented below, is particularly useful in summarizing the steps in the pest management process for *O. pseudotsugata* over the year.

Reference

Shepherd, R. F; Otvos, I. S.; Chorney, R. J. 1984. Pest management of Douglas-fir tussock moth (Lepidoptera: Lymantriidae): a sequential sampling method to determine egg mass density. Canadian Entomologist 116: 1041-1049.

## Schedule of Procedures

The essential steps and procedures of the pest management system for the Douglas-fir tussock moth in British Columbia are listed with the approximate time of initiation relative to the first year of defoliation.

| | | |
|---|---|---|
| 1. | Planning stage before problems arise | Identify stands susceptible to outbreaks by comparing overlay maps of historical outbreaks, forest types, plant communities and climatic zones. |
| 2. | July to September anually | Within susceptible stands, establish and maintain monitoring sites to determine year-to-year trends in number of moths caught in pheromone traps. |
| 3. | October annually | Check pheromone traps and if catches at the permanent monitoring sites have increased for at least 2 years and moth density has reached 8-10 moths/trap, an outbreak is probably only 2 years away; initiate step 4. |
| 4. | July of each year until the outbreak subsides | Deploy a network of auxiliary pheromone traps to help locate infested stands. |
| 5. | October of each year until the outbreak subsides | If moth counts in pheromone traps at the permanent monitoring sites have increased for 2–3 years and average moth density has reached 25 moths/trap, an outbreak may be expected the following year; initiate step 6. |
| 6. | October of each year until the outbreak subsides | Search for egg masses in stands close to permanent or auxiliary traps that caught an average of 25 or more moths/trap. When a pocket of egg masses is found, determine the density through a lower-branch sequential egg-mass survey and predict the level of defoliation for next year (Shepherd et al. 1984); initiate step 7. |
| 7. | November of each year until the outbreak subsides | If egg masses are present, consider all available options for managing the insect problem. If insecticide or virus treatment or harvesting is chosen, conduct surveys to map infestation boundaries, determine areas, timber volumes, etc. as necessary and plan the operation. |
| 8. | May or June in year when defoliation is expected | If the harvest option is chosen, completely cut the infested stands and burn the residual slash by May prior to larval hatch. If insecticide or virus control is chosen, carry out application immediately after larval hatch and dispersal. |

# Douglas Fir Tussock Moth

***Orgyia pseudotsugata* (McDonnough)**

**Lepidoptera: Lymantriidae**

Sower, L. L.; Daterman, G. E.; Stelzer, M. J.; Nielsen, D. G. 1983. Vertical distribution of Douglas-fir tussock moth (Lepidoptera: Lymantriidae) eggs in suboutbreak conditions. Environmental Entomology 12: 1590-1591.

**Objectives**

To determine the vertical distribution of *O. pseudotsugata* egg masses; to identify growing populations during suboutbreak conditions using timed visual samples of foliage.

**Abstract**

Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDonnough), is a periodic defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.), and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly every 7–10 years and usually persist for 3–4 years. Defoliation by *O. pseudotsugata* can be severe and cause widespread tree mortality during the first year of an outbreak. Surviving trees may exhibit growth loss, top-kill, and tree deformity.

Few studies have examined *O. pseudotsugata* in suboutbreak conditions, when intermediate populations begin to expand. During outbreak conditions egg masses and cocoons are typically found in the lower crown because high densities of larvae have defoliated the upper crown (Luck and Dahlsten 1967; Mason 1970). Distribution of eggs within the host tree may differ during suboutbreak populations, when less defoliation has occurred.

The vertical distribution of *O. pseudotsugata* egg masses in suboutbreak conditions was examined on felled trees and a recommendation for timed visual samples was made for standing trees. Egg masses were found throughout the canopy but with a concentration towards the upper crown. Approximately 10% of the total egg masses present on the trees were visible to an observer conducting timed, 1-minute visual samples of the foliage. Thirty 1-minute observational periods of individual trees within a 20 ha area could serve as a rapid survey of expanding populations with outbreak potential. Damaging outbreaks during the following season are considered unlikely if several egg masses cannot be found within 30 minutes of observation.

**Sampling Procedure**

Randomly select trees for sampling from a distance at which any cocoons present on the trees

cannot be distinguished. At each selected tree, spend one minute visually searching for cocoons and egg masses. Focus on visually sampling the lower crown, where cocoons and egg masses can be seen more easily. Thirty 1-minute observational periods of individual trees within a 20 ha area could serve as a rapid survey of expanding populations with outbreak potential. Damaging outbreaks during the following season are considered unlikely if several egg masses cannot be found within 30 minutes of observation.

**Notes**

The trees selected for this study were 15–20 cm diameter at breast height, approximately 12 m tall, and with a crown approximately 5 m wide at its widest. In addition, selected trees had foliage close to the ground and grew close to neighboring trees. These sampling specifications were set by the land manager and the authors' observations may not hold for trees with differing characteristics.

The authors acknowledge that a more specific sampling scheme using visual observations should be developed. While not explicitly stated by the authors, sampling cut trees as specified would supplement the visual sampling of the lower crown as presented here. Felled trees with more egg masses in the upper crown would indicate the presence of low or intermediate-level populations, while larger numbers of egg masses in the lower crown would suggest that populations are building to outbreak levels, or an outbreak is underway.

**References**

Luck, R. F.; Dahlsten, D. L. 1967. Douglas-fir tussock moth (*Hemerocampa pseudotsugata*) egg mass distribution on white fir in northeastern California. Canadian Entomologist 99: 1193-1203.

* Mason, R. R. 1970. Development of sampling methods for the Douglas-fir tussock moth, *Hemerocampa pseudotsugata* (Lepidoptera: Lymantriidae). Canadian Entomologist 102: 836-845.

# Black Army Cutworm

***Actebia fennica* (Tauscher)**

**Lepidoptera: Noctuidae**

Shepherd, R. F.; Gray, T. G.; Maher, T. F. 1992. Management of black army cutworm. Information Rpt. BC-X-335. Victoria, B.C.: Forestry Canada; 17 p.

**Objective**

To describe a monitoring system for *A. fennica*, with predicted defoliation levels, useful for managing plantings of conifer seedlings.

**Abstract**

Black army cutworm, *Actebia fennica* (Tauscher), adults are attracted to recently burned areas where they lay their eggs. Hatching caterpillars prefer to feed on numerous non-conifer food plants sprouting in burned areas, but they will increasingly feed on seedlings of numerous conifer species planted on that site as caterpillar densities increase. White spruce [*Picea glauca* (Moench) Voss] and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) are commonly attacked. Older instars produce most of the damage. Defoliation reduces seedling height growth, may kill terminals, and inhibits root production. Feeding damage is compounded by moisture stress at the planting site. Sporadic but severe outbreaks of *A. fennica* occur in British Columbia. Most of the defoliation will occur the first year caterpillars appear, with little damage or none occurring in subsequent years. Chemical control is not advisable for *A. fennica* as severe defoliation may occur before a treatment can be applied. Management of *A. fennica* should emphasize monitoring the activity of *A. fennica* adults and larvae in susceptible areas and minimizing planting in areas of higher risk.

Sites susceptible to outbreaks of *A. fennica* in British Columbia are found within the Engelmann spruce-subalpine fir, montane spruce, sub-boreal spruce, and interior cedar-hemlock biogeoclimatic zones. In particular, recently burned areas prone to droughty conditions should be monitored as moisture stress compounds any feeding damage produced by *A. fennica*. Sites with adequate moisture are less prone to extended damage and sites burned after September 15 are not likely to be attractive to *A. fennica*.

**Sampling Procedure**

Sampling should begin at the end of June. Use green Multi-Pher traps (model MP-1; Bio-Contrôle Services, Ste-Foy, Quebec, Canada) baited with a rubber septum releasing 1,000 µg of (Z)-7-dodecenyl acetate and (Z)-11-tetradecynyl acetate pheromone mixture at a ratio of 1:20. Traps should also hold a 2.5-cm2 square of an insecticide strip in the bottom of the

trap to kill attracted moths. Place traps 0.5–1.0 m above ground and at least 100 m apart on south-facing slopes in areas burned by natural or prescribed fires within the past 12 months. One trap will service a 1-km$^2$ (or smaller) area if checked every 1–2 weeks to ensure it is in good shape and operating properly. Rodents may raid traps to feed on captured moths. Traps should remain in place from July 1 to September 15. Tally the total number of moths caught in each trap during this period and compare to the levels of caterpillar infestation and defoliation predicted for the following spring.

| Moth density per trap | Predicted caterpillar infestation level the following spring | Predicted defoliation level of conifer seedlings the following spring |
|---|---|---|
| <350 moths | Low | Low risk of damage; plant in the spring |
| 350–1,200 moths | Moderate | Moderate risk of defoliation at some, but not all sites; check vegetation on site for plants favored by *A. fennica* before planting |
| >1,200 moths | High | High risk of severe defoliation |

Sites identified as having a risk of a moderate caterpillar infestation level should be visited the following spring immediately after snow melt. Preferred food plants (Table 1) should be examined for feeding damage by *A. fennica*. Randomly select 20–30 plants at the site, including at least 5 different species. Significant damage to planted conifer seedlings is likely if most of the inspected host plants show "shotgun holes" or similar feeding damage. If no damage is observed, flag the plants, return in 1 week, and check the plants again. If damage is present at the second visit, and if 14 days of feeding likely remains (before the end of May if at low elevations), then significant damage to conifer seedlings is still possible. If no damage is found at the second visit, then significant damage to conifer seedlings is unlikely and planting should proceed.

For sites where a significant or high risk of defoliation is possible, consider delaying planting until pupation occurs (June 15 at low elevations and up to 3 weeks later at higher elevations) or until the following spring. Should an outbreak occur after planting, mark the area infested at the time of peak damage and survey the area again the following spring before replanting in that area. Replace any trees that are dead, have more than 60% defoliation, or have dead terminal leaders. Potential damage by *A. fennica* can be minimized by planting conifer seedlings in good growing sites with adequate soil moisture and using appropriate planting techniques that avoid damaging the roots. Newly planted seedlings in moist sites and with healthy roots, and older plantings with established root systems, may survive an unexpected defoliation by *A. fennica*.

**Notes**

Damage by sphinx caterpillars (hornworms) or infection by *Rhizinia* root rot can be mistaken for damage by *A. fennica*. Always collect caterpillars and identify them to verify that *A. fen-*

*nica* is responsible for observable damage. Cutworm caterpillars typically hide in the soil near damaged plants during the day.

Table 1. Food plants commonly found in the Columbia Valley and Cariboo mountains listed from highest to lowest feeding preference by the black army cutworm.

| common | botanical name |
|---|---|
| Valerian | *Valeriana diocia* |
| Western meadowrue | *Thalictrum occidentale* |
| common horsetail | *Equisetum arvense* |
| Fireweed | *Epilobium angustifolium* |
| False hellbore | *Veratrum eschscholtzii* |
| Heart-leaved arnica | *Arnica cordifolia* |
| False Solomon's seal | *Smilacina racemosa* |
| Hooker's fairybells | *Disporum hookeri* |
| Rosy twistedstalk | *Streptopus roseus* |
| Honeysuckle | *Lonciera* spp. |
| Western larch | *Larix occidentalis* |
| Saskatoon | *Amelanchier alnifolia* |
| Rose, currants, thimbleberries | *Rosa, Ribes, Rubus* spp. |
| Birch-leaved spirea | *Spiraea betulifolia* |
| Bunchberry | *Cornus canadensis* |
| Soopolallie | *Shepherdia canadensis* |
| Aspen, willow | *Populus tremuloides, Salix* spp. |
| Douglas-fir | *Pseudotsuga menziesii* |
| Englemann spruce | *Picea engelmanii* |
| Lodgepole pine | *Pinus contorta* var. *latifolia* |

**Table 1 reproduced with the permission of the Minister of Public Works and Government Services, granted May 1, 2009.**

# Saddled Prominent

### *Heterocampa guttivata* (Walker)

### Lepidoptera: Notodontidae

Spear-O'Mara, J.; Allen, D. C. 2007. Monitoring populations of saddled prominent (Lepidoptera: Notodontidae) with pheromone-baited traps. Journal of Economic Entomology 100: 335-342.

**Objective**

To monitor *H. guttivitta* populations in sugarbush using pheromone traps; to predict mean peak flight and flight termination by *H. guttivitta* using a degree-day model.

**Abstract**

Saddled prominent, *Heterocampa guttivitta* (Walker), is a periodic defoliator of sugar maple (*Acer saccharum* Marsh.), and other hardwoods in northern USA. Populations of *H. guttivitta* are of a concern in sugarbush management as multiple years of heavy defoliation results in extensive crown damage with reduced yield and quality of sap in healthy, growing trees and mortality in younger, understory maples. Trends in *H. guttivitta* populations can be estimated using bucket traps baited with a 90/10 blend of Z13-hexdadecen-11-yn-1-yl aldehyde (Z13Y11-16:ALD) and hexadec-11-yn-1-yl aldehyde (Y11-16:Ald) with sufficient time for sugarbush operators to consider management options for this pest. Egg density approximates 1.0 viable eggs per 10 leaf clusters when the average peak trap catch equals 70-80 moths. At this approximate density, defoliation of terminal branches in overstory maples becomes visible from the ground level and warrants control measures. Using a base temperature of 5.5°C with temperature data provided by the closest weather stations, mean peak flight and termination of flight period occurred at 304 ± 10 and 571 ± 8 degree-days, respectively.

**Sampling Procedure**

Traps should be installed by late May. Use either Pherocon 1C wing sticky traps (Trécé Inc., Salinas, CA) or green Multipher bucket traps (Le Groupe Biocontrol, Ste. Foy, Quebec). High-capacity, nonsaturating bucket traps are preferable when moth populations are high because sticky traps will saturate quickly. However, sticky traps may be more effective than bucket traps when *H. guttivitta* populations are very low. Bait traps of either type with rubber septa containing 10 µg of a 90/10 blend of Z13Y11-16:ALD and Y11-16:Ald (Research and Productivity Council, Fredericton, New Brunswick). Install a 90 x 25 mm strip of insecticide-impregnated tape in each trap to kill attracted moths. Hang traps below the canopy of each stand and approximately 2 m above the ground. Use a stake with a cross bar instead of hanging traps directly on a tree branch. Place traps at least 20 m within the stand,

with 40 m between traps. Service traps every 4 days and leave in place until termination of the flight period. Mean peak flight and termination of flight period can be predicted at 304 ± 10 and 571 ± 8 degree-days, respectively, using a base temperature of 5.5°C with temperature data provided by the closest weather stations. Sugarbush operators should consider management options when the average peak trap catch equals 70-80 moths, which approximates the threshold of defoliation on branch terminals that is visible from the ground.

**Notes**

Sugarbush management represents the management of sugar maple for its sap to make maple syrup or sugar. Conspecific notodontid species were not attracted to the pheromone blend. The authors did not suggest a specific number of traps to be installed in each stand, but 5 sticky traps were placed in each stand in this study. Estimates of *H. guttivitta* populations should consider the density of sugar maple to other favored hardwoods, particularly American beech (*Fagus grandifolia* Ehrh.), within the stand.

# Variable Oakleaf Caterpillar

### *Heterocampa manteo* (Doubleday)

### Lepidoptera: Notodontidae

Surgeoner, G. A.; Wallner, W. E. 1978. Foliage consumption by the variable oak leaf caterpillar, *Heterocampa manteo* (Lepidoptera: Notodontidae), its use in defoliation predictions. Canadian Entomologist 110: 241-244.

**Objective**

To predict defoliation by *H. manteo* on *Quercus* spp. based on the density of early instars.

**Abstract**

Variable oakleaf caterpillar, *Heterocampa manteo* (Doubleday), commonly defoliates oaks, *Quercus* spp., and other hardwoods in eastern North America. White oak, *Quercus alba* L., is a preferred host of *H. manteo*. Periodic outbreaks reduce tree growth but typically subside after 2-–3 years and before tree mortality occurs. Two generations occur in the south and one generation occurs in the north.

Foliage consumption by *H. manteo* on leaves of both white and red, *Quercus rubra* L., oaks was determined in the lab. An average of 6.9 and 5.2 leaves per larva were observed for white and red oak leaves, respectively. Life studies of *H. manteo* conducted in Michigan indicated predation had little impact on larval survival, therefore a crude prediction of expected defoliation can be made from the density of early instars on oaks. Complete defoliation is likely when early instars average one per 5 leaves, and 50% defoliation can be expected when densities average one per 10 leaves.

**Sampling Procedure**

Randomly sample terminals from canopies of oak trees, using a pole pruner if necessary. Examine the leaves of each terminal for the presence of early instar *H. manteo*. First instars are gregarious on the underside of leaves. Expect 50 and 100% defoliation when early instars average one per ten and five leaves, respectively.

**Notes**

The authors did not specify how many terminals per tree, trees per stand, or leaves per terminal should be sampled to predict defoliation by *H. manteo*. Land managers should examine a sufficient number of trees and leaves per tree to adequately sample the pest population throughout the area of concern. Defoliation estimates will vary if larval parasitism is prevalent as parasitized larvae consume significantly less foliage.

# Pine Butterfly

***Neophasia menapia* (Felder & Felder)**

**Lepidoptera: Pieridae**

Cole, W. E. 1956. Surveys and control methods of the pine butterfly during an outbreak in southern Idaho, 1953-1954. Res. Note RN-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 9 p.

**Objective**

To develop appraisal surveys for *N. menapia* for evaluation of spray treatment efficacy or predict infestations requiring control measures.

**Abstract**

Pine butterfly, *Neophasia menapia* (Felder & Felder), has been a serious pest of ponderosa pine, Pinus ponderosa P. & C. Lawson, and other *Pinus* spp. in the northwest USA. The caterpillars consume all age classes of pine needles, causing significant defoliation and mortality of infested trees. Aerial spray operations were initiated against this pest, but managers had no feasible sampling method to evaluate treatment efficacy. A sampling scheme is described for the eggs of *N. menapia,* the easiest life stage to sample this insect.

Sampling ridges was preferred over creek bottoms due to reduced variance in estimates from ridges. Greater than 10, 5–9, 2–4 and <2 eggs per 38 cm twig sample of new growth indicated epidemic, heavy, light, and endemic population of pine butterfly, respectively. Controls were warranted at densities of >5 eggs per twig.

**Sampling Procedure**

Sampling intensity and distribution of samples depend on the density and distribution of the butterfly population in the area of concern. Avoid sampling in creek bottoms as the distribution of pine butterfly is patchy and therefore requires significantly greater sampling effort to estimate populations within 25% of the mean.

To evaluate treatment efficacy, randomly select a survey line parallel to aerial spray lines. Select a tree every 100.6 m (5 chains) until the required number of trees have been sampled. If the spray block is too short to accommodate all trees on one line, start another line in the same spray block or area of concern. Randomly sample the required number of twigs from ground level to a height of ≈7 m above ground. The following recommendations, based on a 68% confidence interval with a 25% standard error of the mean, generally gave acceptable precision for management purposes:

1. Heavy infestations: sample two 38 cm twigs from each of 10 sequentially selected trees per area, or 10 twigs from each of three trees.
2. Moderate infestations: sample five 38 cm twigs from each of 20 trees per area.
3. Light infestations: sample five 38 cm twigs from each of 20 trees per area.
4. Endemic infestations: sample five 38 cm twigs from each of 25 trees per area.

To predict infestations requiring control measures, sample trees as described above. Population estimates are further refined as:

1. Epidemic infestation: ≥10 eggs per 38 cm twig
2. Heavy infestation: 5–9 eggs per 38 cm twig
3. Light infestation: 2–4 eggs per 38 cm twig
4. Endemic infestation: <2 eggs per 38 cm twig

Control measures are warranted if the average density of pine butterfly eggs on new growth is >5 per twig.

**Note**

This sampling scheme was developed in Idaho and should be used with caution until validated in other areas.

# Bagworm

***Thyridopteryx ephemeraeformis* (Haworth)**

**Lepidoptera: Psychidae**

Raupp, M. J.; Davidson, J. A.; Koehler, C. S.; Sadof, C. S.; Reichelderfer, K. 1988. Decision-making considerations for aesthetic damage caused by pests. Bulletin of the Entomological Society of America 34: 27-32.

**Objective**

To provide a sampling plan for *T. ephemeraeformi*s with reference to quantified economic and aesthetic injury levels for making management decisions.

**Abstract**

Bagworm, *Thyridopteryx ephemeraeformis* (Haworth), is a defoliator of many trees and shrubs, including arborvitae, *Thuja occidentalis* L.. Bagworm larvae are covered by a characteristic loose silk bag covered with bits of organic material, which they construct for concealment. Larvae hang on the branches and feed on the foliage of the host tree, and high densities of bagworms give the tree the appearance of being covered with unsightly brown cones.

An economic injury level (EIL) was developed for retail nurserymen based on the estimated cost of management, the market value, and the injury produced by *T. ephemeraeformi*s for a 1.2-m arborvitae. The EIL was estimated to be 4 first instar *T. ephemeraeformi*s per 1.2-m tree. The low value of the EIL reflects the low tolerance of homeowners and their perceptions of greatly reduced value associated with the presence of the insect on an ornamental plant.

An aesthetic injury level (AIL) was developed for bagworm based on when half the customers at a nursery retail center would initiate control measures for the pest. The relationship between when customers believed the arborvitae had been damaged by *T. ephemeraeformi*s and when control measures were required was quantified. Regression analysis indicated that half of the polled customers perceived the foliage injury produced by approximately 9 first instars per 1.2-m of tree height sufficient to warrant control measures. This aesthetic threshold corresponds to approximately 7% of the crown being discolored or defoliated. Half of the polled customers would consider the foliage injury produced by approximately 6 first instars per 1.2-m tree as damaging to the plant. This AIL represents <8% of the crown being discolored or defoliated.

**Sampling Procedure**

Examine arborvitae for the presence of *T. ephemeraeformi*s in its characteristic bags. If the density of *T. ephemeraeformi*s on an individual tree is ≥6 first instars per 1.2 m of tree stem, nursery managers should initiate control measures to maintain a desirably high aesthetic quality of ornamental arborvitae.

**Notes**

The AIL of 6 or more first instar *T. ephemeraeformi*s per 1.2 m of arborvitae stem, based on customer perception of aesthetic damage, is marginally higher than the EIL of 4 first instars per 1.2 m of tree stem, which was based on economic parameters. The actual injury by *T. ephemeraeformi*s observed on arborvitae during this study was largely cosmetic as the plants tolerated high levels of defoliation without associated mortality and injury was not evident several years later after refoliation.

# Orangestriped Oakworm

***Anisota senatoria* (J.E. Smith)**

**Lepidoptera: Saturniidae**

Coffelt, M. A.; Schultz, P. B. 1993a. Relationship among orangestriped oakworm (Lepidoptera: Saturniidae) frass length, frass production, host plant, and defoliation. Journal of Entomological Science 28: 291-298.

## Objective

To relate *A. senatoria* frass length and quantity to defoliation levels on pin oak.

## Abstract

The orangestriped oakworm, Anisota senatoria (J.E. Smith), is a native defoliator of various oaks, *Quercus* spp., and other hardwood species in the eastern US and Canada. Severe outbreaks of *A. senatoria* occurred in some urban areas of Virginia in the early 1990s, leading to the development of integrated pest management strategies. Coffelt and Schultz (1990) developed an aesthetic injury level of 25% defoliation for *A. senatoria* on urban pin oak, *Quercus palustris* Muenchhausen. In the urban landscape, citizens objected to frass accumulation and noticeable larvae more than actual defoliation by *A. senatoria* (Coffelt and Schultz 1990).

Field and laboratory experiments were designed to develop decision-making guidelines for *A. senatoria* management based on frass measurements. Frass length and production per larva were affected by *Quercus* spp. host, but mean frass length could be used to estimate which instars were present on pin oak. The presence of early instar *A. senatoria* may signal the need to consider control measures in the urban landscape. Frass production on pin oak was positively related to percentage defoliation ($y = 24.12 + 0.43x$; $r^2 = 0.62$), allowing for the prediction of defoliation levels based on frass accumulation. Using the aesthetic injury level developed by Coffelt and Schultz (1990), 2.2 g of frass collected on a 2.62 $m^2$ circle of fabric under a tree equated to 25% defoliation on pin oak and would thus warrant control measures.

## Sampling Procedure

Place a circular piece (2.62 $m^2$) of polypropylene landscape fabric under the canopy of selected pin oaks in late July. Leave fabric circles in place until late August, then weigh all the frass pellets collected on the fabric to the nearest gram. Use the equation $y = 24.12 + 0.43x$, where y = percent defoliation and x = frass weight in g per 2.62 $m^2$, to predict defoliation. Frass production of 2.2 g per 2.62 $m^2$ circle of fabric would warrant control measures if using the aesthetic injury level of 25% defoliation.

To determine if early instars are present, take a subsample of 25 frass pellets from each tree.

Measure pellet length to the nearest 0.01 mm using a stereomicroscope fitted with an ocular micrometer. Compare the average length of collected pellets to those presented in Table 1 to determine the stage of instars present on the tree. The presence of early instars could indicate the need for control strategies.

**Notes**

This technique assumes that the operator has a certain familiarity with the characteristics of lepidopteran frass. The presence of *A. senatoria* larvae should be verified on sampled trees before assuming any collected frass was produced by *A. senatoria*. The relationship between frass production and percent defoliation on pin oak was developed from data taken on small trees approximately 2 m tall and with a 6.3 cm diameter breast height. Further research is needed to determine if the relationship is valid for larger pin oaks, or for oaks of different species.

**Reference**

Coffelt, M. A.; Schultz, P. B. 1990. Development of an aesthetic injury level to decrease pesticide use against orangestriped oakworm (Lepidoptera: Saturniidae) in an urban pest management project. Journal of Economic Entomology 83: 2044-2049.

Table 1. Mean frass length and total frass produced by *A. senatoria* instars, 1989 field experiments.*

| Instar | Frass Length (mm) | *n* | Total Frass Produced† | *n* |
|---|---|---|---|---|
| First | 0.58 ± 0.003 e | 15 | 4.96 ± 0.33 c | 15 |
| Second | 1.06 ± 0.01 d | 9 | 12.63 ± 1.76 c | 15 |
| Third | 1.64 ± 0.02 e | 11 | 35.54 ±3.89 c | 15 |
| Fourth | 2.57 ± 0.05 b | 11 | 233.65 ± 17.5 b | 11 |
| Fifth | 3.33 ± 0.09 a | 6 | 340.33 ± 70.8 a | 6 |

* Means (± SEM) within columns followed by the same letter are not significantly different ($P > 0.05$) (Student-Newman-Keuls test) (SAS Institute 1985).

†Total frass produced by instar of an *A. senatoria* group with an estimated initial mean population size of 485 larvae.

**Table 1 reproduced with the permission of the Journal of Entomological Science, granted April 2, 2009.**

# Orangestriped Oakworm

***Anisota senatoria* (J.E. Smith)**

**Lepidoptera: Saturniidae**

Coffelt, M. A.; Schultz, P. B. 1993b. Quantification of an aesthetic injury level and threshold for an urban pest management program against orangestriped oakworm (Lepidoptera: Saturniidae). Journal of Economic Entomology 86: 1512-1515.

**Objective**

To develop thresholds for densities of *A. senatoria* egg masses on trees of increasing size that are predictive of the 25% leaf defoliation level on pin oak, *Quercus* palustris Muenchhausen.

**Abstract**

The orangestriped oakworm, *Anisota senatoria* (J.E. Smith), is a native defoliator of various oaks, *Quercus* spp., and other hardwood species in the eastern U.S. and Canada. Outbreaks became severe in some urban areas of Virginia in the early 1990s, leading to the development of integrated pest management strategies. Coffelt and Schultz (1990) developed an aesthetic injury level of 25% defoliation for *A. senatoria* based on estimating defoliation levels each day. This procedure was time consuming and often control measures were applied too late to protect trees from significant defoliation.

The authors developed an alternative method of predicting defoliation levels on urban pin oak, *Quercus palustris* Muenchhausen, by relating egg mass density to subsequent defoliation by *A. senatoria*. The density of egg masses was related positively to defoliation level on pin oaks for four size classes (12.6, 19.1, 26.4 and 35.4 cm DBH). Applying the 25% defoliation threshold to size class gave egg mass density thresholds of 0.9, 4.8, 6.6, and 9.0 per tree. Sampling egg masses should provide managers sufficient time to make control decisions before the aesthetic injury level is exceeded. Because *A. senatoria* larvae remain in gregarious clusters as young instars, these thresholds are also applicable to first and second instars.

**Sampling Procedure**

Measure the DBH of each pin oak sampled and assign the tree to the nearest DBH class (12.6, 19.1, 26.4 or 35.4 cm). Although not explicitly stated in the article, rounding DBH to the nearest cm is probably sufficient.

Orangestriped oakworm lays its eggs on the underside of oak leaves on terminal shoots in July in eastern Virginia. The yellow egg masses are easily spotted, but they may be more vis-

ible when sampling on a cloudy day with less glare. Walk completely around a selected pin oak and count the number of egg masses visible on the underside of the leaves in the lower canopy (P. Shultz, pers. comm.). Compare the estimate with the threshold value of egg mass density that may result in 25% or more defoliation (see Table 1). Control measures should be applied if the aesthetic injury level of 25% defoliation will be exceeded on trees with high aesthetic value.

**Note**

This sampling plan should only be used for *A. senatoria* infesting pin oak as the thresholds may vary with other species of oaks.

**References**

* Coffelt, M. A.; Schultz, P. B. 1990. Development of an aesthetic injury level to decrease pesticide use against orangestriped oakworm (Lepidoptera:Saturniidae) in an urban pest management project. Journal of Economic Entomology 83: 2044-2049.

Table 1. Mean diameter and height of *Q. palustris* and number of *A. senatoria* egg masses that caused 25 and 100% defoliation, 1987–1990.

| Tree DBH[a] (rounded to nearest cm) | DBH Range | No. egg masses that cause 25% defoliation | No. egg masses that cause 100% defoliation |
|---|---|---|---|
| 12.6 | 8.9–13.7 | 0.9 | 4.0 |
| 19.1 | 14.0–22.6 | 4.8 | 14.5 |
| 26.4 | 23.0–30.0 | 6.6 | 17.0 |
| 35.4 | 31.0–40.4 | 9.0 | 28.3 |

[a]DBH, diameter at breast height.

**Table 2 modified and reproduced with permission from the Journal of Economic Entomology, granted April 2, 2009.**

# Western Blackheaded Budworm

***Acleris gloverana* (Walsingham)**

**Lepidoptera: Tortricidae**

Gray, T. G.; Shepherd, R. F.; Wood, C. S. 1973. A hot-water technique to remove insect eggs from foliage. Canadian Forest Service Bi-monthly Res. Notes 29: 29.

**Objective**

To develop a hot water extraction technique useful for separating *A. gloverana* eggs from hemlock foliage.

**Abstract**

Western blackheaded budworm, *Acleris gloverana* (Walsingham), is an occasional pest of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., in the western US and Canada. An extraction technique using hot water was developed to remove *A. gloverana* eggs from hemlock branches in less time and with greater reliability than a sodium hydroxide solution soak. Using this technique, two people can process up to 200 branches a day if screens are not used. Two people can process 70 branches a day if samples require the use of screens to remove debris before filtration.

**Sampling Procedure**

Randomly sample 46-cm branch tips from trees in the area of concern. Soak each branch individually in a 3,000 ml beaker of boiling water (100 ºC) for a maximum of 30 secs. Soaking the branches for longer will remove all the foliage in addition to the eggs, requiring additional screening of the needles from the sample. Using tongs, agitate the branch in the water to ensure that all *A. gloverana* eggs are released from the foliage. Eggs will settle to the bottom of the beaker. Remove the branch and slowly pour the water containing the eggs into an 18.5-cm Buchner funnel. Rinse the beaker with additional water to ensure no eggs remain and pour this rinsate into the funnel as well. Vacuum filtrate the material through filter paper. A plexiglass ring can be used to weight the filter paper down and ensure that eggs stay on the upper surface of the paper. This ring should also be rinsed adequately and the rinsate filtered as well.

Cumbersome branches should be clipped into smaller segments to fit in the beaker, but this will increase the amount of debris in the water. Debris can be removed by pouring the contents of the beaker onto a #20 mesh screen fitted onto a #50 mesh screen (US Series Equivalent). The top screen will filter coarse debris while the bottom screen will capture the eggs. Wash the debris on the top screen with additional rinses using plenty of water. When done,

wash the bottom screen into a funnel fitted into a 1-liter container. Use plenty of water to remove all the eggs on the screen, then vacuum filtrate as described above.

**Notes**

Express egg density as the total number of eggs counted on the filter paper divided by the initial wet weight of the 46-cm branch sample. Filter papers may be refrigerated or frozen for counting at a later date; store labeled filter papers between polyethylene sheets. The authors showed that a single wash using this technique recovered 84% of the total eggs while three washes recovered 98% of the total. This method may be useful with other lepidopteran species, but should be tested and verified before use.

# Western Blackheaded Budworm

***Acleris gloverana* (Walsingham)**

**Lepidoptera: Tortricidae**

Harris, J. W. E.; Collis, D. G.; Magar, K. M. 1972. Evaluation of the tree-beating method for sampling defoliating forest insects. Canadian Entomologist 104: 723-729.

**Objective**

To reduce sampling effort and improve sampling accuracy for populations of *A. gloverana*.

**Abstract**

Western blackheaded budworm, *Acleris gloverana* (Walsingham), is an occasional pest of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., in the western US and Canada. The Canadian Forestry Service includes this species in its annual Forest Insect and Disease Survey (FIDS). The authors focused on *A. gloverana* in a study conducted to examine the appropriateness of the standard 3-tree sample used to monitor populations of insect defoliators. The standard method of sampling 3 trees using a beat sheet was appropriate for *A. gloverana* as large variances were associated with samples of only 1 or 2 trees. A total of 17 samples, calculated from 51 trees, were required for estimating low populations of *A. gloverana* over a sampling area of 60,703 hectares, with a 95% confidence level of remaining within 50% of the arithmetic mean. This relatively small sampling effort was deemed appropriate as the survey focuses on broad population changes over large areas. In addition, samples collected from roadsides did not vary significantly from those collected randomly throughout the area or interest, or those collected from stands of a certain percentage of tree species. Weather did affect the abundance of *A. gloverana*, with fewer larvae collected in the rain or on wet foliage.

**Sampling Procedure**

Randomly sample 3 trees of each species of interest at each selected site by laying a 2.1 by 2.7 m white sheet under a tree and beating the branches with a 3.7 m pole for approximately 30 secs. Identify and count the *A. gloverana* larvae that fall onto the sheet. Sampling from locations that are easily accessible by roads or waterways, i.e. “roadside sampling”, is convenient, economical, and statistically appropriate. To obtain a true estimate of larval populations, surveys for *A. gloverana* should be conducted in dry weather when the foliage is not wet. Current infestation levels can be compared to previous FIDS reports as a rough interpretation of whether populations are increasing, decreasing, or remaining stable.

**Notes**

The green-striped forest looper, Melanolophia imitata (Walker), is a common defoliator of conifers that produced top-kill and tree mortality in western hemlock in British Columbia during the 1960's, but has not had an outbreak since then. The authors recorded data on M. imitata during this study and found similar results as for *A. gloverana*, with the exception that M. imitata was less abundant on clear, sunny days. A total of 16 samples, calculated from 51 trees, was required for estimating low populations of M. imitata over a sampling area of 60,703 hectares, with a 95% confidence level of remaining within 50% of the arithmetic mean.

# Western Blackheaded Budworm

***Acleris gloverana* (Walsingham)**

**Lepidoptera: Tortricidae**

Shepherd, R. F.; Gray, T. G. 1990. A sampling system for eggs of western blackheaded budworm, *Acleris gloverana* (Walsingham) (Lepidoptera: Tortricidae), on western hemlock, *Tsuga heterophylla* (Raf.) Sarg. Canadian Entomologist 122: 555-562.

**Objective**

To develop a sampling plan that estimates the density of *A. gloverana* at three levels of fixed precision and relates density to predicted damage levels.

**Abstract**

Western blackheaded budworm, *Acleris gloverana* (Walsingham), is an occasional pest of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., in the western US and Canada. A sequential estimation plan was developed to improve the efficiency of sampling *A. gloverana* eggs. Previous work described the relationship between egg density and defoliation levels of *A. gloverana* (Silver 1959), but it was labor intensive. The method described here would allow managers to efficiently estimate egg densities to predict defoliation levels of *A. gloverana*.

The fresh weight (or volume) of a 46-cm branch tip per tree is used as the sample unit for the estimation of density of eggs of *A. gloverana*. Branch weight is less variable among crown levels and cardinal points on the tree, and so fewer sample units are required than if using branch volume. The average time to select a tree, remove a sample, and process the sample is 21 minutes.

**Sampling Procedure**

Randomly sample one 46-cm branch tip per tree in the area of concern. Soak each branch individually in a 3,000 ml beaker of hot water for a maximum of 30 secs (Gray et al. 1973; see our summary in this volume). Soaking the branches for longer will remove all the foliage in addition to the eggs, requiring additional screening of the needles from the sample. Using tongs, agitate the branch sample in the water to ensure that all *A. gloverana* eggs are released from the foliage. Eggs will settle to the bottom of the beaker. Remove the sample branch and slowly pour the water containing the eggs into an 18.5-cm Buchner funnel. Rinse the beaker with additional water to ensure no eggs remain and pour this rinsate into the funnel as well. Vacuum filtrate the material through filter paper. A plexiglass ring can be used to weight the filter paper down and ensure that eggs stay on the upper surface of the paper. This ring should also be rinsed adequately and the rinsate filtered as well.

Count the number of *A. gloverana* eggs on the filter paper and divide the count by the fresh weight of the sampled branch. Sample a minimum of four trees as described above. Keep a cumulative tally of egg densities, rounding to the nearest egg per gram of fresh branch weight. Refer to Table 2 for the desired level of fixed precision and stop sampling once the cumulative egg density is equal to or exceeds the appropriate threshold. Compare the estimated density with Table 3 to determine the predicted defoliation class.

**Notes**

This method should only be used before serious defoliation has occurred in the tree. High levels of defoliation alter the distribution of needles, which are oviposition sites for this insect, within the tree crown. This changes the relationship between mean crowding and insect density and changes the relationship between required sample size and egg density at each level of fixed precision used.

Filter papers may be refrigerated or frozen for counting at a later date; store labeled filter papers between polyethylene sheets.

**References**

Gray, T. G.; Shepherd, R. F.; Wood, C. S. 1973. A hot-water technique to remove insect eggs from foliage. Canadian Forest Service Bi-monthly Res. Notes 29: 29.

Silver, G. T. 1959. A method for sampling eggs of the blackheaded budworm. Journal of Forestry 57: 203-205.

Table 2. The cumulative egg densities per gram of fresh branch weight for different required sample sizes to attain allowable errors of 0.10 and 0.20. Sample densities are determined for each branch and accumulated. Stop sampling when the accumulated sample data equals or exceeds the egg density of the chosen allowable error.

| Number of branches sampled | Enter accumulated sample data | Allowable error | |
|---|---|---|---|
| | | 0.20% | 0.10% |
| | | Accumulated egg densities per gram of fresh weight | |
| 4 | | 14 | - |
| 5 | | 9 | - |
| 6 | | 7 | - |
| 7 | | 6 | - |
| 8 | | 6 | - |
| 9 | | 5 | - |
| 10 | | 5 | - |
| 11 | | 5 | - |
| 12 | | 5 | - |
| 13 | | 5 | 175 |
| 14 | | 4 | 100 |
| 15 | | 4 | 70 |
| 16 | | 4 | 56 |
| 20 | | 4 | 35 |
| 30 | | 4 | 23 |
| 40 | | 4 | 20 |
| 50 | | 4 | 18 |

Table 3. Range of egg densities per branch and per gram of fresh branch weight for three defoliation classes.

| Damage class | Number of eggs per 46cm branch | Number of eggs per gram of fresh weight |
|---|---|---|
| Nil to light | 0–26 | 0–1.40 |
| Moderate | 27–59 | 1.41–3.20 |
| Severe | 60 + | 3.21 |

**Table 2 and 3 reprinted as fair us under 17 USC § 107.**

# Two-year-cycle Spruce Budworm

## *Choristoneura biennis* Freeman

### Lepidoptera: Tortricidae

Nealis, V. G.; Turnquist, R. 2003. Predicting defoliation by *Choristoneura biennis* (Lepidoptera: Tortricidae). Canadian Entomologist 135: 903-907.

**Objective**

To predict defoliation within stands by *C. biennis* in its second year based on feeding damage observed during its first year.

**Abstract**

Two-year-cycle spruce budworm, *Choristoneura biennis* Freeman, occurs exclusively in high elevation stands of subalpine fir, *Abies lasiocarpa* Hook., and white spruce, *Picea glauca* (Moench) Voss, in British Columbia. During the first year, the insect develops to the fourth instar and overwinters. In the second year, the fourth instars resume feeding, pupate, emerge as adults, and lay eggs. Their progeny develop until the second instar and then overwinter, completing the 2-year life cycle. The last three instars of *C. biennis* (i.e., fourth, fifth, and sixth instars) produce most of the defoliation of subalpine fir and white spruce. Periodic outbreaks occur every 30 years and can last 5–10 years.

Most surveys for *C. biennis* rely on direct sampling of egg masses or larvae, but egg mass density is a weak predictor of larval density or defoliation. Historical and contemporary survey data were used to develop a method of estimating the defoliation within stands expected the second year of the *C. biennis* life cycle, based on feeding damage observed during the first year. A strong linear relationship exists between the percentage of shoots damaged by first-year larvae and the percentage of defoliation produced by larvae in their second year ($r^2 = 0.78$; $P < 0.001$). This relationship is expressed by the equation $d = -4.24 + 1.053x$, where d = the percentage of defoliation expected in the second year, x = the percentage of shoots damaged in the first year of feeding, and both d and x are arcsine-transformed values.

Feeding damage is relatively easy to assess using the method of Fettes (1950) and is not subject to the sampling bias of observers who may fail to find all *C. biennis* larvae in a branch sample. Land managers can use the predicted defoliation levels to judge whether control measures are necessary in the upcoming year.

**Sampling Procedure**

Establish 50 x 50 m plots at least 50 m inside the forest boundary. Each corner of the plots

should have clusters of codominant white spruce and subalpine fir. Sample plots only after first-year larvae have finished feeding. Randomly select 10 mature trees of both white spruce and subalpine fir within the four corner clusters (10 trees per species/plot). Randomly cut one or two 45-cm branch tips from each tree using pole pruners. Bag and return branches to the laboratory. Visually estimate the percentage of defoliation (needles removed) on current-year shoots of each branch using the illustration in Figure 6 from Fettes (1950).

Convert the defoliation class values to percentage shoots damaged using the mid-point of the defoliation class as the mean. Calculate the percentage of shoots damaged within the stand by pooling all branch data for both white spruce and subalpine fir.

Use the following equation to estimate defoliation in the subsequent year:

$$d = -4.24 + 1.053x$$

where d = the percentage of defoliation expected in the second year, x = the percentage of shoots damaged in the first year of feeding, and both d and x are arcsine-transformed values.

**Reference**

Fettes, J. J. 1950. Investigations of sampling techniques for population studies of the spruce budworm on balsam fir in Ontario. Annual Rep. 1949. Sault Ste. Marie: Canadian Forest Service, Forest Insect Lab; 11 p.

Fig. 6. Fettes method of estimating defoliation.

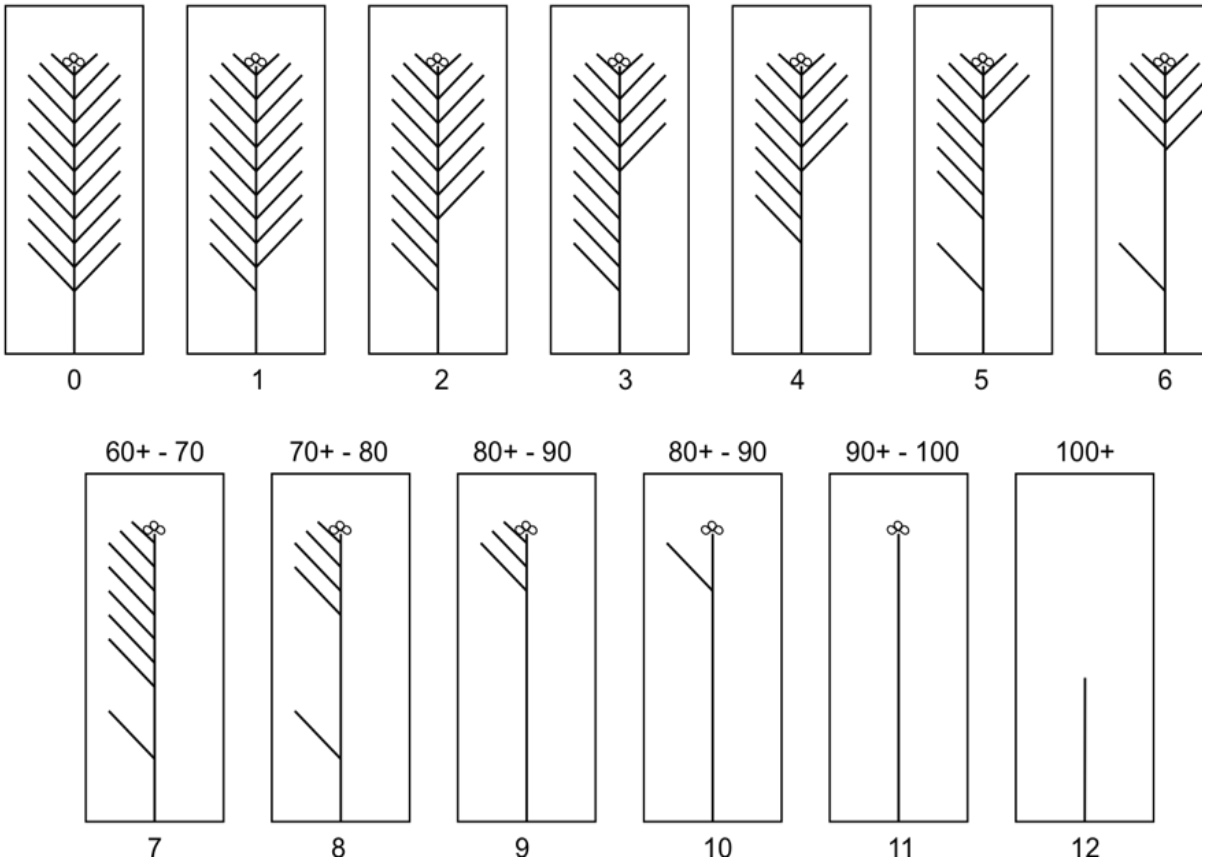


**Figure 6 taken from:**
**Montgomery, B. A.; Simmons, G. A.; Witter, J. A.; Flexner, J. L. 1982. The spruce budworm handbook: a management guide for spruce-fir stands in the Lake States. Handb. 82-7. Ann Arbor, MI: Michigan Cooperative Forest Pest Management Program; 35 p.**

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Fowler, G. W.; Simmons, G. A. 1985. Spruce budworms handbook: sampling procedures for spruce budworm egg-mass surveys (with reference to the Lake States). Agric. Handb. 635. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 33 p.

**Objectives**

To summarize the methods used to estimate the density of *C. fumiferana* egg masses in spruce-fir stands and calculate the associated variance of the mean, the allowable error percentage, and the 75% upper and lower error boundaries.

**Abstract**

Spruce budworm, *Choristoneura fumiferan*a (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

The methods for sampling *C. fumiferana* egg masses summarized in this handbook are a compilation resulting from a cooperative effort between the U.S. Department of Agriculture and the Canadian Department of the Environment (CANUSA). Sampling procedures and associated statistics are described in detail for single stands as well as forest management units and larger areas. A system to determine the hazard rating and treatment priority of stands is presented as well. These methods are appropriate for pure or mixed stands of white and black spruce, *Picea mariana* (P. Mill.) B.S.P., or balsam fir.

**Sampling Procedure**

Estimating egg mass density for a single stand: Choose high risk stands to sample based on whether an outbreak is in progress, the stand value is high, the stand is ≥2 ha, the stand contains more than 30% spruce-fir, dominant/codominant trees are ≥9 m tall, and the area is accessible for management and harvesting. Determine the number of plots appropriate for the size of the stand based on the following:

| Stand size | Size and rank of stand | Recommended number of sampling plots (consisting of 3 trees each) |
|---|---|---|
| <10 ha | Small, rank 1 | 2 |
| 10–20 ha | Medium, rank 2 | 3 |
| 20–40 ha | Large, rank 3 | 4 |
| >40 ha | Very large, rank 4 | 5 |

Determine where to place the plots using a compartment map or aerial photo of the stand. Draw a line bisecting the long axis of the stand. Divide the number of samples to be taken into the length of the line to determine the interval between sample points on the line. Use a random number generator to pick a random number between 0 and the interval length. This number determines how far into the plot the first sample point will be located. Space the remaining sample points along the line from this initial point using the interval length.

In the field, randomly select the 3 host trees closest to the designated sample point. Selected trees should be either spruce or fir if the stand is mixed. Trees should be dominant/codominant and between 9–18 m tall, have a 50–100% live crown ratio, and be relatively open grown. For each tree in a sampling point, cut two branches randomly selected from the midcrown of each sample tree, being sure that each sample includes all the live foliage on the branch. Clip all the live foliage off the branches and place together in one large bag labeled with the date, stand number or name, the plot number, and the tree number.

In the laboratory, carefully measure the length and width of foliage on each branch and record the measurements on the data sheet (Table 1). Clip the foliage into 10–15 cm sections and examine each for fresh egg masses. Any egg masses on new foliage are considered fresh. Egg masses on old foliage are considered fresh if they are a clean white, fully inflated, and show no signs of damage or parasitization. Grey, deflated, or otherwise damaged egg masses are considered old. Egg masses with at least 50% black eggs are considered parasitized. Remove all egg masses and needles and place in a container. Record the total number of fresh egg masses and the total number of parasitized egg masses found on the datasheet. Return the branch segments and egg masses back to the labeled bag if a checker is re-examining bags for searcher accuracy.

To check the accuracy of personnel searching for egg masses, re-examine 25–50 randomly selected bags previously processed by one searcher. The original searcher should not know which bags will be selected and should not do the re-examination. Using Table 2, calculate the accuracy proportion of each searcher by adding the total number of new egg masses found in a bag by the first searcher to the number of new egg masses found during re-examination. Divide this number into the total number of new egg masses found in a bag by the first searcher to generate the accuracy proportion for the searcher. Correct future egg mass counts by that searcher by dividing the number of egg masses found in a bag by the accuracy proportion calculated for that searcher.

$$\text{Accuracy proportion} = \frac{\text{Total number new egg masses found by searcher}}{\text{Total number new egg masses found by searcher + total number of egg masses found during re-examination}}$$

As a rule, all samples should be checked twice for accuracy if populations of spruce budworms are low (>0.4 egg mass/1,000 $cm^2$ foliage). There is no need to calculate a correction factor in this case.

Use the following formulae to calculate the average stand egg mass density (SA), the variance of the average [$s^2(SA)$], the allowable error percent (AE%), and the 75% error boundaries per stand:

$$SA = \sum PD_i / n$$

where n = the number of plots of three trees each, $PD_i = \sum T_j/3$ represents the plot average egg mass density for the $i^{th}$ plot, and $T_j$ is the tree egg mass density for the $j^{th}$ tree as determined from the two branches sampled from that tree.

$$s^2(SA) = \frac{\sum PD_i^2 - \left(\sum PD_i\right)^2 / n}{n(n-1)}$$

$$AE\% = [2s(SA)/SA] \times 100$$

$$\text{Upper bound} = SA + 2s(SA)$$
$$\text{Lower bound} = SA - 2s(SA)$$

These sample statistics provide current information on *C. fumiferana*, which can be used to estimate the potential for defoliation and damage in the future. A hazard rating and treatment priority can be determined for the stand using these sample statistics as described below under "Estimating Egg mass Density in a Forest Management Unit."

Estimating Egg Mass Density in a Forest Management Unit: Sampling all stands within the forest management unit allows a manager to determine if harvest is needed and, if so, which stands should be harvested first. Calculate egg mass density and associated sample statistics for each stand sampled using the procedures described above. Continue by determining the hazard rating and treatment priority for the unit using the procedures described below.

1. Rank each stand based on the stand's vulnerability to spruce budworm damage. These hazard ratings are based on the particular system used, such as Batzer and Hastings (1981) for Minnesota and Lynch et al. (1984) for the Upper Peninsula of Michigan.

| Rank of stand | Vulnerability rating |
|---|---|
| 1 | Low |
| 2 | Moderate |
| 3 | High |
| 4 | Extreme |

2. Rank each stand based on the defoliation of current year foliage (Montgomery et al. 1982):

| Rank of stand | Defoliation of current-year foliage | % Defoliation |
|---|---|---|
| 1 | None; defoliation minimal or not observed | 0–20% |
| 2 | Light to moderate | 21–50% |
| 3 | Heavy | 51% or more but no evident topkill |
| 4 | Severe | 51% or more; topkill evident |

3. Rate each stand equal to the number of successive years visible defoliation has occurred.
4. Add +2 if the spruce budworm population is increasing or −2 if the population is declining.
5. Rate each stand based on the estimated future defoliation based on the following:

| | Average egg mass density | | Expected defoliation | |
|---|---|---|---|---|
| Rating | Pure Fir or mixed spruce fir | Pure Spruce | Percent | Intensity |
| 1 | <0.4 | <0.8 | <26 | Light |
| 2 | 0.4–1.09 | 0.8–2.19 | 26–50 | Moderate |
| 3 | 1.1–1.7 | 2.2–3.4 | 51–75 | Heavy |
| 4 | >1.7 | >3.4 | >75 | Severe |

The level of expected defoliation on white spruce should be lower than defoliation on balsam fir for similar egg mass densities, so the critical values for average egg mass density are raised for stands of pure spruce.

Sum the five ratings described above for each stand to determine the treatment priority for the stand. Stands rated as “high” should be harvested immediately. Harvest can be postponed 2–3 years for stands rated as “intermediate”, while stands rated as “low” should be monitored for a change in treatment priority until harvested.

| Treatment priority | Sum of 5 ratings |
|---|---|
| 1= low | 2–7 |
| 2 = intermediate | 8–11 |
| 3 = high | 12+ |

**Notes**

Not all stands in a forest management unit need to be sampled for *C. fumiferana*. Egg mass density can be estimated from at least half of the stands in the unit or from at least five stands; managers should choose whichever is greater in number. The guidelines for sampling a limited number of stands within a forest management unit, instead of sampling all stands in the unit, are based on the authors' experiences. Refer to the original publication for the formulae used to calculate the sample statistics for a management unit if sampling a selected number of stands instead of all stands.

Refer to the original publication for detailed information regarding the calculations and formulae used with these methods, and for methods used to monitor *C. fumiferana* populations over larger regions. The authors also suggest that the procedures used for egg mass estimates could be adopted for use with sampling overwintering larvae and pupae from foliage samples, or sampling adult moths using light/pheromone traps.

**References**

Batzer, H. O.; Hastings, A. R. 1981. Rating spruce-fir stands for spruce budworm vulnerability in Minnesota. In: Hedden, R. L.; Barras, S. J.; Coster, J. E., technical coordinators. Hazard-rating systems in forest insect pest management. Gen. Tech. Rep. WO-27. Washington, D.C.: U.S. Department of Agriculture, Forest Service; p. 105-108.

Lynch, A. M.; Fowler, G. W.; Witter, J. A. 1984. Development of empirical models to rate spruce-fir stands in Michigan's upper peninsula for hazard from the spruce budworm (Lepidoptera: Tortricidae): a case history. Great Lakes Entomologist 17: 163-174.

# Montgomery, B. A.; Simmons, G. A.; Witter, J. A.; Flexner, J. L. 1982. The spruce budworm handbook: a management guide for spruce-fir stands in the Lake States. Handb. 82-7. Ann Arbor, MI: Michigan Cooperative Forest Pest Management Program; 35 p

Table 1. Field data sheet for recording data to estimate stand eff mass density.

Stand no. or name:

| Plot no. | Tree no. | Branch no. | Foliage measurements (cm) | | No. of new egg masses | |
|---|---|---|---|---|---|---|
| | | | Length | Maximum width | Total | Parasitized |
| 1 | 1 | 1 | | | | |
| | | 2 | | | | |
| | 2 | 1 | | | | |
| | | 2 | | | | |
| | 3 | 1 | | | | |
| | | 2 | | | | |
| 2 | 1 | 1 | | | | |
| | | 2 | | | | |
| | 2 | 1 | | | | |
| | | 2 | | | | |
| | 3 | 1 | | | | |
| | | 2 | | | | |
| 3 | 1 | 1 | | | | |
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| | 2 | 1 | | | | |
| | | 2 | | | | |
| | 3 | 1 | | | | |
| | | 2 | | | | |
| 4 | 1 | 1 | | | | |
| | | 2 | | | | |
| | 2 | 1 | | | | |
| | | 2 | | | | |
| | 3 | 1 | | | | |
| | | 2 | | | | |
| 5 | 1 | 1 | | | | |
| | | 2 | | | | |
| | 2 | 1 | | | | |
| | | 2 | | | | |
| | 3 | 1 | | | | |
| | | 2 | | | | |

Table 2. Data sheet for recording data to estimate a searcher's accuracy proportion.

| Bag no. | No. egg masses found | | | Bag no. | No. egg masses found | | | Bag no. | No. egg masses found | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Searcher | Checker | Total | | Searcher | Checker | Total | | Searcher | Checker | Total |
| 1 | | | | 18 | | | | 35 | | | |
| 2 | | | | 19 | | | | 36 | | | |
| 3 | | | | 20 | | | | 37 | | | |
| 4 | | | | 21 | | | | 38 | | | |
| 5 | | | | 22 | | | | 39 | | | |
| 6 | | | | 23 | | | | 40 | | | |
| 7 | | | | 24 | | | | 41 | | | |
| 8 | | | | 25 | | | | 42 | | | |
| 9 | | | | 26 | | | | 43 | | | |
| 10 | | | | 27 | | | | 44 | | | |
| 11 | | | | 28 | | | | 45 | | | |
| 12 | | | | 29 | | | | 46 | | | |
| 13 | | | | 30 | | | | 47 | | | |
| 14 | | | | 31 | | | | 48 | | | |
| 15 | | | | 32 | | | | 49 | | | |
| 16 | | | | 33 | | | | 50 | | | |
| 17 | | | | 34 | | | | | | | |
| | | | | | | | | Total | | | |

P = Searcher acciracy proportion
S = Total number of egg masses found by searcher
SC = Total number of egg masses found by searcher and checker

P = S/SC = _____ = ☐

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

MacLean, D. A.; MacKinnon, W. W. 1998. Sample sizes required to estimate defoliation of spruce and balsam fir caused by spruce budworm population accurately. Northern Journal of Applied Forestry 15: 135-140.

**Objective**

To determine the sampling intensity required to predict *C. fumiferana* defoliation accurately as a function of host tree species.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, with epidemics lasting 5–10 years.

An assessment of 172,300 individual shoots from 6,890 mid-crown branches taken from 135 spruce and balsam fir stands throughout New Brunswick was conducted to determine sample sizes required for estimating *C. fumiferana* defoliation. Dominant host species were white spruce, red spruce (*P. rubens* Sarg.), and black spruce [*P. mariana* (Mill.) B.S.P.], as well as balsam fir. Host species and the mean defoliation level, as classified with a preliminary assessment, determine the required sample size of shoots per branch or branches per stand needed to predict budworm defoliation. Sample sizes were estimated at the 90 or 95% probability level that the confidence interval was within ±10% defoliation as a function of average defoliation level and tree species. For a desired probability level of 90%, 17–19, 24–37, and 44–58 shoots per branch should be sampled when mean defoliation is light, moderate, and severe, respectively. For a desired probability level of 95%, 26–28, 67–88, and 44–56 shoots per branch should be sampled when mean defoliation is light, moderate, and severe, respectively. The mean number of branches required to estimate defoliation ranged from 7–24 per stand, depending on tree species and the desired probability level. Sampling took about 5–10 min to collect mid-crown branches with an additional 10–30 sec per shoot to estimate defoliation.

**Sampling Procedure**

Select the desired probability level and appropriate tree species to be sampled from Table 1 if sampling individual trees or from Table 2 if sampling stands. The minimum number of

shoots per branch or branches per stand required for sampling each species is given in the 'light' defoliation columns. Collect the appropriate minimum number of branches from randomly selected trees and rate the observed defoliation on the minimum number of shoots or branches into the following classes:

| Percent defoliation observed | Defoliation level |
|---|---|
| 0–30% | Light |
| 31–70% | Moderate |
| 71–100% | Severe |

This preliminary assessment provides a rough idea of the defoliation on a tree or within the stand and can be used to eliminate unnecessary sampling.

**Sampling individual trees:** Reference Table 1 to determine the required number of shoots to assess on each branch given the desired probability level, tree species, and mean defoliation level determined from the preliminary assessment of the minimum number of shoots. Using pole pruners, remove one whole branch sample from the mid-crown of randomly selected, dominant or co-dominant trees. Assess defoliation only on current year foliage, moving from the tip of the branch to the base until the required number of shoots on a branch has been processed. In general, sampling a whole branch will provide sufficient shoots for classifying individual trees, but a second mid-crown branch from the same tree may be necessary if few shoots are present on the first branch. Classify the tree according to the percentage of observed defoliation as described above.

**Sampling stands:** Reference Table 2 to determine the required number of branches to assess within a stand given the desired probability level, tree species, and mean defoliation level determined from the preliminary assessment of the minimum number of branches. Using pole pruners, remove one whole branch sample from the mid-crown of randomly selected, dominant or co-dominant trees in each stand. Sample only one branch from each tree (i.e., the number of branches required is also the number of trees to be sampled). If the average defoliation level from the initial sample of the minimum number of branches is moderate or severe, reference Table 2 to determine the additional number of whole, mid-crown branch samples required. Assess defoliation only on current-year foliage. Classify the stand according to the percentage of defoliation observed on the branches as described above.

**Notes**

The effort required to process the full range of shoots or branches justifies the recommended practice of first sampling the minimum number of required shoots or branches to classify the stand as having light, moderate, or severe defoliation. Increasing the probability level from 90 to 95% increases the sampling effort by 50%. This sampling plan assumes that no backfeeding occurred and all defoliation within an age class resulted from feeding during the year the foliage was produced. Red and black spruces were combined into a single class for

this study because they hybridize readily. No red-black spruce stands with severe defoliation were sampled in this study. Managers should select the dominant susceptible species in each stand as the host species in Tables 1 and 2.

Table 1. Mean number of shoots per branch required to estimate spruce budworm defoliation with 90 or 95% probability that the 95% confidence interval is within ±10% defoliation, as a function of average defoliation level and tree species.

| | | Average Defoliation Level[a] | | | |
|---|---|---|---|---|---|
| Variable | Species | Light | Moderate | Severe | Total[b] |
| A. No. of observations[c] | Balsam fir | 1,610 | 970 | 395 | 2,975 |
| | White spruce | 757 | 470 | 96 | 1,323 |
| | Red-black spruce | 2,208 | 361 | 25 | 2,594 |
| B. Required no. of shoots per branch with 90% probability | Balsam fir | 19 | 44 | 24 | 29 |
| | White spruce | 18 | 45 | 27 | 30 |
| | Red-black spruce | 17 | 58 | 37 | 37 |
| C. Required no. of shoots per branch with 95% probability | Balsam fir | 28 | 67 | 36 | 44 |
| | White spruce | 27 | 68 | 40 | 45 |
| | Red-black spruce | 26 | 88 | 55 | 56 |

[a] Defoliation classes for calculating sample sizes were defined as light 0-30%, moderate 31-70%, and severe 71- 100%.

[b] Total values are sums for number of observations and means per species for required number of shoots per branch.

[c] Number of branches sampled per species and defoliation level, with individual ratings of defoliation on 25 shoots per branch.

Table 2. Mean number of branches per stand required to estimate spruce budworm defoliation with 90 or 95% probability that the 95% confidence interval is within ±10% defoliation, as a function of average defoliation level and tree species.

| | | Average Defoliation Level[a] | | | |
|---|---|---|---|---|---|
| Variable | Species | Light | Moderate | Severe | Total[b] |
| A. No. of observations[c] | | | 156 | 38 | 359 |
| | Balsam fir | 165 | | | |
| | White spruce | 30 | 31 | 3 | 64 |
| | Red-black spruce | 295 | 31 | 0 | 326 |
| B. Required no. of shoots per branch with 90% probability | Balsam fir | 9 | 24 | 13 | 15 |
| | White spruce | 8 | 17 | 10 | 12 |
| | Red-black spruce | 7 | 19 | – | 13 |
| C. Required no. of shoots per branch with 95% probability | Balsam fir | 14 | 39 | 21 | 25 |
| | White spruce | 13 | 26 | 15 | 18 |
| | Red-black spruce | 10 | 30 | – | 20 |

[a] Defoliation classes for calculating sample sizes were defined as light 0-30%, moderate 31-70%, and 00%.
[b] Total values are sums for number of observations and means per species for required number of branches per stand.
[c] Number of stands sampled per species and defoliation level, with ≥5 mid-crown branches sampled per stand.

**Tables 1 and 2 reprinted with permission from the Society of American Foresters, granted June 9, 2009.**

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Moody, B. H.; Otvos, I. S. 1980. Distribution of hibernating spruce budworm larvae within crowns of balsam fir trees in Newfoundland. Information Rpt. N-X-182. St. John's, Newfoundland: Environment Canada, Forestry Service, Newfoundland Forest Research Centre; 21 p.

**Objective**

To determine the appropriate crown level for sampling *C. fumiferana* larvae overwintering in balsam fir trees.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

Estimates of second instar *C. fumiferana* are used to predict the risk of defoliation the subsequent year. A study was carried out in two stands of immature balsam fir in Newfoundland to determine the distribution pattern of overwintering second instars. The results indicated that a high proportion of larvae hibernated in the mid-crown of balsam fir, which is the most appropriate sampling universe for this larval stage. Only 5 and 18% of the second instars were found on the main stem and internodal branches, respectively. Entire nodal (whorl) branches cut at 2.5 cm from the trunk should be sampled, as only 36% of the larvae found on branches from the mid-crown occurred within the apical 45 cm of the branch. Sampling efficiency, expressed as coefficients of variation, were lower for the upper and middle crowns than the lower crown.

**Sampling Procedure**

Randomly select and remove whole nodal branches from the mid-crown of balsam fir. Branches should be cut 2.5 cm from the trunk. Count and record the number of second instars on the entire branch. The branch surface area (calculated as the total length of branch X the width at half the total length) should be determined if larval density is to be expressed on a per-hectare basis. Either measure all sampled branches or subsample a smaller number of branches to estimate a mean branch area for each plot.

**Notes**

This study is based on 5 randomly selected immature balsam firs from two locations in Newfoundland. As such, the distribution of second instar *C. fumiferana* reported by the authors may not represent distribution of instars on other host trees or in other regions in North America. The authors did not suggest how many branches should be removed from each tree for practical sampling, but they selected two branches from the mid-crown for their study.

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Montgomery, B. A.; Simmons, G. A.; Witter, J. A.; Flexner, J. L. 1982. The spruce budworm handbook: a management guide for spruce-fir stands in the Lake States. Handb. 82-7. Ann Arbor, MI: Michigan Cooperative Forest Pest Management Program; 35 p.

**Objectives**

To provide a summary of sampling plans for adults, larvae, pupae, and egg masses of *C. fumiferana* for stands of white spruce and balsam fir in the Great Lakes region; to describe methods of estimating defoliation in this region.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years and epidemics can last 5–10 years.

Methods used to sample *C. fumiferana* in the Great Lakes region of the US are summarized as a cooperative effort between the U.S. Department of Agriculture and the Canadian Department of the Environment. Detailed information on sampling all life stages of *C. fumiferana*, as well as aerial surveys of feeding damage, are presented in the handbook. Such methods allow forest managers to monitor endemic populations of *C. fumiferana* and detect increasing densities before defoliation and tree mortality occurs.

**Sampling Procedure**

**Aerial survey of defoliation:** Conduct surveys in late July when infested foliage appears reddish-brown. At a height of 305 m, fly east and west lines 4.8 km apart. Use 1:50,000 scale maps to delineate areas of infestation and measure the acreage with a dot grid. Determine the level of defoliation and stand condition using the following codes established by the USDA Forest Service, State and Private Forestry:

| | Defoliation | | Stand Condition |
|---|---|---|---|
| L | Light to moderate, 0–50% of crown showing red-brown discoloration | | No tree mortality or top kill |
| H | Heavy, 51–100% of crown showing red-brown discoloration | | No tree mortality or top kill |
| S | Severe, 51–100% of crown showing red-brown and gray discoloration | | |

Follow the aerial survey with a ground check of 10% of the heavily or severely defoliated areas to verify that *C. fumiferana* produced the observed damage and that the aerial mapping was accurate.

**Ground assessment of defoliation using the Fettes Method:** This technique is generally used with a sampling method for insects. In July and August, cut branches from the mid-crown of white spruce or balsam fir trees. Visually estimate the percentage of defoliation (needles removed) from each current-year shoot on each branch (Fig. 6). Average the percentage of defoliation of the current-year shoots to obtain an overall percentage of defoliation for the branch. Determine the level of defoliation using the following categories:

| Defolation level | Percent defoliation |
|---|---|
| Trace | 0–5 |
| Low | 6–20 |
| Moderate | 21–50 |
| High | 51–80 |
| Severe | 81–100+ |

Binocular assessment of defoliation: This technique is used independently of insect populations. Evaluate stand defoliation of spruce and fir trees using binoculars. Rank the green (live foliage) portion of the crown using the following categories:

| | |
|---|---|
| 1 | No defoliation: no observable feeding damage, 0–20% of total foliage missing. |
| 2 | Light to moderate defoliation: 21–50% defoliation of total foliage. |
| 3 | Heavy defoliation: 51% or greater defolation with no observable top-kill. |
| 4 | Severe defoliation: 51% or greater defoliation with obvious top-kill. |

Sampling pupae: Sampling should not be conducted until all larvae have pupated (late June or early July) but can continue through moth emergence (August) by counting pupal cases. However, empty pupal cases can be dislodged from branches so sampling earlier will provide a more accurate estimate of population density. Pupal sampling requires less time and is less expensive than sampling egg masses.

Randomly select two dominant or co-dominant balsam fir or white spruce trees at each of five collection sites in a stand. Clip one branch at least 45-cm long from the upper mid-crown

of both trees. Use pole pruners with a collection basket below the cutting head to catch the branches. Examine each branch and tally the number of pupae and empty pupal cases on the apical 45-cm length. Compare the cumulative pupal density to Table 3 to classify the population of *C. fumiferana* in the stand as high or low densities.

Sampling adults: As of 1982, pheromone traps had been tested but not used operationally in the Great Lakes region. Test trials showed that traps baited with *C. fumiferana* sex pheromone effectively attracted males even when larval densities were below 1 larva per branch.

Prioritize stands for sampling, taking into consideration stand accessibility, value, and risk rating. Establish 1 to 5 permanent sampling sites in 25 to 50% of the stands identified as having the highest risk. Deploy traps baited with synthetic spruce budworm pheromone at the permanent sampling sites in early summer, before larvae pupate. Hang traps on branches 2 m above ground with no branches or foliage within 30 cm of each trap to open the air space (trim foliage if needed). Leave traps undisturbed from late June through July until the flight period is completed and then tally the number of captured moths in each trap. Plot the total trap catch over years to detect increasing densities. Large increases in the number of trapped moths over several consecutive years may signal an incipient outbreak of *C. fumiferana* within 3–5 years and precautions should be considered to limit tree damage and mortality.

Sampling egg masses: Egg mass surveys are more time-consuming and expensive than sampling pupae. Sampling should begin after adult moths are no longer present (usually August) and can continue through September. Randomly select 1 to 3 collection sites for each 16-ha stand. At each collection site, use pole pruners to cut three 38-cm mid-crown branches from each of 3 balsam firs or 5 white spruces. Trees should be dominant or co-dominant. Count the number of current-year egg masses (i.e., round, green/white egg masses) on each branch. Do not include old egg masses that appear flat and gray or parasitized egg masses, which appear black. Calculate the mean number of current-year egg masses per branch and use Table 4 to predict the defoliation level expected for that stand the following summer.

Sampling small larvae (second instars): This procedure is a useful alternative if egg mass surveys are limited by available resources. Sample second instars between September and April in most areas. Using pole pruners, cut several 45-cm branch tips randomly through the upper mid-crown of several dominant balsam firs or white spruces. Trees should be widely distributed. Allow branch samples to thaw overnight in the laboratory before cutting them into 5–10 cm pieces. Place pieces in a wire basket and submerge into a bucket containing 9 liters of 2% aqueous solution of sodium hydroxide between 49-60°C (120-140°F) overnight. Agitate the soaked branch pieces and collect all needles and bark scales into labeled collection jars. Filter the contents of each jar through sieves and a separation funnel. Add hexane to the oil/water interface where most of the larvae collect and vacuum filter the larvae onto gridded filter paper. Using a stereomicroscope, count the number of larvae on the filter paper to determine the number of larvae per branch. Refer to Sanders (1980) for more detailed information regarding this procedure.

**Notes**

These procedures are established for balsam fir and white spruce in upper Minnesota and Wisconsin as well as Michigan's Upper Peninsula. As such, these procedures may not be effective for other host trees or in other geographical regions. The authors did not specify the number of branch samples per tree or the number of trees to be sampled when sampling second instars. Do not expose hexane to flame or another heat source as it is an explosive, volatile chemical.

**References**

* Sanders, C. J. 1980. A summary of current techniques used for sampling spruce budworm populations and estimating defoliation in eastern Canada. Rep. 0-X-306. Canadian Forest Service, Great Lakes Forestry Centre; 33 p.

| Number of sampled branches per stand | Population category (Cumulative pupae) | |
|---|---|---|
| | Low | High |
| 2 | – | 33 or more |
| 4 | 1 or less | 50 |
| 6 | 5 | 66 |
| 8 | 10 | 83 |
| 10 | 14 | 100 |

The same classification is also currently being used for white spruce.

Table 4. Defoliation predictions based on the average number of egg masses per 15-in. (38-cm) balsam fir branch.

| Average number of egg masses/branch/stand | Expected defoliation | |
|---|---|---|
| | % | Intensity |
| Less than 0.2 | less than 26 | Light |
| 0.2–0.5 | 26–50 | Moderate |
| 0.5–0.9 | 51–75 | Heavy |
| more than 1.0 | more than 75 | Severe |

Less defolation would be expected for similar egg mass density levels on white spruce.

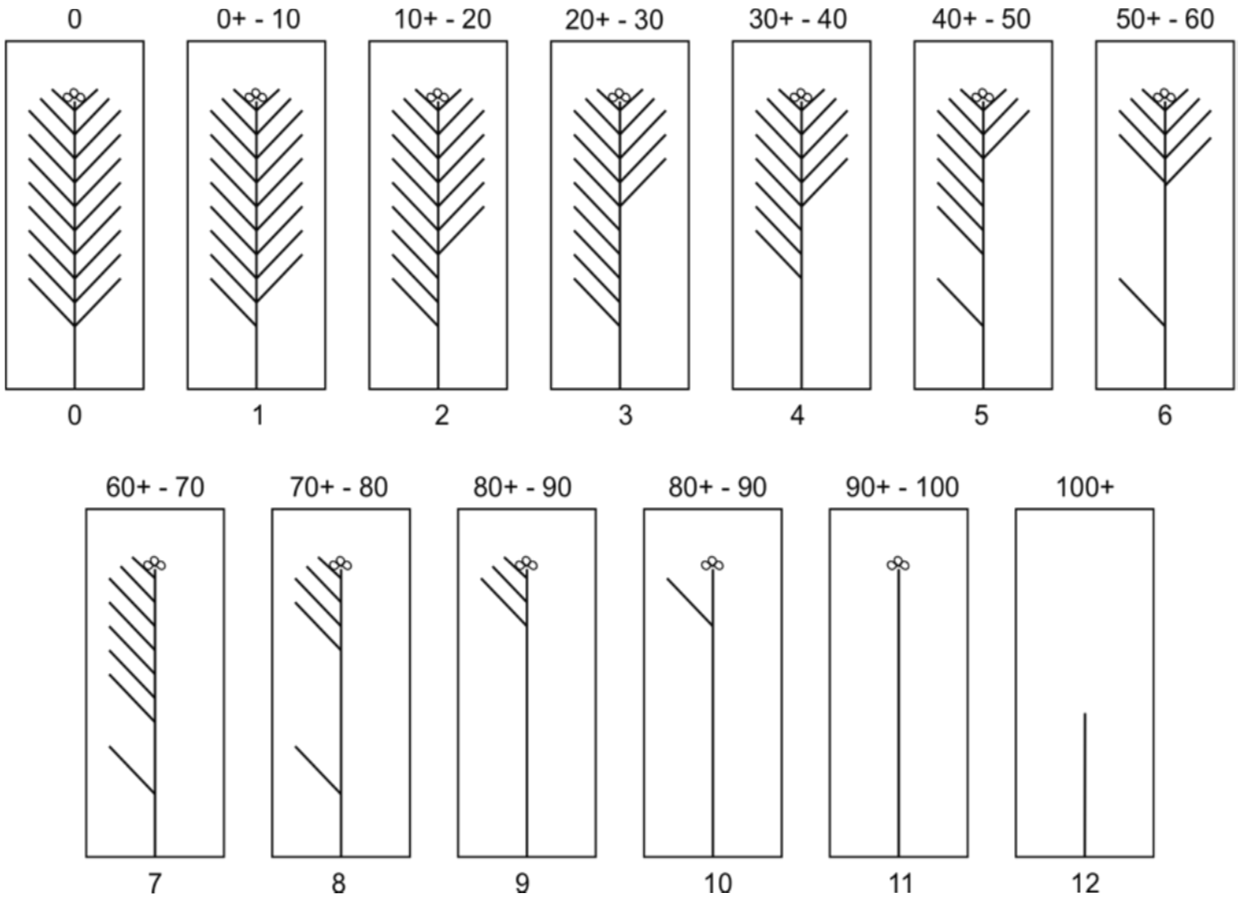


Figure 6. Fettes method of estimating defoliation.

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Morris, R. F. 1954. A sequential sampling technique for spruce budworm egg surveys. Canadian Journal of Zoology 32: 302-313.

**Objective**

To develop a sequential sampling plan for *C. fumiferana* egg mass surveys.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

A sequential sampling plan was developed for *C. fumiferana* egg mass surveys in eastern Canada based on whether pole pruners can be used to sample the mid-crown of balsam fir, *Abies balsamea* (L.) Mill., within a stand. Trees selected for sampling are felled if the overall stand height is too tall for sampling the mid-crown with pole pruners (Method I). Fewer trees are needed to classify the egg mass density within a stand using Method I than if mid-crown branches are sampled using pole pruners (Method II), but felling trees requires more effort. A maximum of 10 or 15 trees are sampled with Methods I and II, respectively. With Method II, as few as 1 or 2 branches need be sampled per plot when *C. fumiferana* populations are extremely low or high (Table III). Field sampling parties preferred Method II due to ease of making collections without sacrificing accuracy.

Egg mass density is estimated by sampling multiple branches sampled from the crown divided into quarters with Method I, and by sampling one branch from the mid-crown with Method II. With both methods, egg mass density is expressed as the number of egg masses per 9.29 $m^2$. Light, moderate, and severe infestations are defined as <25, 50–100, and >200 egg masses per 9.29 $m^2$. If, after sampling the maximum number of branches per plot, the cumulative number of egg masses falls between the light and moderate bands, or between the moderate and severe bands, then infestation is classified as either light-moderate or moderate-severe, respectively.

**Sampling Procedure**

Begin sampling after the oviposition period has ended. Sampling can continue into egg hatch

provided that workers can distinguish between old and new egg masses. Randomly select trees in each plot. If the trees in a stand are too tall to reach the mid-crown with pole pruners, then trees selected for sampling are felled (Method I). From each felled tree, sample a whole branch from both the apical and second quarters of the crown, and sample a half of a branch from the third and basal quarters of the crown. This division distributes sampling intensity throughout the tree, but pool branch samples to provide a single mean density for the tree. Discard the nonfoliated basal stem of each whole branch collected. If the mid-crown of the selected trees can be reached using pole pruners, then sample a single whole branch from the mid-crown (Method II).

With whole branches collected with either method, measure the length of the foliated stem and the width at the midpoint of the stem. Multiply the two measurements to obtain a crude estimate of the foliated area of each branch. For half branches collected with Method I, divide each half branch longitudinally by removing all lateral branches along one side of the main stem. Count the number of healthy egg masses on each foliated branch half and express as the number of egg masses per 9.29 $m^2$ of foliage surface. Pool counts for branches collected with Method I to provide a single mean density for each tree.

Reference Table III for each pooled sample for a tree if using Method I or after processing each branch if using Method II. Continue sampling until the cumulative number of egg masses falls into one of the zones (i.e., light, moderate, or severe), then stop and classify the infestation level accordingly.

The general expected egg mass density found during light, moderate, and severe infestations are as defined below:

| No. of egg masses per 9.29 $m^2$ | Infestation |
|---|---|
| ≤ 25 | Light |
| 50–100 | Moderate |
| > 200 | Severe |

If the cumulative count falls within either the light-moderate or the moderate-severe bands after sampling the maximum number of branches per plot, classify the infestation as either light-moderate or moderate-severe.

**Notes**

Workers should have experience in distinguishing between old and new egg masses and between healthy and parasitized or predated egg masses. Branches should be re-examined at least partially by a second worker to check that egg masses are counted correctly. Only one method should be used to classify the infestation level within a stand.

Table III. Sequential table for use by field parties, read from the acceptance and rejection lines (Figs. 1 and 2, *in original publication*). (Sampling is continued until the cumulative result falls outside the bands into one of the zones.)

| Tree | Cumulative no. of egg masses per 9.29 $m^2$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Light vs. moderate band | | | | Moderate vs. severe | | | | |
| *Sampling Method I* | | | | | | | | | |
| 1 | LIGHT ZONE | 8 | – | 59 | MODERATE ZONE | 42 | – | 225 | SEVERE ZONE |
| 2 | | 42 | | 93 | | 183 | | 366 | |
| 3 | | 78 | | 129 | | 323 | | 506 | |
| 4 | | 112 | | 163 | | 460 | | 643 | |
| 5 | | 147 | | 198 | | 599 | | 782 | |
| 6 | | 182 | | 233 | | 738 | | 921 | |
| 7 | | 216 | | 267 | | 878 | | 1061 | |
| 8 | | 251 | | 302 | | 1016 | | 1199 | |
| 9 | | 286 | | 337 | | 1154 | | 1337 | |
| 10 | | 320 | | 371 | | 1291 | | 1474 | |
| *Sampling Method II* | | | | | | | | | |
| 1 | LIGHT ZONE | 0 | – | 90 | MODERATE ZONE | 0 | – | 360 | SEVERE ZONE |
| 2 | | 5 | | 126 | | 35 | | 498 | |
| 3 | | 41 | | 162 | | 174 | | 637 | |
| 4 | | 77 | | 198 | | 312 | | 775 | |
| 5 | | 110 | | 231 | | 452 | | 915 | |
| 6 | | 145 | | 266 | | 591 | | 1054 | |
| 7 | | 179 | | 300 | | 728 | | 1191 | |
| 8 | | 215 | | 336 | | 868 | | 1331 | |
| 9 | | 249 | | 370 | | 1005 | | 1468 | |
| 10 | | 284 | | 405 | | 1144 | | 1607 | |
| 11 | | 318 | | 439 | | 1283 | | 1746 | |
| 12 | | 355 | | 476 | | 1420 | | 1883 | |
| 13 | | 389 | | 510 | | 1559 | | 2022 | |
| 14 | | 422 | | 543 | | 1698 | | 2161 | |
| 15 | | 457 | | 578 | | 1837 | | 2300 | |

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Morris, R. F. 1955. The development of sampling techniques for forest insect defoliators, with particular reference to the spruce budworm. Canadian Journal of Zoology 33: 225-294.

**Objective**

To review the development of sampling techniques for *C. fumiferana*.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

This publication represents an exhaustive compendium of sampling techniques for *C. fumiferana* that evolved during the classic "Green River" ecological study of the population dynamics of this defoliator and its natural enemies in New Brunswick, Canada. These methods represent one of the first rigorous sampling plans refined for a defoliating forest pest and were the basis for the life table for *C. fumiferana* constructed by Morris and Miller (1954). The table of contents for the article is presented here; interested readers should review the publication for detailed information regarding the theory and mechanics of sampling forest defoliators.

# THE DEVELOPMENT OF SAMPLING TECHNIQUES FOR FOREST INSECT DEFOLIATORS, WITH PARTICULAR REFERENCE TO THE SPRUCE BUDWORM

By R. F. Morris

TABLE OF CONTENTS

**Reference**

Morris, R. F.; Miller, C. A. 1954. The development of life tables for the spruce budworm. Canadian Journal of Zoology 32: 283-301.

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Régnière, J.; Lysyk, T. J.; Auger, M. 1989. Population density estimation of spruce budworm, *Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae) on balsam fir and white spruce from 45-cm mid-crown branch tips. Canadian Entomologist 121: 267-281.

**Objectives**

To relate density of *C. fumiferana* on balsam fir to density on white spruce; to examine *C. fumiferana* density within host canopy; and to improve the accuracy of estimation through error corrections.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

Densities of *C. fumiferana* are often estimated from 45-cm branch tip samples taken from the mid-crown of host trees. This sampling method is used on both balsam fir and white spruce, but the appropriateness of comparing densities estimated by this technique between host species has not been evaluated previously. Foliage density in these branch samples is determined by branch architecture, which differs between white spruce and balsam fir. Research conducted in eastern Canada indicated that white spruce had foliage nearly 40% denser than balsam fir. Pest density should be expressed in a consistent manner to allow comparisons between host trees and among studies. Densities of *C. fumiferana* expressed as per sample, per m2 surface area, per kg fresh weight, and per foliage bud were compared but none of the expressions presented a clear advantage over the others in regards to reduction in variability. Fresh weight is generally easier to calculate than surface area, so the authors recommend expressing density of *C. fumiferana* per kg fresh foliage weight.

The distribution of *C. fumiferana* within the host canopy differs with life stages. While changes in the vertical distribution of *C. fumiferana* did not appear to affect density estimates, changes in the horizontal distribution along branches are more important. Overwintering larvae prefer the base of branches over the apical tips where branch samples are taken. In contrast, the authors found more first through fourth instars (60%) and more egg masses (67%) within 45-cm of the branch tips. Density estimates of different life stages of *C. fumiferana* on 45-cm mid-crown branch samples can be compared using a correction factor for each host species.

**Sampling Procedure**

Sample 45-cm branch tips from the mid-crown of host trees using pole pruners. Use collection baskets attached to the head of the pole pruners when large instars are present as they tend to drop off branches when disturbed. Return samples to the laboratory and tally the number of *C. fumiferana* present in each life stage. Have samples randomly checked by experienced personnel for accuracy in detecting *C. fumiferana*. Weigh the fresh foliage present in the samples. Express the density of *C. fumiferana* in terms of mean kg fresh weight. If of interest, measure branch sample surface area so foliage density, an index of tree health, can be expressed as kg/m2. Use the method of Miller et al. (1971) to extract small overwintering larvae from the foliage using a caustic solution of sodium hydroxide (NaOH).

Corrections for changes in horizontal distribution along mid-branch samples and examination error by personnel processing the branch samples can be made simultaneously for each host species. Use the following equations to estimate *C. fumiferana* density on whole branches (*d*) from the density of *C. fumiferana* per kg fresh foliage weight estimated from 45-cm branch tip samples ($d_1$):

$$d = d_1 (\underline{u} + [(1 - u)/-5.31 + 4.14a - 0.45\ a^2])(1 - \exp[1.94 - 1.14a])^{-1} \text{ and}$$

$$d = d_1 (\underline{u} + [(1 - u)/-1.80 + 1.88a - 0.21\ a^2])(1 - \exp[1.94 - 1.14a])^{-1}$$

for balsam fir and white spruce, respectively. In both equations, $a$ = the average instar of *C. fumiferana* present. The variable $u$ represents the proportion of foliage by weight present in the 45-cm branch tip samples taken from the mid-crown. Use the approximate values of $u$ = 0.47 and $u$ = 0.30 for balsam fir and white spruce, respectively. However, $u$ varies for both host species among stands, so consider estimating u in each sampled stand of balsam fir and white spruce for the most accurate value.

If sampling egg masses or overwintering larvae, use the average value of $a$ = 2 and set the examination error term of $[1 - \exp(1.94 - 1.14a)]^{-1}$ to 1 as the authors did not determine the examination error for these life stages.

When branch samples are examined for accuracy by a second experienced observer, the correction factor for the examination term, which is $[1 - \exp(1.94 - 1.14a)]^{-1}$, can be eliminated from the equations.

**Notes**

The simultaneous correction factor should not exceed 1.5 as values larger than this were not examined in this study.

## Reference

Miller, C. A.; Kettela, E. G.; McDougall, G. A. 1972. A sampling technique for overwintering spruce budworm and its applicability to population surveys. Inf. Rep. M-X-25. Fredericton, N.B.: Canadian Forest Service; 11 p.

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Sanders, C. J. 1988. Monitoring spruce budworm population density with sex pheromone traps. Canadian Entomologist 120: 175-183.

**Objective**

To evaluate the use of pheromone traps to monitor changes in *C. fumiferana* populations.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5-10 years.

Pheromone traps are extremely useful in monitoring adult populations of *C. fumiferana* as rising trap catches can indicate a potential outbreak. Trap catches were positively correlated to larval densities over a 21-year period in Ontario (r2 = 81%). In general, land managers should consider their management options when trap catches increase over 3 successive years or when >50 moths are captured per trap. Branch sampling may pinpoint where control options should best be applied in the near future as larval populations increase. Pheromone traps are now used as an early warning system for increasing densities of *C. fumiferana* in eastern North America.

**Sampling Procedure**

Use high-capacity traps such as Uni-traps (International Pheromone Systems, Wirral, U.K.), which are less likely to become saturated with captured adults. Sticky traps can be used in areas that generally have had low densities, but with the risk of trap saturation with increasing population density. Bait traps with the lure recommended for the current year. Lures with a very low potency (0.0003% [w/w]) are recommended as they remain effective in attracting male moths but do not lead to trap saturation. Traps should include a killing agent to immobilize attracted male moths.

Deploy traps in stands with at least 50% balsam fir and/or white spruce 1–2 weeks before the adult flight period. In the center of each stand, hang traps 2 m above ground in a triangular cluster with 20 m between each trap. Leave traps in place until the flight period has ended, then collect traps and count the number of moths in each trap. Land managers should consid-

er their management options when trap catches increase over 3 successive years or when >50 moths are captured per trap. Traps should be set out each year to monitor population trends of *C. fumiferana* over time and provide an early warning of potential outbreak densities.

**Note**

Land managers may consider initiating branch sampling when trap catches reach this "early warning threshold" as larval densities sufficiently high to warrant control measures may still not occur for several seasons. Branch sampling may pinpoint where control options should best be applied in the near future as larval populations increase.

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Sanders, C. J. 1996. Guidelines for using sex pheromone traps to monitor eastern spruce budworm population densities. Frontline Tech. Note No. 94. Sault Ste. Marie, ON: Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre; 4 p.

**Objectives**

To describe guidelines for the use of pheromone traps in monitoring low densities of *C. fumiferana*; to predict subsequent larval densities based on trap catch of male moths.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

Pheromone traps are extremely useful in monitoring adult populations of *C. fumiferana*, especially when populations are low. Rising trap catches can indicate a potential outbreak. Furthermore, trap catch of adult males can be used to predict subsequent larval densities using the equation $\text{Log10}(y+1) = -1.454 + 1.440(x+1)$, where x = moth catch and y = larvae per 10 $m^2$ foliage ($r^2 = 0.48$). Using this formula, a trap catch of 100 moths corresponds to subsequent larval densities of 25 larvae per 10 $m^2$ foliage, or approximately 3 larvae per branch. Land managers should consider initiating larval sampling at this threshold, but continue monitoring adult populations using pheromone traps below this threshold.

**Sampling Procedure**

Use Multi-pher (le Groupe Biocontrôle, Ste-Foy, Québec) or Uni-traps (International Pheromone Systems, Wirral, U.K.) baited with the recommended lures for the current year. Traps should include a killing agent to immobilize male moths attracted to the lure.

Deploy traps before the adult flight period and leave in place until the flight period has ended. Traps should be placed in mature forest consisting of at least 50% white spruce and/or balsam fir of at least 10 ha in area. The recommended trap layout consists of three traps in a triangle evenly spaced at least 40 m apart and at least 40 m from the edge of the stand. Hang traps on dead branches at eye level at least 50 cm from the trunk.

Collect traps after the flight period has ended and count the number of moths. Use the following equation to estimate the density of the subsequent larval population:

$$\text{Log10}(y+1) = -1.454 + 1.440(x+1)$$

where x = moth catch and y = larvae per 10 $m^2$ foliage. A trap catch of 100 moths corresponds to subsequent larval densities of 25 larvae per 10 $m^2$ foliage, or approximately 3 larvae per branch. Larval sampling at this density becomes practical, so managers can use this threshold as a guideline of when to begin sampling second instar *C. fumiferana*. Continue monitoring adult populations with pheromone traps below this threshold.

**Notes**

The formula given in the original publication is incorrect. The correct formula, Log10(y+1) = –1.454 + 1.440(x+1) (D. B. Lyons, NRC Canadian Forest Service, Great Lakes Forestry Centre, Ontario, pers. comm.), is provided in this summary.

Traps can be reused over several years, but the plastic will absorb some of the pheromone. As the pheromone of one insect pest may be an inhibitor for another species, traps should always be reserved for the same species. These recommendations are based on research conducted in mature mixed stands in the Great Lakes region. These recommendations may not accurately reflect other forest types in different locations and should be used with caution until validated for other regions.

# Spruce Budworm

## *Choristoneura fumiferana* (Clemens)

### Lepidoptera: Tortricidae

Witter, J. A.; Lynch, A. M. 1985. Spruce budworms handbook: rating spruce-fir stands for spruce budworm damage in eastern North America. Agric. Handb. 636. Washington, D.C.: U.S. Department of Agriculture, Forest Service; 22 p.

**Objective**

To describe several hazard-rating systems for *C. fumiferana* that provide information for short-term management decisions.

**Abstract**

Spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir, *Abies balsamea* (L.) Mill., and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars cause most of the defoliation. Periodic outbreaks occur every 30 years, while epidemics can last 5–10 years.

The hazard-rating systems for *C. fumiferana* summarized in this handbook are a compilation resulting from a cooperative effort between the U.S. Department of Agriculture and the Canadian Department of the Environment (CANUSA). Ground-based and aerial sampling procedures allow forest managers to identify high-risk areas suitable for protective spraying or salvage operations using short-term (1–3 year) management decisions.

**Sampling Procedure**

Ground-based sampling (based on Trial and Devine 1983): Conduct aerial surveys over spruce-fir stands in July and August and map the extent of defoliation over regional areas. Sample egg masses or overwintering second instars in August and September over widespread areas (1,000+ sampling sites used in Maine, 1982). Cut one branch from each of three dominant or codominant fir trees at each sampling site. Estimate the number of fresh egg masses or second instar *C. fumiferana* per 9.3 $m^2$ (100 sq. ft.) from the three branch samples. Estimate the level of defoliation of the current year and the previous year, as well as tree vigor, from these branch samples. In early fall, calculate a hazard-rating value for each stand or sample site using Table 1 and summing the values for each parameter included in the table. Develop a budworm population prediction map using the egg mass or second instar densities. Develop a composite hazard map using the individual stand hazard values generated from Table 1. Select spray or salvage areas for next year based on the composite hazard map while considering the availability of resources and weighing other inputs (i.e., social, politi-

cal, and economic conditions).

Aerial sampling system (based on McCarthy et al. 1983): Take color photographs (35- or 70-mm) with stereo overlap from fixed-wing, light aircraft over spruce-fir stands. Interpret stand defoliation, mortality, density, and proportion of host species from the photos using Table 2. Rank crown defoliation as follows:

1 = 0–20%
2 = 21–50%
3 = 51% or more without topkill
4 = 51% or more with topkill

Compute the average tree defoliation rank for a stand and compare to the overall class label in Table 2. Calculate the percent mortality of host tree species in the stand and assign a class rank. Describe each stand as open, average, or dense. Calculate the proportion of stand comprised of host tree species and assign a class rank according to stand density. Finally, determine the overall stand hazard-rating value by summing the class ranks described above and comparing to Table 2. The hazard-rating value reflects the relative probability that a particular stand will be attacked and damaged by *C. fumiferana* during the next several years.

**Notes**

The ground-based sampling procedure is based on practices conducted in Maine in 1982. For more information, see Trial and Devine 1983. Olsen et al. (1982) produced an instruction manual for use with the aerial sampling system; see the original publication for more information.

**References**

Trial, H., Jr.; Devine, M. E. Spruce budworm in Maine: results of the 1982 project, biological conditions in 1982 and expected infestation conditions for 1983. Tech. Rep. 19. Augusta, ME: Maine Department of Conservation, Maine Forest Service; 1983. 76 p.

McCarthy, J.; Olson, C. E., Jr.; Witter, J. A. 1983. Assessing spruce budworm damage with small-format aerial photographs. Canadian Journal of Forest Research 13: 395-399.

Olson, C. E., Jr.; Sacks, P. J.; Witter, J. A.; Bergelin, L. A. 1982. Spruce budworm damage assessment with 35 mm air photos: a training manual. Rep. 82-1A. Ann Arbor, MI: The University of Michigan, School of Natural Resources, Remote Sensing Laboratory. 41 p.

Table 1. Table 1. Hazard-rating system used in Maine during 1982 (modified from Trial and Devine 1983).

| Current defoliation | (%) | Value | Previous defoliation | (%)[1] | Value[2] |
|---|---|---|---|---|---|
| Trace | 0–5 | 0 | Trace | 0–9 | 0 |
| Light | 6–20 | 1 | Light | 10–49 | 3 |
| Moderate | 21–50 | 2 | Moderate | 50–129 | 6 |
| Heavy | 51–80 | 4 | Severe | 130+ | 9 |
| Severe | 81+ | 6 | | | |

**Egg-mass or overwintering larval desposit (number)**

| *Category* | *Egg masses*[3] | *Second instar larvae*[4] | *Value* |
|---|---|---|---|
| Light | 0–99 | 0–175 | 1 |
| Moderate | 100–239 | 176–500 | 2 |
| High | 240–399 | 501–1099 | 3 |
| Very high | 400–999 | 1100+ | 5 |
| Extreme | 1000+ | 1100+ | 5 |

| **Tree Vigor** | **Value** | **Total hazard rating** *Category* | *Hazard value* |
|---|---|---|---|
| Good (current foliage healthy | 0 | Low | 0–6 |
| Fair (shoot production moderate | 1 | Moderate | 7–15 |
| Poor (some growth capacity) | 2 | High | 16–22 |
| Very poor (nil) | 3 | Severe | 23–26 |

[1]The 2 previous years' needles.
[2]Add three points if there are trees with dead tops in the area (10 to 20 percent of the trees).
[3]Number of budworm egg masses/100 $ft^2$ (9.3 $m^2$) of foliage.
[4]Number of second-instar budworm larvae/100 $ft^2$ of foliage.

Table 2. Stand hazard-rating values obtained from 35-mm photographs and used to predict amount potential damage (modified from Olson et al. 1982, McCarthy et al. 1983).

| **Average stand defoliation rank** | **Class label** | | **Class value** |
|---|---|---|---|
| | | | |
| 0.0–1.2 | Trace | | 0 |
| 1.3–1.9 | Light | | 1 |
| 2.0–2.9 | Moderate | | 2 |
| 3.0–4.0 | Heavy | | 3 |
| | | | |
| **Stand Mortality (%)** | | **Value** | |
| Low | 0–9 | 0 | |
| Medium | 10–29 | 2 | |
| High | 30–49 | 4 | |
| Severe | ≥50 | 6 | |
| | | | |
| **Proportion of stand in host species** | | | |
| | *Stand density value* | | |
| *Proportion of host species* | Open | Average | Dense |
| | | | |
| <30 | 1 | 1 | 2 |
| 30 to 60 | 2 | 2 | 4 |
| >60 | 3 | 4 | 6 |
| | | | |
| **Standard hazard-rating value** | | | |
| | | | |
| | *Category* | *Hazard value* | |
| | | | |
| | Low | 0–4 | |
| | Moderate | 5–8 | |
| | High | 9–10 | |
| | Severe | 11–15 | |

# Western Spruce Budworm

## *Choristoneura occidentalis* Freeman

### Lepidoptera: Tortricidae

Buffam, P. E.; Carolin, Jr., V. M. 1966. Determining trends in western spruce budworm egg populations. Journal of Economic Entomology 59: 1442-1444.

**Objective**

To develop a method of analyzing population trends of *C. occidentalis* in the Pacific Northwest using egg mass surveys from a single year.

**Abstract**

Western spruce budworm, *Choristoneura occidentalis* Freeman, is a widely distributed and destructive defoliator of conifers in western North America. Larvae feed on needles, buds, staminate flowers, and developing conelets. Repeated defoliation may result in topkill, further reducing cone production for years after outbreaks subside. Young seedlings attacked by *C. occidentalis* often die, reducing stand densities and retarding forest regeneration. Periodic outbreaks occur irregularly and can last for decades. Severely defoliated Douglas-fir [*Pseudotsugae menziesii* (Mirb.) Franco] may be susceptible to subsequent attack by Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, and the fir engraver beetle, *Scolytus ventralis* LeConte.

Population trends of *C. occidentalis* can be predicted when egg mass densities on foliage are categorized as either new or old. New egg masses are those deposited during the current year while old egg masses are those laid the previous year, or two years ago in some cases. Old egg masses represent the new egg masses laid the previous year so that population estimates can be made for both the current year and the previous year using the same sample branch samples. The difference between the number of new and old egg masses, compared using a standard t test, can be used to determine if populations are declining, increasing, or remain static when significant at the 5% level of probability. A large number of 1- or 2-year old egg masses present in the sample may exaggerate the rate of decline detected by this method. However, the technique is still useful in detecting a decline in the population regardless of rate. This method was tested using data collected from white fir, *Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr., stands in the Pacific northwestern USA over 4 consecutive years.

**Sampling Procedure**

Sample egg masses after the oviposition period has ended, generally by late August in the Pacific Northwest. A minimum of 4 plots should be sampled in areas of 6,070–16,187 ha, and

at least 1 plot per 4,047 ha for even larger areas. Each plot should contain five co-dominant trees of a single host species.

Sample 2 mid-crown branches from the same or adjacent whorls from each tree within a plot for a total of 10 branches per plot. Branches should be taken from opposite sides of the tree. Strip and discard the twigs from the left side of the first branch and the right side of the second branch. Calculate the area of the foliated area of the two half-branch sample by multiplying the measurements of the total length and the width at mid-length on the foliated side (Morris 1955). Closely examine each sample for *C. occidentalis* egg masses. Separate all egg masses present into new and old age categories. Characteristically new egg masses appear shiny with visible emergence holes if the larvae have eclosed. New eggs with larvae that failed to eclose are greenish turning to yellowish. Old egg masses appear milky, have an eroded surface, and are brownish if the larvae failed to eclose. Old egg masses may be present on foliage for more than a year. Tally the number of old and new egg masses and compare these numbers using a student's t test. If the differences between densities of old and new egg masses within a given year are significant at the 5% level of probability, a positive difference indicates a building population while a negative difference indicates a population in decline. Differences close to zero would indicate a static population trend.

**Notes**

Workers must be able to distinguish between old and new egg masses. Branches should be re-examined at least partially by a second worker to check that egg masses are counted and categorized by age correctly. The authors calculated the density of egg masses per 1,000 in2 of foliage, but density data based on branch area are not necessary if examining the population trend within a single sampling season. Egg mass density can be expressed as egg masses per m2 if population trends will be compared over multiple years.

This 1966 paper was published before Freeman (1967) separated western spruce budworm, *Choristoneura occidentalis*, from the closely related spruce budworm, *Choristoneura fumiferana*.

**References**

Freeman, T. N. 1967. On coniferophagous species of Choristoneura (Lepidoptera: Torticidae) in North America. I. Some new forms of *Choristoneura* allied to *C. fumiferana*. Canadian Entomologist 99: 449-455.

# Morris, R. F. 1955. The development of sampling techniques for forest insect defoliators, with particular reference to the spruce budworm. Canadian Journal of Zoology 33: 225-294.

# Western Spruce Budworm

## *Choristoneura occidentalis Freeman*

### Lepidoptera: Tortricidae

Harris, J. W. E.; Dawson, A. F.; Brown, R. G. 1981. Selecting sampling points for larvae of western spruce budworm, *Choristoneura occidentalis* (Lepidoptera: Tortricidae), from survey records in British Columbia. Journal of the Entomological Society of British Columbia 78: 7-9.

**Objective**

To reduce sampling effort for populations of *C. occidentalis* by selecting sampling locations from survey records.

**Abstract**

Western spruce budworm, *Choristoneura occidentalis* Freeman, is a periodically severe defoliating pest of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs (*Abies* spp.) in northwestern North America. The Canadian Forestry Service conducts an annual survey of Douglas-firs for *C. occidentalis* larvae as part of its Forest Insect and Disease Survey (FIDS). The authors examined the historical database produced by FIDS and applied a set of criteria to the records in an attempt to reduce the number of locations sampled annually without altering the population trend estimated using the entire database. Data from 1949 to 1978 were analyzed and 17 sampling locations from the original dataset of 98 sites were identified that effectively predicted the population trend of *C. occidentalis*. Sampling a subset of the sites allows for a reduction in sampling effort with concomitant savings in labor and associated costs.

**Sampling Procedure**

Only sample *C. occidentalis* at sites that meet the following criteria:

1. Site has been sampled for 5 or more years.
2. *C. occidentalis* larvae were found in at least 30% of the years the site has been sampled.
3. Site had a larval population greater than the average of all locations sampled in at least 30% of the sample years.
4. Site has had noticeable defoliation within the sampled Universal Transverse Mercator map grid for 5 or more years.
5. Defoliation at the site was visible in the first year defoliation was detected within the surrounding drainage.

Sample 3 trees of each species of interest at each selected site by laying a 2.1 by 2.7 m white sheet under a tree and beating the branches with a 3.7 m pole for approximately 30 secs (Harris et al. 1972). Identify and count the larvae that fall onto the sheet. Sampling from locations that are easily accessible by roads or waterways, i.e. "roadside sampling", is convenient, economical, and statistically appropriate.

**Reference**

# Harris, J. W. E.; Collis, D. G.; Magar, K. M. 1972. Evaluation of the tree-beating method for sampling defoliating forest insects. Canadian Entomologist 104: 723-729.

# Western Spruce Budworm

## *Choristoneura occidentalis* Freeman

### Lepidoptera: Tortricidae

Schmid, J. M. 1984. Larval densities, mortality, and sampling at different canopy levels during a western spruce budworm (Lepidoptera: Tortricidae) suppression project. Environmental Entomology 13: 781-786.

**Objective**

To evaluate four sampling designs for *C. occidentalis* larvae on Douglas-fir and white fir before and after chemical application for suppression.

**Abstract**

Western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir [*Psuedotsugae menziesii* (Mirb.) Franco], true firs (*Abies* spp.), Englemann spruce (*Picea englemannii* Parry ex. Englem.), and larch (*Larix occidentalis* Nutt.) in the western US and Canada. Infestations in mature stands result in growth loss, top kill, and occasional tree mortality. Post-spray sampling of *C. occidentalis* larvae has followed a plan adapted from *C. occidentalis* egg mass surveys, where two mid-crown branches are taken from opposite sides from each of three Douglas-firs in a cluster, with 25 clusters of trees sampled throughout the spray unit. It was unknown if this plan accurately estimated larval mortality in lower crowns. Four new sampling designs were evaluated on Douglas-fir and white fir [*Abies concolor* (Gord. & Glend.] in northern New Mexico, USA. The sampling plans consisted of taking from each plot: 1) one branch from a single tree, 2) one branch from each tree in a cluster of three trees, 3) two branches from each tree in a cluster of three trees, or 4) a single branch from each tree in a cluster of six trees.

Variation in larval densities among crown levels was rarely significant in Douglas-fir, suggesting that samples could be collected from the lower crown if the lowest branches were avoided, thereby decreasing sampling effort and costs. In contrast, sampling should be restricted to the mid-crown of white fir due to inter-crown variation when sampling from clusters of trees. Sampling additional branches from a crown level, or taking one branch from both the mid- and lower crown increased sampling effort and cost with no improvement in sampling precision.

Mid-crown larval densities were similar for all four plans, indicating that each design was similar in accuracy. While the single branch per tree plan was the most economical in terms of sampling costs, it was not as precise as the other plans using clusters of trees at a higher associated cost of sampling. Significant variation among plots was observed, but significant

variation among trees within plots was minimal. These results suggest that sampling a larger number of plots would improve the precision of all designs, but sampling a cluster of three or more trees does not necessarily improve the precision while increasing the cost of sampling. The authors recommended sampling a single branch from one tree in each plot if reduced sampling cost was desirable, or sampling a single branch from each tree in a cluster of three trees within a plot if increased precision was more desirable. Either design was considered advantageous over the current sampling plan of two mid-crown branches from each of three Douglas-firs in a cluster.

**Sampling Procedure**

Refer to Table 4 for the appropriate number of plots and trees needed to obtain the desired coefficient of variance of 0.1 or 0.2. Establish the appropriate number of plots 100–200 m apart in areas to be sampled. Plots must be evenly distributed throughout the sampling area to fully measure the variation in *C. occidentalis* larval populations.

Each plot should contain seven Douglas-fir or white fir trees 8–15 m tall, even though not all seven trees will be sampled. Randomly select trees for sampling within each plot. Sample either Douglas-fir or white fir; do not combine data from both tree species. If minimizing sampling costs is an objective, sample one branch from a single tree within each plot. If increased precision is an objective, sample one branch from each tree in a cluster of 3 trees within each plot. Sample trees when third and fourth *C. occidentalis* instars are present. Collect pre- and post-spray samples if studying the efficacy of chemical suppression.

Using pole pruners, sample 35–50 cm branch tips from either the middle crown of white fir or from the lower crown of Douglas-fir. Avoid sampling the lowest branches on Douglas-fir. Record the number of *C. occidentalis* larvae, the number of new shoots or buds present, and the overall area of the branch ($cm^2$) for each sample. Express the data as the number of larvae per 100 buds and/or $m^2$ of foliage.

Table 4. Number of plots and trees needed to obtain coefficients of variation (CV) of 0.1 and 0.2 of the mean number of larvae per $m^2$ of foliage on middle crown branches of Douglas-fir and white fir.

| Host / Sampling period | Sampling Design | | | |
|---|---|---|---|---|
| CV | 1 branch from 1 tree | 1 branch from each of 3 trees | 2 branches from each of 3 trees | 1 branch from each of 6 trees |
| Douglas fir | | | | |
| Before spraying | | | | |
| 0.1 | 76 (76)[a] | 40 (120) | 35 (105) | 30 (180) |
| 0.2 | 19 (19) | 10 (30) | 9 (27) | 8 (48) |
| After spraying | | | | |
| 0.1 | 272 (272) | 175(525) | 113 (339) | 154 (924) |
| 0.2 | 68 (68) | 44 (132) | 28 (84) | 39 (234) |
| White fir | | | | |
| Before spraying | | | | |
| 0.1 | 48 (48) | 20 (60) | 20 (60) | 14 (84) |
| 0.2 | 12 (12) | 5 (15) | 5 (15) | 3 (18) |
| After spraying | | | | |
| 0.1 | 320 (320) | 174 (522) | 107 (321) | 133 (798) |
| 0.2 | 80 (80) | 43 (129) | 27 (81) | 33 (198) |

[a] Number of trees in parenthesis.

**Table 4 reproduced with permission of Environmental Entomology, granted April 2, 2009.**

# Western Spruce Budworm

## *Choristoneura occidentalis Freeman*

**Lepidoptera: Tortricidae**

Schmid, J. M.; Farrar, P. A. 1982. Distribution of western spruce budworm egg masses on white fir and Douglas-fir. Res. Pap. RM-241. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 7 p.

### Objective

To improve sampling precision by determining the inter- and intra-crown distribution of *C. occidentalis* egg masses on white fir and Douglas-fir.

### Abstract

Western spruce budworm, *C. occidentalis* Freeman, is a periodically severe defoliating pest of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs (*Abies* spp.) in northwestern North America. Egg sampling is preferred over the other life stages of this pest due to ease of sample collection and assessment. Moreover, egg density of *C. occidentalis* can be sampled long in advance of damage, which helps when planning suppression projects for this pest.

Variation in egg mass densities was studied between and within trees to improve sampling precision. White fir was included in the study as the distribution of *C. occidentalis* on this host is not well known but is of importance when white fir occurs in mixed stands with Douglas-fir. Inter-tree variation in egg mass counts was high for both white fir and Douglas-fir. Consequently, the number of trees selected for sampling should be large enough to account for this variation. Earlier studies have suggested that 25 trees within the area of concern should be sufficient (McKnight et al. 1970). Egg mass density did not vary significantly between the lower and middle crown of Douglas-fir. Moreover, egg mass density did not vary significantly among cardinal directions sampled.

### Sampling Procedure

Randomly select 25 trees within an area of concern. Randomly cut one 45-cm long (18 in.) branch from either the lower or midcrown of each tree and examine for egg masses. Avoid lower branches with little or no foliage. Trees should be widely spaced throughout the stand to account for variability within the stand. If the stand is homogeneous, it may be possible to reduce sampling effort somewhat by sampling 9 clusters of 3 trees each, spaced throughout the stand.

**Note**

This sample methodology should yield more precise estimates of budworm density for management decision-making, but no decision level was established for egg mass densities.

**Reference**

* McKnight, M. E.; Chansler, J. F.; Cahill, D. B.; Flake, H. W., Jr. 1970. Sequential plan for western budworm egg mass surveys in the central and southern Rocky Mountains. Res. Note RM-174. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 8 p.

# Western Spruce Budworm

## *Choristoneura occidentalis Freeman*

### Lepidoptera: Tortricidae

Shore, T. L.; Alfaro, R. I. 1988. Predicting Douglas-fir defoliation from the percentage of buds infested by the western spruce budworm. Journal of the Entomological Society of British Columbia 85: 21-25.

**Objective**

To predict stand defoliation by *C. occidentalis* on Douglas-fir using logarithmic or linear regression models based on the percentage of infested flower and foliage buds.

**Abstract**

Western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir [*Psuedotsugae menziesii* (Mirb.) Franco], true firs (*Abies* spp.), Englemann spruce (*Picea englemannii* Parry ex. Englem.), and larch (*Larix occidentalis* Nutt.) in the western US and Canada. Infestations in mature stands result in growth loss, top kill, and occasional tree mortality.

The authors explored the relationship between the percentage of Douglas-fir buds infested by *C. occidentalis* and the resulting stand defoliation observed that summer. Buds from the mid-crown of three dominant or co-dominant trees were sampled for infestation and percentage infestation was calculated as an average of the three tree estimates. A total of 60 combined estimates of percentage bud infestation were made between 1977 and 1982 from 12 locations. When larval feeding had ended in late summer of the same year, percent defoliation was estimated from 10 randomly selected dominant or co-dominant trees at the same locations using binoculars. Defoliation estimates were made from the upper-, mid-, and lower-crowns of each tree. Total tree defoliation was calculated from the crown-level estimates of each tree and stand defoliation was calculated as the average of the 10 tree estimates.

A statistically significant relationship exists between the percentage of buds infested by *C. occidentalis* and the percent stand defoliation. The best regression model for this relationship is a logarithmic model:

$$\ln (\text{Defoliation} + 1) = -0.3491 + 1.2053 \ln(\text{Buds} + 1)$$

where ln = natural logarithm, Defoliation = average tree defoliation (%) per location and Buds = % buds infested by WSB per location ($R^2 = 0.76$, F = 136.8, MSE = 0.667, $P < 0.01$, and n = 46). A simple linear model is also appropriate:

$$\text{Defoliation} = -0.3491 + 1.2053(\text{Buds})$$

where Defoliation = average tree defoliation (%) per location and Buds = % buds infested by WSB per location ($R^2 = 0.68$, $F = 94.4$, $MSE = 0.319$, $P < 0.01$, and $n = 46$). The linear model is easy to use and closely fits the model developed by Carolin and Coulter (1972), therefore the authors recommend its use even though the logarithmic model was more precise.

**Sampling Procedure**

It is critical that Douglas-fir buds are sampled at the appropriate phenological stage, between the white scale stage and the brush stage as defined by Shepherd (1983, see publication for photographs of each stage of bud development). Larvae should be third and fourth instars during these stages.

Using pole pruners, sample mid-crown branch tips until 100 buds have been examined from each of three dominant or co-dominant trees (i.e. , a total of 300 buds). Calculate the percentage of infested buds as an average of the three individual tree estimates. Use Table 1 to determine the expected defoliation associated with the percentage of infested buds as predicted by either the logarithmic or linear model. Defoliation classes are those used by the Canadian Forestry Service in British Columbia.

**Notes**

The model will overestimate stand defoliation if high larval mortality occurs after infested buds have been sampled. Sampling infested buds allows managers to define areas where sprays are not likely to be needed after winter mortality and check the effectiveness of earlier spray applications. However, sampling infested buds will not allow operation managers enough time to plan and execute spray operations to avoid defoliation by the current generation of larvae. Spray operations for current outbreaks of *C. occidentalis* larvae should be based on egg mass surveys or other sampling methods conducted in the fall.

**References**

* Carolin, V. M.; W. K. Coulter. 1972. Sampling populations of western spruce budworm and predicting defoliation on Douglas-fir in eastern Oregon. USDA For. Serv. Res. Pap. PNW-149; 38 pp.

Shepherd, R. F. 1983. A technique to study phenological interactions between Douglas-fir buds and emerging second instar western spruce budworm. In R. L. Talerico and M. Montgomery (Eds.). Forest defoliator-host interactions: a comparison between gypsy moth and spruce budworms. Conference Proceedings. USDA For. Serv. Gen. Tech. Rpt. NE-85; 141 pp.

Table 1. Percentage of buds infested by western spruce budworm and expected defoliation of Douglas-fir.

| Buds infested (%) | | Expected defoliation | |
|---|---|---|---|
| Linear | Logarithmic | Class | Percent |
| 0 | 0 | none | 0 |
| 1–13 | 1–19 | lihgt | 1–25 |
| 14–35 | 20–41 | moderate | 26–65 |
| 36–100 | 42–100 | severe | 66–100 |

**Table 1 reproduced with permission from the authors, granted April 7, 2009.**

# Western Spruce Budworm

## *Choristoneura occidentalis Freeman*

### Lepidoptera: Tortricidae

Srivastava, N.; Beckwith, R. C.; Campbell, R. W.; Torgersen, T. R. 1981. A method for sampling western spruce budworm pupae. Res. Note PNW-372. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 6 p.

**Objective**

To validate a method of stratified sampling for *C. occidentalis* pupae on branch tips.

**Abstract**

Western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir [*Psuedotsugae menziesii* (Mirb.) Franco], true firs (*Abies* spp.), Englemann spruce (*Picea englemannii* Parry ex. Englem.), and larch (*Larix occidentalis* Nutt.) in the western US and Canada. Infestations in mature stands result in growth loss, top kill, and occasional tree mortality.

Methods of sampling spruce budworm, Choristoneura fumiferana (Clemens), were validated for use with *C. occidentalis* pupae in north-central Washington. Mean pupal densities from 45-cm branch tips accurately estimated the whole-tree pupal density. Pupal densities varied among the upper, middle, and lower crown levels, thus stratified sampling from all three levels is recommended. Pupal densities did not differ among terminal tips, lateral tips, and whole branches. The recommend sampling unit consists of two 45-cm terminal or lateral branch tips from each crown level of a tree. In this study, the mean number of pupae per 100 buds ranged 0.6–11.3 (± 0.18–3.50 SEM). At this range of densities, the authors suggest sampling 10 clusters of three trees each to estimate pupal densities with a 15% level of precision.

**Sampling Procedure**

Conduct sampling in early to mid-July when most *C. occidentalis* larvae have pupated. Randomly select 10 sampling points within 5-ha plots. At each point, randomly select three host trees for sampling. Divide the live crown of each tree into thirds. Cut at least two 45-cm terminal or lateral branch tips from the upper, middle, and lower crown levels of each tree. Count the number of pupae and the number of buds present on each branch tip. Express pupal densities as counts per m2 foliage or per 100 buds.

Check the precision level after sampling 10 clusters of three trees each. In this study, the mean number of pupae per 100 buds ranged 0.6–11.3 (± 0.18–3.50 SEM). At this range of densities, the authors suggest sampling 10 clusters of three trees each to estimate pupal densities with a 15% level of precision. Continue sampling if the desired precision level has not been met yet.

**Note**

The authors found that variation among trees had a greater effect on pupal density than variation among clusters, therefore they suggest sampling additional trees in each cluster rather than including additional clusters of three trees each.

# Western Spruce Budworm

## *Choristoneura occidentalis Freeman*

### Lepidoptera: Tortricidae

Torgersen, T. R.; Scott, D. W.; Gillespie, A. J. R.; Hosman, K. P. 1994. Relationship between lower-crown sampling and midcrown sampling for *Choristoneura occidentalis* (Lepidoptera: Tortricidae) after treatment with Bacillus thuringiensis. Journal of Economic Entomology 87: 1022-1026.

**Objective**

To develop a model predicting mid-crown densities of late-instar *C. occidentalis* based on lower-crown densities.

**Abstract**

Western spruce budworm, *C. occidentalis* Freeman, is an important defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs (*Abie*s spp.) in western North America. Infestations in mature stands cause growth loss, top kill, and occasionally tree mortality. Traditional sampling methods for *C. occidentalis* include sampling midcrown foliage using pole-pruners and beating lower crown foliage over a beatsheet. The beatsheet technique is quicker and less expensive than the use of pole-pruners.

Mid- and lower crown larval densities of *C. occidentalis* were studied on grand-fir, *Abies grandis* (Dougl. ex D. Don) Lindl., and Douglas-fir in Oregon. An equation was developed to estimate the density of late instars found in the midcrown based on larval densities found in the lower crown by beatsheeting. The developed equation is helpful in relating the simpler, quicker lower crown sampling to the more time-consuming mid-crown sampling.

**Sampling Procedure**

Sample when late instars (fourth to sixth instar) are present. Select 25 plots to sample, each containing a cluster of five Douglas-fir or grand fir trees. Trees should be 6–14 m tall. In each plot, sample three lower-crown branches from each of the five trees in the cluster by striking the branch over a beatsheet. Count all *C. occidentalis* larvae in the fourth, fifth, and sixth instar.

Use the following equation to predict the number of fourth to sixth instar per midcrown tip from the number of larvae per 3-tip lower-crown sample in 25 tree clusters of five trees each:

$$Y = 0, \text{ for } X < 0.9764$$

$$Y = -1.0168 + 1.0414X, \text{ for } 0.9764 < X < 22.0$$

where Y = the estimated mean number of late instar larvae per midcrown tip and X = the mean number of larvae per 3-tip lower-crown sample ($R^2 = 0.932$, MSE= 4.5189).

Notes

The authors do not recommend extrapolating above 22 *C. occidentalis* larvae per sample as that was the upper limit of their data. In addition, their model is based on sampling 25 plots with 5 trees per plot (n = 125 trees). The model is less accurate in predicting the number of late instar *C. occidentalis* per branch tip in the mid-crown if fewer plots or fewer trees per plot are used. The model should not be used to predict midcrown densities in single trees because of inter-tree variation.

# Jack Pine Budworm

## *Choristoneura pinus pinus* Freeman

### Lepidoptera: Tortricidae

Hall, R. J.; Volney, W. J. A.; Wang, Y. 1998. Using a geographic information system (GIS) to associate forest stand characteristics with top kill due to defoliation by the jack pine budworm. Canadian Journal of Forest Research 28: 1317-1327.

**Objective**

To relate stand characteristics with top kill by *C. pinus pinus* using a geographic information system (GIS).

**Abstract**

The jack pine budworm, *Choristoneura pinus pinus* Freeman, is a native, periodically significant defoliator of jack pine, *Pinus banksiana* Lamb., in North America. Top kill is common during outbreaks, but tree mortality is rare unless infestations coincide with periods of drought.

Using 1:900 and 1:2500 large-scale color photographs from a forested area in Saskatchewan, Canada, top kill by *C. pinus pinus* was categorized into discrete levels of severity according to a classification system devised by the authors (Table 1). Forest inventory maps were converted in GIS for spatial analysis of stand characteristics of age, height, crown closure, and site quality. Maps of top kill and stand characteristics were analyzed spatially to identify stands vulnerable to damage by *C. pinus pinus*. Overall, site quality was strongly associated with top kill by *C. pinus pinus* ($x^2 = 350.4$; $\alpha = 0.05$), followed in ranking by stand maturity ($x^2 = 328.9$; $\alpha = 0.05$) and stand height ($x^2 = 294.3$; $\alpha = 0.05$). Stands associated with moderate and severe top kill were overmature (>85 years), 15–20 m tall, with 31–55% crown closure and established on sites with poor quality. Land managers should consider treatment or harvest options for stands with these characteristics to avoid or limit top kill by *C. pinus pinus*.

**Sampling Procedure**

Using a GIS, convert 1:12,500 scale forest inventory maps of the area under study from vector to raster with a cell size of 12.5 m. Classify forest cover polygons separately according to stand age, stand height, and crown closure. Stand age classes can be condensed to young (25–35 years), mature (45–65 years), or overmature (85–125 years). Assign site quality by interpreting landform and plant community patterns from 1:12,500 and 1:5,000 infrared aerial photographs of the area. Randomly establish field plots of approximately 300 $m^2$

within the area being mapped. At each field plot, record data on the plot location, soil profile, vegetative community, drainage, slope, aspect, and other related measurements. Produce a map of site quality using this field information and 1:25,000 large-scale color photographs. Map the distribution of stand maturity, height, and crown closure as a ratio of the area relative to the entire study area.

Stands identified as >85 years old, 15–20 m tall, with 31–55% crown closure and established on sites with poor quality should be harvested to avoid or limit top kill by *C. pinus pinus*. Stands with these structural characteristics were associated with moderate and severe ratings of top kill (Table 1).

**Notes**

The authors established 27 field plots within the 44-km$^2$ study area. Refer to the original publication for more details regarding mapping stand characteristics within GIS.

Table 1. Top-kill map classification system.

| Severity rating | Class limits (%) | Description |
|---|---|---|
| Nil | 0 | No visible top kill |
| Light | 1–25 | Up to 25% of trees in delineated polygons with visible top kill |
| Moderate | 26–50 | From 26 to 50% of trees in delineated polygons with visible top kill |
| Severe | 51–100 | > 50% of trees in delineated polygons with visible top kill |
| Unclassified | Not applicable | Regenerating areas or areas not supporting forest stands |

# Jack Pine Budworm

## *Choristoneura pinus pinus* Freeman

### Lepidoptera: Tortricidae

Nealis, V. G.; Lomic, P. V. 1996. Forecasting defoliation by the jack pine budworm. Frontline Tech. Note No. 91. Sault Ste. Marie, Ont.: Natural Resources Canada, Canadian Forest Service; 4 p.

**Objective**

To describe an improved method of forecasting defoliation by *C. pinus pinus* in individual stands.

**Abstract**

Jack pine budworm, *Choristoneura pinus pinus* Freeman, is a native, periodically significant defoliator of jack pine, *Pinus banksiana* Lamb., in North America. Prior to this effort, defoliation assessments for jack pine budworm had been adapted from those used for the spruce budworm, *Choristoneura fumiferana* (Clemens). However, surveys that related egg and/or overwintering larvae densities to subsequent defoliation by spruce budworm were inaccurate for predictions of jack pine budworm defoliation. This method was improved by including estimates of jack pine pollen cone abundance, an important food source for the survival of young jack pine budworm larvae.

A prediction model was developed whereby estimates of egg mass and/or pollen cone density are used to predict defoliation level. The model was tested against 35 independent data sets and was found to be 77% accurate if using the lowest defoliation class (30% needles consumed) and 89% accurate at the highest defoliation class (>75% needles consumed). This level of accuracy was deemed acceptable for forecasting of budworm defoliation by monitoring and/or for suppression projects. Egg mass sampling can also be combined with defoliation and/or pollen cone surveys to save time and handling of foliage.

Sampling Procedure

Sample egg masses in August and September. Pollen cones can be sampled from October through April, but sampling in fall or winter provides more time to implement control tactics than sampling in the spring.

To sample either egg masses or pollen cones, randomly sample a 1-m terminal branch from the midcrown of six randomly chosen jack pines in a stand. Count the total number of egg masses and pollen cones (microstrobili) on the branch samples. Log ($\log_{10}$) transform each

estimate, then use them in the following equation to estimate the density of feeding jack pine budworm larvae per 100 shoots (Nt+1):

$$N_{t+1} = \frac{10^{(1.31*EGG+0.70)}}{10^{(-.60*CONE+0.94)}}$$

where Nt+1 is the estimated number of feeding larvae per 100 shoots, EGG is the $\log_{10}$ density of egg masses per 1-m branch sample, and CONE is the log10 density of pollen cones per 1-m branch sample.

Compare the density estimate to the following density thresholds that coincide with estimated levels of defoliation.

| Budworm density per 100 shoots | Defoliation |
|---|---|
| >6.1 | >30% |
| >16.8 | >50% |
| >55.2 | >75% |

Defoliation can be assessed from the same 1-m branches sampled for egg masses and/or pollen cone assessments. Defoliation is usually estimated from one 1-m branch sample taken from 6-10 trees.

| Defoliation | Percentage current-year shoots removed |
|---|---|
| light | <25% |
| moderate | 25–75% |
| severe | >75% |

**Notes**

Obviously sampling for feeding budworm larvae provides a reasonably accurate estimate of defoliation potential (see Fig. 2 in original publication; r2 = 0.62). However, sampling for feeding larvae is time consuming and tedious. Moreover, larval samples must be made in late spring, which does not give managers sufficient lead-time to implement control tactics.

# Jack Pine Budworm

## *Choristoneura pinus pinus* Freeman

### Lepidoptera: Tortricidae

Volney, W. J. A. 1992. The distribution and estimation of jack pine budworm defoliation. Canadian Journal of Forest Research 22: 1079-1088.

**Objective**

To streamline estimation of defoliation by *C. pinus pinus* on current year shoots and to estimate defoliation levels at a level of fixed precision.

**Abstract**

Jack pine budworm, *Choristoneura pinus pinus* Freeman, is an important defoliator of jack pine, *Pinus banksiana* Lamb., and to a lesser extent on red pine, *P. resinosa* Ait., in the Great Lakes region and Canada. Extensive top kill is common during outbreaks, but tree mortality is rare unless infestations coincide with periods of drought.

Defoliation by *C. pinus pinus* varies among stands, among trees, and within tree crowns. This variation was quantified and used to determine sample sizes needed to estimate defoliation levels with fixed levels of precision. Ten shoots from a 45-cm branch are used to estimate defoliation levels. The number of plots, trees, and branches needed to estimate C. pinus defoliation levels to within 5% of the true mean varied with the mean of the true defoliation levels. In general, the least amount of total effort was needed if true defoliation levels were <10 and >80%. Depending on the defoliation level in the stand, between 3 to 6 h are needed to complete the survey.

**Sampling Procedure**

Refer to Table 7 for the appropriate number of plots, trees, and branches to sample. Randomly select trees within plots and branches on trees, although systematic sampling of trees along a transect may be more appropriate than random selection given the variation in defoliation that occurs within a stand. Each sampled branch should be at least 45-cm in length. Branches sampled from the middle third of the live crown produce defoliation estimates with the smallest sampling bias. Estimate the defoliation level of 10 randomly selected shoots on each branch following the method of Fettes (1950). The Fettes method estimates defoliation of shoots in 10% defoliation level classes. Average the estimates of defoliation level among trees within a stand to determine stand defoliation levels within 5% of the true mean.

**Notes**

The 5% level is very precise and might not be efficient for surveys of large areas for management purposes. This procedure could be used to estimate *C. pinus pinus* density (see Nealis and Lomic 1996, this volume).

References

* Fettes, J. J. 1950. Investigations of sampling techniques for population studies of the spruce budworm on balsam fir in Ontario. Annual Rep. 1949. Sault Ste. Marie: Canadian Forest Service, Forest Insect Laboratory; 11 p.

# Nealis, V. G.; Lomic, P. V. 1996. Forecasting defoliation by the jack pine budworm. Frontline Tech. Note 91. Sault Ste. Marie: Natural Resources Canada, Canadian Forest Service; 4 p.

Table VII. Optimal allocation of effort in a sample scheme to estimate stand defoliation with a standard error of 5% of the mean.

| Percent defoliation | Number of sample units* | | | Time† (min) |
|---|---|---|---|---|
| | Plots | Trees | Branches | |
| 10 | 9 | 1 | 2 | 185 |
| 20 | 10 | 1 | 2 | 215 |
| 25 | 9 | 2 | 1 | 217 |
| 30 | 8 | 2 | 1 | 236 |
| 40 | 4 | 6 | 1 | 302 |
| 50 | 3 | 9 | 1 | 363 |
| 60 | 3 | 9 | 1 | 370 |
| 70 | 3 | 8 | 1 | 343 |
| 80 | 3 | 5 | 1 | 275 |

* Number of units was rounded to the next highest integer.

† Estimated time required to complete assessment.

# Oak Leaftier

## *Croesia semipurpurana* (Kearfott) Freeman

### Lepidoptera: Tortricidae

Ciesla, W. M. 1969. Forecasting population trends of an oak leaf tier, *Croesia semipurpurana*. Journal of Economic Entomology 62: 1054-1056.

**Objective**

To describe a fixed sampling method for predicting defoliation by *C. semipurpurana* based on egg density.

**Abstract**

Oak leaftier, *Croesia semipurpurana* (Kearfott), is a native defoliator of oaks (*Quercus* spp.,) in the eastern USA. Larvae favor oaks in the red oak group. Young larvae mine oak buds as they open in the spring and can remove much of the new growth. Older larvae tie remaining leaves together with silk to form feeding refuges. Repeated defoliation over several consecutive years may result in twig and branch dieback, growth loss, and susceptibility to attack by secondary insects and fungi.

Eggs are present from midsummer through the following spring, therefore egg density can be sampled in winter and used to forecast population trends. The distribution of *C. semipurpurana* eggs on branches of scarlet oak, *Quercus coccinea* Muenchh., was studied to develop a fixed sampling method to predict subsequent defoliation by this pest. Mean *C. semipurpurana* egg density on a 0.38 m terminal branch sample is positively related (r = 0.79) to the percentage of defoliation. This relationship can be expressed by the following equation:

$$y = 2.18 + 2.56x$$

where x = the mean number of eggs per 0.38 m terminal branch sample and y = percentage of expected defoliation. Land managers can use this formula to decide if *C. semipurpurana* populations warrant control measures.

**Sampling Procedure**

In each designated plot, randomly select 4 scarlet oaks or other members of the red oak group in late winter. Using pole pruners, randomly cut two 0.38 m terminal branches from the lower or mid-crown of each tree. Discard any lateral branches or previous years' growth from the samples. Bag samples and transport to a laboratory. Using a stereomicroscope, examine each sample for *C. semipurpurana* eggs, paying close attention to the upper surface of

the branch, and areas of rough bark or leaf scars. A larger percentage of eggs will be found on the basal section of the branch sample. Use the formula $y = 2.18 + 2.56x$, where $x$ = the mean number of eggs per 0.38 m terminal branch sample and $y$ = percentage of defoliation, to predict the level of expected defoliation. Alternatively, consult Table 2 to predict the level of expected defoliation.

**Note**

The sampling plan was developed on scarlet oaks in the mid-Atlantic. Results may vary on different host trees in other regions.

Table 2. Mean number *C. semipurpurana* eggs per 15-in. branch sample and predicted defoliation, James River District, George Washington National Forest, Va. 1967.

| Mean no. eggs/15 in. sample | Predicted | % Defoliation |
|---|---|---|
| 0–8.0 | Negligible-light | 0–25 |
| 8.1–28.2 | Moderate | 26–75 |
| >28.2 | Heavy | ≥76 |

**Table 2 reproduced with permission from the Journal of Economic Entomology, granted April 2, 2009.**

# Spruce Bud Moth

## *Zeiraphera canadensis* Mutuura & Freeman

### Lepidoptera: Tortricidae

Régnière, J.; Boulet, B.; Turgeon, J. J. 1988. Sequential sampling plan with two critical levels for spruce bud moth (Lepidoptera: Tortricidae). Journal of Economic Entomology 81: 220-224.

**Objective**

To develop a sequential sampling plan for *Z. canadensis* in white spruce plantations based on larval density.

**Abstract**

Spruce bud moth, *Zeiraphera canadensis* Mutuura & Freeman, is a pest of white spruce, *Picea glauca* (Moench) Voss in eastern North America. Larvae tend to feed on the current year's growth in the upper crown, limiting damage to reduced growth and crown distortion. Damage is particularly important in plantations of white spruce, where reduced growth may postpone harvest for several years. Older larvae occasionally feed on the bark of tender twigs, which may predispose the tree to attack by wood boring insects and decay fungi. In the urban setting, unsightly feeding damage may be of a concern to homeowners.

The authors developed a sequential sampling plan with a 68% confidence level for *Z. canadensis* larvae based on two critical levels of two and eight larvae per sample.

| Larvae per branch sample | Threshold density |
|---|---|
| $\mu \leq 2$ | Low |
| $2<\mu \leq 8$ | Moderate |
| $\mu > 8$ | High |

Previous research used a critical level of 5 larvae per branch sample (Turgeon and Régnière 1987). Generally 20 branch samples were needed for larval densities near the lower critical level, but smaller sample sizes were required for most densities. Typically the plan took 1–2 hours to conduct in plantations where more than 1.5 larvae were found in each sample. At least 16 min were needed for a plantation when no spruce bud moth larvae are found on the minimum sample size of only five branches. Because larvae aggregate in the crown, excessively large sample sizes would be needed for confidence levels of 90–95%, which would make the plan impractical for most pest managers.

## Sampling Procedure

Select white spruce trees at equally spaced intervals throughout the plantation. Randomly cut one 15-cm terminal branch from the upper third of the crown of each tree.

Count the number of third and fourth instars in each 15-cm branch sample as a cumulative tally. Compare the cumulative tally to Table 1. Counts can be classified as low, moderate, or high if the cumulative tally crosses the boundaries of the lower or upper critical zones. If the tally remains in a zone, continue sampling until 50 branch samples have been examined in the lower critical zone or 20 branch samples have been examined for the upper critical zone. If a maximum of 50 branch samples are examined in the lower critical zone, the population can be classified as low if n <100 larvae or as moderate if n ≥100 larvae. If a maximum of 20 branch samples are examined in the upper critical zone, the population can be classified as moderate if n <160 larvae or as high if n ≥160 larvae.

## Notes

Because *Z. canadensis* larvae tend to occur in aggregations, the authors caution that trees should be selected for sampling at random throughout the plantation to avoid biasing the counts and misclassifying the infestation. This sampling plan was developed for use in white spruce plantations in northern New Brunswick and Québec. The authors do not recommend its use in natural stands or plantations outside of these regions without further testing.

## Reference

* Turgeon, J. J.; Régnière, J. 1987. Development of sampling techniques for the spruce budmoth, Zeiraphera canadensis (Lepidoptera: Tortricidae). Canadian Entomologist 119: 239-249.

Table 1. Sequential sampling plan with two critical levels for the spruce bud moth in white spruce plantations

| No. samples examined | Cumulative no. larvae found ($n$)[a] | | | |
|---|---|---|---|---|
| | Lower critical zone | | Upper critical zone | |
| 5 | 2–18 | | 20–60 | |
| 6 | 3–21 | | 27–69 | |
| 7 | 4–24 | M | 33–79 | H |
| 8 | 6–26 | | 39–89 | |
| 9 | 7–29 | O | 46–98 | I |
| 10 | 9–31 | D | 52–108 | G |
| 11 | 10–34 | | 59–117 | |
| 12 | 11–37 | E | 66–126 | H |
| 13 | 13–39 | | 72–136 | |
| 14 | 14–42 | R | 79–145 | |
| 15 | 16–44 | A | 86–154 | |
| 16 | 18–46 | | 93–163 | |
| 17 | 19–49 | T | 101–172 | |
| 18 | 21–51 | | 107–181 | |
| 19 | 22–54 | E | 114–190[b] | |
| 20 | 24–56 | | Terminal decision: if $n$ <160, moderate: if $n$ ≥160, high | |
| 21 | 25–59 | | | |
| 22 | 27–61 | | | |
| 23 | 29–63 | | | |
| 24 | 30–66 | | | |
| 25 | 32–68 | | | |
| 26 | 34–70 | | | |
| 27 | 35–73 | | | |
| 28 | 37–75 | | | |
| 29 | 39–77 | | | |
| 30 | 40–80 | | | |
| 31 | 42–82 | | | |
| 32 | 44–84 | | | |
| 33 | 45–87 | | | |
| 34 | 47–89 | | | |
| 35 | 49–91 | | | |
| 36 | 50–94 | | | |
| 37 | 52–96 | | | |
| 38 | 54–98 | | | |
| 39 | 55–101 | | | |
| 40 | 57–103 | | | |
| 41 | 59–105 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 42 | | 61–107 | | | |
| 43 | | 62–110 | | | |
| 44 | | 64–112 | | | |
| 45 | | 66–114 | | | |
| 46 | | 67–117 | | | |
| 47 | | 69–119 | | | |
| 48 | | 71–121 | | | |
| 49 | | 73–123 | | | |
| 50 | | Terminal decision: if n <100, low; if n≥100, moderate | | | |

[a]Sampling is pursued until the cumulative number of larvae exits the indicated inclusive ranges, or until maximum sample size is reached.

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# Introduced Basswood Thrips

## *Thrips calcaratus* Uzel

### Thysanoptera: Thripidae

Werner, S. M.; Nordheim, E. V.; Raffa, K. F. 2004. Comparison of methods for sampling *Thysanoptera* on basswood (*Tilia americana* L.) trees in mixed northern hardwood deciduous forests. Forest Ecology and Management 201: 327-334.

**Objective**

To compare three methods of sampling *T. calcaratus* on basswood.

**Abstract**

Canopy insects can be sampled using a variety of techniques. Pole pruners are commonly used, but foliage can also be collected using a shotgun or tree climbers. These methods were used to sample the introduced basswood thrips, *Thrips calcaratus* Uzel, on American basswood, *Tilia americana* L. *T. calcaratus* is associated with defoliation and crown dieback on basswood in northern US forests (Raffa and Hall 1989). In general, research objectives, legal ramifications, economic costs, and logistics should all be considered when selecting a sampling method for foliage insects.

Each collection method (pole pruner, shotgun, and tree climber) had its advantages and disadvantages. A tree climber who bagged foliage samples before releasing them to the ground collected more thrips per sample numerically than the other methods, but bagging the samples was time-consuming and increased the per-hour cost of hiring a certified tree climber. Furthermore, the mean density of thrips per sample obtained by a tree climber who did not bag the samples before releasing them to the ground did not differ from the mean density of thrips obtained by using a pole pruner or a shotgun. The pole pruner or shotgun methods can sample multiple areas of the canopy in a shorter period of time compared to a tree climber, but pole pruners may not reach all sections of the canopy equally well and the use of a shotgun may not be permitted in certain areas. A tree climber may introduce bias in the selection of foliage samples, but it may be comparable to that introduced by someone using a pole pruner.

Samples of *T. calcaratus* collected by the tree climber were positively related to those collected using pole pruners for both adult ($r^2 = 0.73$; $P = 0.01$) and larval thrips ($r^2 = 0.71$; $P = 0.01$), whereas samples collected using a shotgun were not related to samples collected by either a tree climber or a pole pruner. Densities of adult *T. calcaratus* obtained by the pole pruner method can be used to predict densities obtained by the tree climber using the formula $y = 0.83x + 0.04$, where y = density of thrips obtained by pole pruner method and x = density of thrips obtained by tree climber method.

**Sampling Procedure**

The sample unit consists of the three terminal leaves or leaf buds on each small basswood branch. Bag each sample separately for transportation back to the laboratory. Place each sample in 70% ethanol and collect the thrips present onto filter paper using vacuum filtration. Identify the species and life stage of the thrips under magnification.

Collect foliage samples from basswood trees using one of the following techniques:

1. Use a 1.83 m pole pruner to cut small branches from the canopy. Use 1.83 m pole extensions as needed.
2. Use a 20-gauge (15.90 mm bore diameter) shotgun to blast small branches from the canopy.
3. Hire a certified tree climber to climb trees, clip small branches, and either drop the branches to the ground or bag each branch separately before dropping them to the ground.

Thrips densities obtained by the tree climber or pole pruner methods are highly correlated and one can be used to predict the results of the other method. Use the following equation:

$$y = 0.83x + 0.04$$

where y = density of adult *T. calcaratus* obtained by pole pruner method and x = density of adult *T. calcaratus* obtained by tree climber method.

For *T. calcaratus* larvae, use the following equation:

$$y = 0.56x + 0.74$$

where y = density of larval thrips obtained by pole pruner method and x = density of larval thrips obtained by tree climber method.

**Notes**

Eight basswood trees were sampled using each method, but the authors did not specify the number of samples taken from each tree. Contact the authors for additional information.

**Reference**

Raffa, K. F.; Hall, D. J. 1989. *Thrips calcaratus* Uzel (Thysanoptera: Thripidae), a new pest of basswood trees in the Lake States. Canadian Journal of Forest Research 18: 1661-1662.

# MISCELLANEOUS INSECTS

Mussey, G. J.; Potter, D. A. 1997. Phenological correlations between flowering plants and activity of urban landscape pests in Kentucky. Journal of Economic Entomology 90: 1615-1627.

**Objective**

To predict pest activity based on the phenology of indicator plants.

**Abstract**

Pest management decisions are often based on calendar dates because frequent monitoring and sampling, which are more effective means of gauging the need for control measures, can be time consuming and labor intensive. A phenology calendar that correlates pest activity to the flowering of common indicator plants may be more useful for landscape managers with little knowledge of pest life cycles or appropriate sampling methodology. Such calendars allow managers to predict when insect pests are likely to be in a life stage vulnerable to control measures. Additional scouting can confirm the presence of vulnerable life stages of a given pest and when most of the population has entered this stage.

**Sampling Procedure**

Use Table 4 to identify phenological events of common plants associated with the presence of selected insect pests of forest and shade trees. Consider applying control measures during the given phenological events, but after most of the pest population has entered the life stage vulnerable to control. Use Table 6 to compare the average dates of phenological events between Louisville, Kentucky and Midland, Michigan (Herms 1990).

**Note**

The phenology calendar was developed in central Kentucky and may be appropriate for surrounding states, but should be used with caution in other regions.

**Reference**

Herms, D. A. 1990. Biological clocks. American Nurseryman 172: 56-63.

Table 4. Phenological sequence of woody plant flowering and insect events in Lexington, KY, 1992-1994

| **Insects** | Indicator plant | Phenological event | 3-yr. Avg |
|---|---|---|---|
| | *Acer saccharinum* L. | 1st bloom | 18 Feb. |
| | *Cornus mas* L. | 1st bloom | 21 Feb. |
| | *Acer saccharinum* L. | 50% bloom | 24 Feb. |
| | *Cornus mas* L. | 50% bloom | 03 Mar. |
| | *Acer saccharinum* L. | 95% bloom | 10 Mar. |
| | *Forsythia xintermedia* Zabel | 1st bloom | 12 Mar. |
| | *Cornus mas* L. | 95% bloom | 13 Mar. |
| **Eastern tent caterpillar** *Malacosoma americanum* (F.) | | Egg hatch | 16 Mar |
| | *Berberis* x *mentorensis* L. M. Ames | 50% bloom | 09 Apr. |
| | *Amelanchier arborea* (Michaux, F.) Fernald | 50% bloom | 09 Apr. |
| | *Viburnum* x *juddii* Rehder | 1st bloom | 10 Apr. |
| | *Magnolia* x *soulangiana* Soulange-Bodin | 95% bloom | 11 Apr. |
| | *Acer platanoides* L. | 50% bloom | 11 Apr. |
| | *Amelanchier arborea* (Michaux, F.) Fernald | 95% bloom | 11 Apr. |
| | *Malus floribunda* Van Houtte | 1st bloom | 11 Apr. |
| | *Berberis* x *mentorensis* L. M. Ames | 95% bloom | 13 Apr. |
| | *Viburnum* x *juddii* Rehder | 50% bloom | 13 Apr. |
| | *Cercis canadensis* L. | 1st bloom | 14 Apr. |
| | *Malus floribunda* Van Houtte | 50% bloom | 15 Apr. |
| | *Syringa vulgaris* L. | 1st bloom | 15 Apr. |
| | *Acer platanoides* L. | 95% bloom | 15 Apr. |
| | *Aesculus* x *carnea* Hayne | 1st bloom | 16 Apr. |
| | *Malus sargentii* Rehder | 1st bloom | 16 Apr. |
| | *Cornus florida* L. | 50% bloom | 17 Apr. |
| | *Cercis canadensis* L. | 50% bloom | 17 Apr. |
| | *Viburnum* x *juddii* Rehder | 95% bloom | 17 Apr. |
| | *Prunus serrulata* Lindley 'Kwansan' | 1st bloom | 19 Apr. |
| | *Prunus serrulata* Lindley 'Kwansan' | 50% bloom | 19 Apr. |
| **Honeylocust plant bug**, *Diaphnocoris chlorionis* (Say) | | Emergence | 20 Apr. |
| | *Syringa vulgaris* L | 50% bloom | 20 Apr. |
| | *Malus sargentii* Rehder | 50% bloom | 20 Apr. |
| | *Prunus serrulata* Lindley 'Kwansan' | 95% bloom | 20 Apr. |

| | | | |
|---|---|---|---|
| **Birch leafminer,** *Fenusa pusilla* (Lepeletier) | | Emergence | 21 Apr. |
| | *Malus floribunda* Van Houtte | 95% bloom | 21 Apr. |
| | *Cercis canadensis* L. | 95% bloom | 21 Apr. |
| | *Cornus florida* L. | 95% bloom | 22 Apr. |
| **Hawthorn lace bug,** *Corythucha cydoniae* (Fitch) | | Emergence | 22 Apr. |
| | *Malus sargentii* Rehder | 95% bloom | 23 Apr. |
| **Oystershell scale,** *Lepidosaphes ulmi* (L.) | | Egg hatch | 23 Apr. |
| **Yellow poplar weevil,** *Odontopus calceatus* (Say)[a] | | Emergence | 23 Apr. |
| | *Syringa vulgaris* L. | 95% bloom | 24 Apr. |
| **Lilac/ash borer** *Podosesia syringae* (Harris) | | 1st flight | 24 Apr. |
| | *Crataegus viridis* L. 'Winter King' | 1st bloom | 27 Apr. |
| | *Cornus kousa* (Hance) | 1st bloom | 28 Apr. |
| | *Chionanthus virginicus* L. | 1st bloom | 28 Apr. |
| | *Aesculus* x *carnea* Hayne | 50% bloom | 29 Apr. |
| **Pine needle scale,** *Chionaspis pinifoliae* (Fitch) | | Egg hatch | 30 Apr. |
| | *Pyracantha coccinea* Roemer | 50% bloom | 08 May |
| | *Cladrastris kentukea* Rudd | 1st bloom | 08 May |
| | *Ilex opaca* Aiton, R. | 1st bloom | 08 May |
| | *Lonicera tatarica* L. | 95% bloom | 11 May |
| | *Ilex opaca* Aiton, R. | 50% bloom | 11 May |
| | *Cladrastris kentukea* Rudd | 50% bloom | 12 May |
| | *Cornus kousa* (Hance) | 95% bloom | 13 May |
| | *Pyracantha coccinea* Roemer | 95% bloom14 May | |
| **Juniper scale,** *Carulaspis juniperi* (Bouché) | | Egg hatch | 15 May |
| | *Ilex opaca* Aiton, R. | 95% bloom | 17 May |
| | *Cladrastris kentukea* Rudd | 95% bloom | 17 May |
| **Bag worm,** *Thyridopteryx ephemeraeformis* (Haworth) | | Egg hatch | 18 May |
| **Dogwood borer,** *Synanthedon scitula* (Harris) | | 1st flight | 20 May |
| | *Crataegus phaenonpyrum* (L. f.) Medicus | 1st bloom | 21 May |

| | | | |
|---|---|---|---|
| **Bronze birch borer,** | | | |
| *Agrilus anxius* Gory | | Emergence | 22 May |
| | *Tilia cordata* Miller | 1st bloom | 23 May |
| | *Syringa reticulata* (Blume) | 1st bloom | 23 May |
| | *Catalpa speciosa* Warder | 1st bloom | 24 May |
| **Calico scale,** | | | |
| *Eulecanium cerasorum* Cockerell) | | Egg hatch | 24 May |
| | *Crataegus phaenonpyrum* (L. f.) Medicus | 50% bloom | 24 May |
| | *Hydrangea quercifolia* Bartrum | 1st bloom | 27 May |
| | *Catalpa speciosa* Warder | 50% bloom | 27 May |
| **Flatheaded appletree borer,** | | | |
| *Chrysobothris femorata* (Oliver) | | Emergence | 28 May |
| | *Crataegus phaenonpyrum* (L. f.) Medicus | 95% bloom | 28 May |
| | *Syringa reticulata* (Blume) | 50% bloom | 29 May |
| **Twolined chestnut borer,** | | | |
| *Agrilus bilineatus* (Weber) | | Emergence | 29 May |
| | *Magnolia grandiflora* L. | 1st bloom | 30 May |
| | *Catalpa speciosa* Warder | 95% bloom | 31 May |
| | *Syringa reticulata* (Blume) | 95% bloom | 02 Jun. |
| | *Hydrangea quercifolia* Bartrum | 50% bloom | 02 Jun. |
| **Japanese beetle,** | | | |
| *Popillia japonica* Newman | | 1st flight | 04 Jun. |
| | *Tilia cordata* Miller | 50% bloom | 07 Jun. |
| **Honeylocust borer,** | | | |
| *Agrilus difficilis* Gory | | Emergence | 07 Jun |
| | *Hydrangea quercifolia* Bartrum | 95% bloom | 07 Jun. |
| | *Magnolia grandiflora* L. | 50% bloom | 08 Jun. |
| **Walnut scale,** | | | |
| *Quadraspidiotus juglansregiae* (Comstock) | | Egg hatch | 09 Jun. |
| | *Tilia cordata* Miller | 95% bloom | 09 Jun. |
| **Cottony maple leaf scale,** | | | |
| *Pulvinaria acericola* (Walsh & Riley)[a] | | Egg hatch | 11 Jun. |
| | *Koelreuteria paniculata* Laxmann | 1st bloom | 16 Jun. |
| | *Abelia* x *grandiflora* (André) Rehder | 1st bloom | 23 Jun. |
| | *Koelreuteria paniculata* Laxmann | 50% bloom | 24 Jun. |
| | *Koelreuteria paniculata* Laxmann | 95% bloom | 26 Jun. |
| **Obscure scale,** | | | |
| *Melanaspis obscura* (Comstock) | | Egg hatch | 06 Jul. |

aNot a common name approved by the Entomological Society of America.

Table 6. Phenological sequence of 10 insects and 25 plant events common to the present study and Herms (1990) study in Michigan.

| Kentucky sequence | | Michigan sequence | |
|---|---|---|---|
| Insects<br>Plants | Avg.<br>date | Insects<br>Plants | Avg.<br>date |
| *Acer saccharinum* L. (1st) | 18 Feb. | *Acer saccharinum* L. (1st) | 29 Mar. |
| *Cornus mas* L. (1st) | 21 Feb. | *Cornus mas* L. (1st) | 09 Apr. |
| *Forsythia* x *intermedia* Zabel (1st) | 12 Mar. | **Eastern tent caterpillar,** *Malacosoma americanum* (F.) | 09 Apr |
| **Eastern tent caterpillar,** *Malacosoma americanum* (F.) | 16 Mar. | *Forsythia* x *intermedia* Zabel (1st) | 16 Apr. |
| *Magnolia stellata* (Seibold & Zaccarini) (1st) | 19 Mar. | *Magnolia stellata* (Seibold & Zaccarini) (1st) | 18 Apr. |
| *Rhododrendron* 'PJM' (1st) | 22 Mar. | *Acer platanoides* L. (1st) | 23 Apr. |
| *Pyrus calleryana* Decaisne 'Bradford' (1st) | 23 Mar. | *Rhododrendron* 'PJM' (1st) | 27 Apr. |
| *Amelanchier arborea* (Michaux, F.) Fernald (1st) | 05 Apr. | *Pyrus calleryana* Decaisne 'Bradford' (1st) | 28 Apr. |
| *Acer platanoides* L. (1st) | 06 Apr. | *Amelanchier arborea* (Michaux, F.) Fernald (1st) | 30 Apr. |
| *Viburnum* x *juddii* Rehder (1st) | 10 Apr. | *Cercis canadensis* L. (1st) | 04 May |
| *Malus floribunda* Van Houtte (1st) | 11 Apr. | **Birch leafminer,** *Fenusa pusilla* (Lepeletier) | 05 May |
| *Cercis canadensis* L. (1st) | 14 Apr. | *Prunus serrulata* Lindley 'Kwansan' (1st) | 06 May |
| *Syringa vulgaris* L. (1st) | 15 Apr. | *Viburnum carlesi* (1st) | 06 May |
| *Malus sargentii* Rehder (1st) | 16 Apr. | *Malus floribunda* Van Houtte (1st) | 07 May |
| *Prunus serrulata* Lindley 'Kwansan' (1st) | 19 Apr. | *Syringa vulgaris* L. (1st) | 09 May |
| **Birch leafminer** *Fenusa pusilla* | 21 Apr. | *Malus sargentii* Rehder (1st) | 10 May |
| **Oystershell scale,** *Lepidosaphes ulmi* (L.) | 23 Apr. | *Lonicera tatarica* L. (1st) | 12 May |
| *Viburnum plicata* var. *tomentosum* (Thunberg) (1st) | 24 Apr. | *Viburnum plicata* var. *tomentosum* (Thunberg) (1st) | 16 May |
| **Lilac/ash borer,** *Podosesia syringae* (Harris) (1st) | 24 Apr. | **Lilac/ash borer,** *Podosesia syringae* (Harris) (1st) | 17 May |
| *Lonicera tatarica* L. (1st) | 25 Apr. | **Oystershell scale,** *Lepidosaphes ulmi* (L.) | 20 May |
| *Crataegus viridis* L. 'Winter King' (1st) | 27 Apr. | *Crataegus viridis* L. 'Winter King' (1st) | 25 May |
| *Chionanthus virginicus* L. (1st) | 28 Apr. | *Chionanthus virginicus* L. (1st) | 28 May |
| **Juniper scale,** *Carulaspis juniperi* (Bouché) | 15 May | **Bronze birch borer,** *Agrilus anxius* Gory | 02 Jun. |

| | | | |
|---|---|---|---|
| **Bronze birch borer,** *Agrilus anxius* Gory | 22 May | *Crataegus phaenonpyrum* (L. f.) Medicus (1st) | 12 Jun. |
| *Crataegus phaenonpyrum* (L. f.) Medicus (1st) | 21 May | **Juniper scale,** *Carulaspis juniperi* (Bouché) | 12 Jun. |
| *Syringia reticulata* (Blume) (1st) | 23 May | *Syringia reticulata* (Blume) (1st) | 13 Jun. |
| *Tilia cordata* Miller (1st) | 23 May | *Catalpa speciosa* Warder (1st) | 15 Jun. |
| *Catalpa speciosa* Warder (1st) | 24 May | *Crataegus phaenonpyrum* (L. f.) Medicus (1st) | 18 Jun. |
| *Crataegus phaenonpyrum* (L. f.) Medicus (95%) | 28 May | *Tilia cordata* Miller (1st) | 22 Jun. |
| *Tilia cordata* Miller (95%) | 09 Jun. | **Cottony maple leaf scale**, *Pulvinaria acericola* (Walsh & Riley) | 25 Jun. |
| **Cottony maple leaf scale**, *Pulvinaria acericola* (Walsh & Riley) | 11 Jun. | *Tilia cordata* Miller (95%) | 27 Jun. |
| *Koelreuteria paniculata* Laxmann (1st) | 26 Jun. | *Koelreuteria paniculata* Laxmann (1st) | 05 Jul. |

Designation in parentheses after plant names refers to 1st or 95% bloom.
[a]Not a common name approved by the Entomological Society of America.

**Tables 4 and 6 modified and reproduced with permission from the Journal of Economic Entomology, granted April 2, 2009.**

# PIERCING AND SUCKING INSECTS AND MITES

# Spruce Spider Mite

## *Oligonychus ununguis* (Jacobi)

### Acari: Tetranychidae

Richmond, D. S.; Shetlar, D. J. 1996. Eclosion time and spatial distribution of overwintering spruce spider mite (Acari: Tetranychidae) eggs on Colorado spruce. Journal of Economic Entomology 89: 447-452.

**Objectives**

To develop a degree-day model for the ecolosion of diapausing *O. ununguis* eggs; to determine the spatial distribution of eggs on Colorado spruce, *Picea pungens*.

**Abstract**

The spruce spider mite, *Oligonychus ununguis* (Jacobi), can be a significant pest of field, nursery, and greenhouse-grown plants. Coniferous hosts include Fraser fir [*Abies fraseri* (Pursh)], pines (*Pinus* spp.), junipers (*Juniperus* spp.), and several spruces (*Picea* spp.). Risk of mite damage is especially high during periods of drought and high temperatures. Under these conditions, mite populations build quickly and can cause serious damage. Infested needles are stippled and covered with webbing; eventually they turn brown and fall prematurely from infested trees. Growth loss and mortality may follow. Ornamental nursery crops are particularly susceptible to aesthetic damage by *O. ununguis* and even low mite densities can result in economic loss. Pest managers would benefit from being able to time chemical applications for *O. ununguis* with the eclosion of winter-diapausing eggs, or direct applications to areas where eggs are laid rather than treating the entire plant.

Research conducted on Colorado spruce, *Picea pungens* Engelmann, in Ohio indicated that 50% of overwintering eggs of *O. ununguis* hatched at approximately 170 degree-days (DD) measured using a base temperature of 5.6ºC beginning March 1, and growers should treat the first generation around 258DD when eclosion reaches 100%. A study of the spatial distribution of overwintering eggs showed that numerically greater numbers of *O. ununguis* eggs were found in the mid-crown level but no eggs were found on the trunks.

On south- and east-facing sides of Colorado spruce, significantly greater numbers of eggs were found on branch axes away from the trunk. On branches on the north- and west-facing sides, eggs were located closer to the trunk along branch axes. Mean egg location along branch axis also varied with crown level. Eggs were located farther away from the trunk on branches in the lower third of the crown as compared to branches in the middle and upper thirds. The spatial distribution of *O. ununguis* eggs likely reflects desiccation by prevailing winter winds.

**Sampling Procedure**

Monitor degree-day accumulation from March 1 using the base temperature of 5.6˚C. Predict the percentage of eclosion by overwintering eggs using the formula:

$$\text{probit } Y = -28.64 + 6.59 \ln X$$

where X = the natural log of accumulated degree-days from base 5.6˚C and Y = cumulative % eclosion in probits. Consider treating trees for first generation *O. ununguis* around 258DD from March 1. Make certain that sprays penetrate the foliage on the lower third of Colorado spruce, where eggs are laid on limbs close to the trunk on the east- and south-facing sides. Trunks do not require treatment.

**Notes**

These recommendations are derived from research conducted on Colorado spruce in Ohio and may not be applicable to other conifers or in other regions. Use these recommendations with caution until validated for other hosts and in other regions

# Spruce Spider Mite

## *Oligonychus ununguis* (Jacobi)

### Acari: Tetranychidae

Shrewsbury, P. M.; Hardin, M. R. 2004. Beat sampling accuracy in estimating spruce spider mite (Acari: Tetranychidae) populations and injury on juniper. Journal of Economic Entomology 97: 1444-1449.

**Objectives**

To relate a method of subsampling *O. ununguis* to its absolute population density; to relate *O. ununguis* feeding injury to estimated population density.

**Abstract**

The spruce spider mite, *Oligonychus ununguis* (Jacobi), can be a significant pest of field, nursery, and greenhouse-grown plants. Coniferous hosts include Fraser fir [*Abies fraseri* (Pursh)], several spruces (*Picea* spp.), and in the case of the current study, juniper (*Juniperus chinensis* A. Henry). In the field, risk of mite damage is especially high during periods of drought and high temperatures. Under these conditions, mite populations build quickly and can cause serious damage. Infested needles are stippled and covered with webbing; eventually they turn brown and fall prematurely from infested trees.

A beat sampling method for estimating *O. ununguis* populations on Juniperus chinensis was related to an absolute population measure as well as feeding injury on its host. The log of spruce spider mite density estimated from the beat sample was related positively to the log of total *O. ununguis* density ($r^2 = 0.80$) and to plant injury level ($r^2 = 0.43$). These findings may allow managers to predict total mite density and feeding injury on infested trees using simple beat counts. These findings may apply to *O. ununguis* populations on other plants with growth patterns similar to juniper. Moreover, knowledge of total mite density from a subsample may facilitate evaluation of biological control success and allow managers to better adjust predator release rates according to mite population density.

**Sampling Procedure**

Randomly select an appropriate number of trees to sample in the area of concern. Use a 0.5 m (1.6 ft.) wooden dowel to beat a 3,540 $cm^3$ (0.13 $ft.^3$) area of foliage in the lower, outer crown of each juniper sampled. Always select the sample area at the same location of each tree sampled. Place a 10 x 14 cm (4 x 5.5 in.) sheet of graph paper on a clipboard beneath the foliage. Rap the foliage sample unit with the dowel 10 times to dislodge mites onto the paper. Count all mites present on the paper.

To estimate total mite density, enter the total number of mites sampled using the beat method into the equation:

$$X = (\text{Log}_{10} \text{ sum of mites} + 0.12)/0.798$$

then calculate the antilog of X to obtain the estimated total number of mites as the authors calculated the regression equation using log10 transformed data.

To estimate percent plant injury, enter counts obtained from the beat method into the equation:

$$\text{Percent plant injury} = 5.37 + 0.0007X$$

where X = sum of mites in beat sample.

**Notes**

The standard error of each regression, which was not presented, would give a range of total density and percent plant injury to expect for a given mite count obtained through beat sampling. This estimate of standard error would allow users to determine if the range of total mite density and/or percent plant injury level included their specific damage or action threshold for *O. ununguis*. The authors cautioned that beat sampling underestimates the density of mites, which must be considered when considering the release of predatory mites for control of *O. ununguis*

# Spruce Spider Mite

## *Oligonychus ununguis* (Jacobi)

### Acari: Tetranychidae

Webster, R. 1993. Sample collection method and sequential sampling plan for mites (*Oligonychus ununquis*) and aphids (*Cinaria laricifex*) on tamarack. Tech. Note No. 278. Forestry Canada, Maritimes Forest Research Center; 5 p.

**Objective**

To propose a fixed precision sequential sampling plan to determine the optimal number of samples needed to monitor populations of *O.ununquis* on larch.

**Abstract**

Spruce spider mite, *Oligonychus ununquis* (Jacobi), is a common pest of spruce, *Picea* spp., and other conifers. Infested needles are covered with webbing, turn yellow, and drop prematurely. High population densities may cause a loss of tree vigor. Infestations are a recurrent problem in seed orchards in New Brunswick.

A sequential sampling plan with fixed precision was developed for *O. ununquis* on larch, Larix spp. Depending on the desired level of precision, 4 to 50 trees need to be sampled using this plan. Known threshold levels can be applied to this sampling plan to determine how many branch samples are necessary to determine if control treatments are warranted. Counting up to 1,000 mites requires 10¬–15 minutes.

**Sampling Procedure**

Randomly select at least 25 larch trees in each stand being surveyed. Sample one branch per tree, beating each branch with a 60-cm long padded stick ten times in rapid succession to dislodge any *O. ununquis* present into a 30 x 20 x 8 cm container held under the branch. Wash the mites out of the collection container with 35–40 ml of Oudeman's solution (8.7 L of 70% alcohol, 0.5 L glycerine, 0.8 L glacial acetic acid to make 10 L of solution) and into a 50-ml screw cap vial. Oudeman's solution kills and preserves all mites in the sample with their appendages extended, allowing for identification at a later date.

Remove needles, large pieces of debris, and excess Oudeman's solution from the sample. Pour the remainder into a petri dish set on a 1 cm grid to facilitate counting. It takes about 2–4 minutes to prepare each sample for counting.

Referencing Fig. B, count the cumulative number of *O. ununquis* in each sample until the

stop line is crossed for the desired level of sampling precision. A precision level of 0.25 is generally sufficient for most purposes. For higher levels of precision, more samples should be taken from >25 trees, especially if *O. ununquis* is present at low densities.

**Note**

This is a proposed sampling plan that still requires validation. Use with caution.

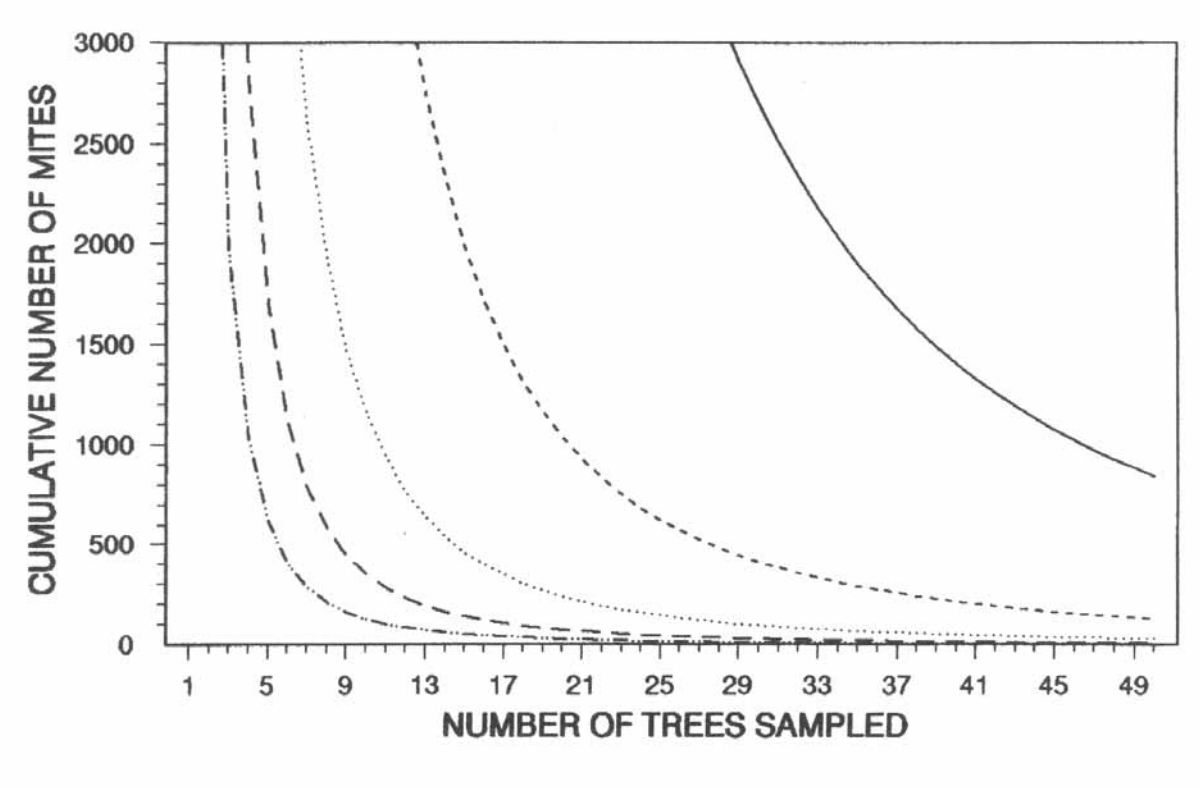


Figure A. Sequential sampling plan for *O. ununquis* on larch based on Taylor's power law. The sequential sample stop lines were calculated from the formula of Green (1970) based on the regression from Taylor's (1961) power law. Sequential sample stop lines are given for precision levels of $D_1 = 0.15$, $D_2 = 0.20$, $D_3 = 0.25$, $D_4 = 0.30$, and $D_5 = 0.35$.

# Balsam Woolly Adelgid

## *Adelges piceae* (Ratzeburg)

### Hemiptera: Adelgidae

Bryant, D. G. 1976a. Sampling populations of (Homoptera: Phylloxeridae) on balsam fir, *Abies balsamea*. Canadian Entomologist 108: 1113-1124.

**Objective**

To describe methods of detecting, monitoring, and estimating populations of *A. piceae*.

**Abstract**

The balsam woolly adelgid, *Adelges piceae* (Ratzeburg), is an introduced species first recorded in North America in Maine in 1908. It has spread throughout the native range of balsam fir, *Abies balsamea* (L.) Mill., and Fraser fir, *A. fraseri* (Pursh) Poir., and is also found in the Pacific Northwest. Trees suffering from extensive stem attacks have characteristic white woolly masses on the stem and die quickly. Methods of detecting, monitoring and measuring population levels of *A. piceae* were developed on balsam fir sampled in Newfoundland, Canada.

The recommended sampling unit used to measure populations of sessile *A. piceae* is a second position node from a secondary branch axis, such as nodes 8, 12, 17, or 30 (Bryant 1972, 1976b). Sampling should be done at these positions on non-flowered, 3-yr-old branch tips of balsam fir. In addition, the author provides a thorough description of the morphology of the stem and crown of balsam fir, including surface features of the bark.

**Sampling Procedure**

Detection survey: Reference Table IV to determine the number of locations in a stand of balsam fir and number of nodes to sample at each location. Randomly select branches throughout the canopy of balsam fir. Use a 6 to 10X hand lens to examine underneath the bud scales of nodes 8, 12, 17, or 30 for the presence of sessile *A. piceae*. Refer to Fig. 2 for a diagram illustrating the node positions (Bryant 1976b). If no adelgids are present on any nodes in the sample, it is safe to classify the location as uninfested with 95% confidence. In Newfoundland, usually one location is sampled for every 10 ha of forest. This sampling intensity has not been verified statistically and would depend heavily on the distribution of *A. piceae* at the stand and forest level, which is not known.

Monitoring Populations: This method is used once an infestation is detected. Use a 6 to

10X hand lens to examine underneath the bud scales of nodes 8, 12, 17, or 30 for the presence of sessile *A. piceae*. Refer to Fig. 2 for a diagram illustrating the node positions (Bryant 1976b). Generally, if <33% of the examined nodes are infested, then *A. piceae* populations do not warrant control measures. However, if >33% of the nodes are infested then more detailed sampling is required to determine if control measures are needed. Refer to Table IV to determine the appropriate sampling intensity.

Measuring Population Levels: Precise sampling methods are often needed to estimate *A. piceae* population levels annually, study its population dynamics, or to evaluate the success of treatments. The required number of sample units was estimated for low (Table V) and high (Table VI) populations at selected levels of precision, a range of allowable error, and a range of levels of assurance. Sample trees as described above, except examine nodes for *A. piceae* at 12 to 20X using a stereomicroscope.

**Note**

The sampling methods described here are only applicable to sessile adelgids and not eggs and crawlers. Evaluation of appropriate nodes might be difficult under certain circumstances. Interested users should refer to Bryant (1972, 1976b) for further details regarding the sample unit. Tables V and VI were developed from populations of *A. picea* on grand fir, *Abies grandis* (Dougl. ex D. Don) Lindl., in British Columbia. They should be used with caution for *A. picea* populations on different hosts in eastern North America. The author does not clarify the distinction between levels of confidence and levels of assurance; this might be clarified by consulting Steel and Torrie (1960).

**References**

Bryant, D. G. 1972. The measurement of population density of the balsam woolly adelgid, *Adelges piceae* (Ratz.) (Homoptera: Phylloxeridae) a highly aggregate species. PhD dissertation, Yale University. 169 p.

Bryant, D. G. 1976b. Distribution, abundance, and survival of the balsam woolly aphid, *Adelges piceae* (Homoptera: Phylloxeridae), on branches of balsam fir, *Abies balsamea*. Canadian Entomologist 108: 1097-1111.

Steel, R. G. D.; Torrie, J. H. 1960. Principles and procedures of statistics. McGraw-Hill, New York. 481 p.

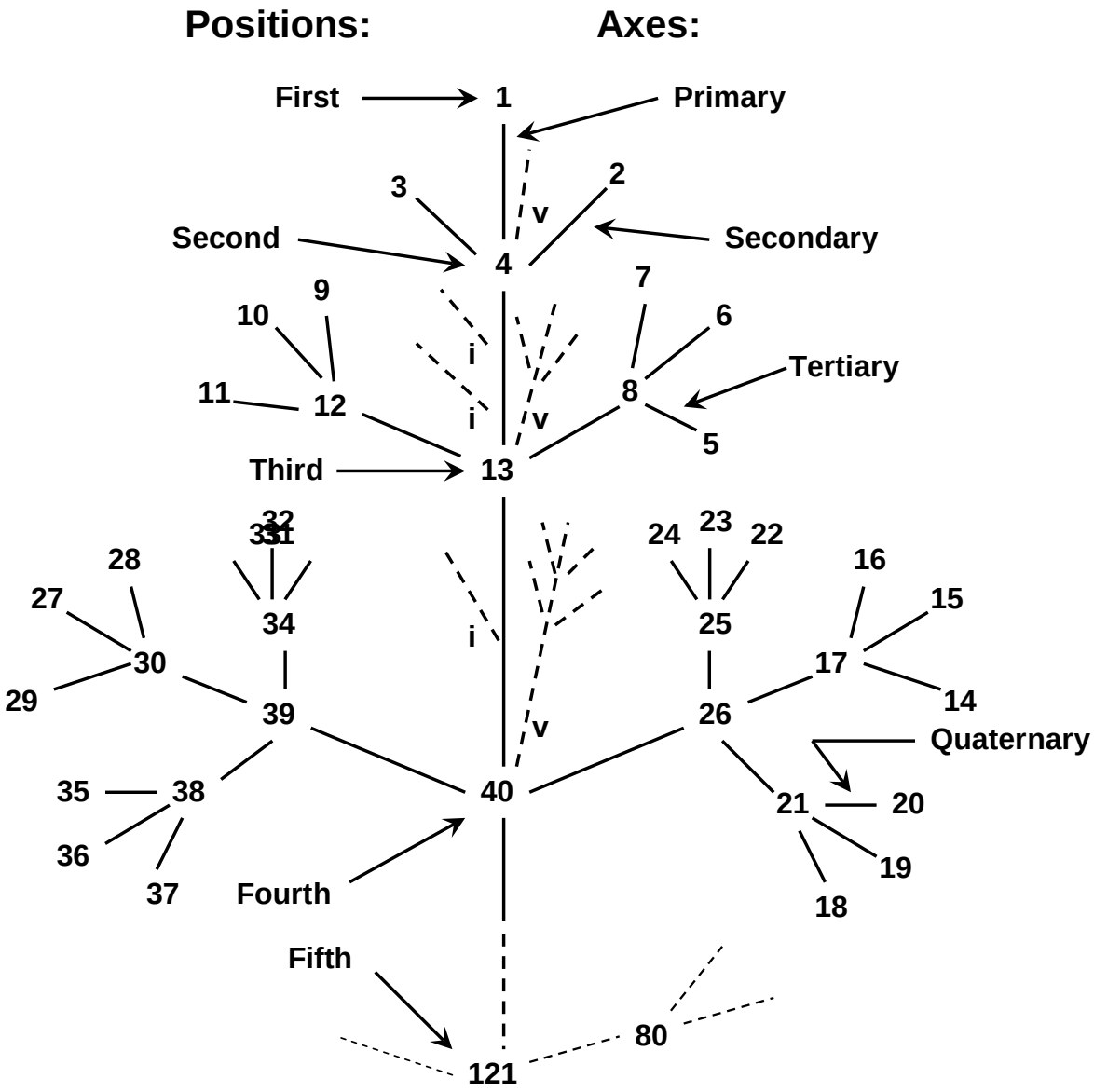


Fig. 2. Illustration of a 5-year-old branch showing four branching axes, five node positions, numbered nodes on the main branchings, and the ventral (v) and internodal (i) twigs.

Table IV. The number (n) of node 8 (or 12, 17, or 30) samples required per sample location (m) to state with over 95% confidence (α) that a balsam fir stand is uninfested by A. piceae where $\alpha = (1-q^n)^m$ and q = 0.53, probability of zero counts in an aphid population (Bryant 1972).

| No. of sample locations in the stand | No. of nodes (one per tree) per location |
|---|---|
| 1 | 5 |
| 2 | 6 |
| 3–5 | 7 |
| 6–10 | 8 |
| 11–16 | 9 |

Table V. Number of sample units (node 8 or its homologue 12, 17 or 30) required in a low population level of aphids to estimate each mean ($[\sum \log (X_i +1)]N^{-1}$) with a confidence of 90 or 95% at an allowable error of 10 to 33% of the mean with an assurance of 0.75, 0.90, or 0.95. $s^2 = 0.042904$ at d.f. = 48.

| Allowable error | Estimate one mean | | | Compare two means | | | Estimate one mean | | | Compare two means | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Level of assurance | | | | | | Level of assurance | | | | | |
| | .75 | .90 | .95 | .75 | .90 | .95 | .75 | .90 | .95 | .75 | .90 | .95 |
| | 90% confidence | | | | | | 95% confidence | | | | | |
| .03 | 166 | 187 | 199 | 313 | 378 | 410 | 228 | 265 | 283 | 457 | 500 | 546 |
| .05 | 59 | 74 | 84 | 117 | 136 | 152 | 92 | 105 | 112 | 170 | 191 | 201 |
| .07 | 31 | 38 | 41 | 60 | 71 | 86 | 44 | 54 | 57 | 72 | 84 | 113 |
| .10 | 18 | 22 | 24 | 31 | 38 | 41 | 24 | 29 | 31 | 44 | 53 | 57 |

[a] Nominally 10%, 15%, 25%, and 33% of the mean.

Table V. Number of sample units (node 8 or its homologue 12, 17 or 30) required in a low population level of aphids to estimate each mean ([ ∑ log (Xi +1)]N-1) with a confidence of 90 or 95% at an allowable error of 10 to 33% of the mean with an assurance of 0.75, 0.90, or 0.95. s2 = 0.042904 at d.f. = 48.

| Allowable error | Estimate one mean | | | Compare two means | | | Estimate one mean | | | Compare two means | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Level of assurance | | | | | | Level of assurance | | | | | |
| | .75 | .90 | .95 | .75 | .90 | .95 | .75 | .90 | .95 | .75 | .90 | .95 |
| | 90% confidence | | | | | | 95% confidence | | | | | |
| .08 | 138 | 163 | 177 | 271 | 302 | 332 | 192 | 222 | 244 | 375 | 428 | 466 |
| .11 | 79 | 94 | 102 | 148 | 172 | 184 | 109 | 119 | 131 | 199 | 237 | 258 |
| .20 | 26 | 33 | 36 | 46 | 35 | 59 | 38 | 41 | 44 | 64 | 82 | 93 |
| .26 | 18 | 20 | 21 | 32 | 37 | 39 | 23 | 29 | 32 | 39 | 47 | 52 |

[a] Nominally 10%, 15%, 25%, and 33% of the mean.

**Figure 2 and Tables IV, V, and VI are reprinted as fair use under 17 USC § 107.**

# Hemlock Woolly Adelgid

## *Adelges tsugae* Annand

### Hemiptera: Adelgidae

Costa, S.; Onken, B. 2006. Standardizing sampling for detection and monitoring of hemlock woolly adelgid in eastern hemlock forests. FHTET-2006-16. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team; 11 p.

**Objective**

To develop an efficient, standardized sampling method for determining the infestation level of *A. tsugae* within a stand (not at the individual tree level) by determining the percentage of infested trees.

**Abstract**

Hemlock woolly adelgid, *Adelges tsugae* (Annand), is a severe pest of eastern hemlock [*Tsuga canadensis* (L.) Carr.] and Carolina hemlock (*Tsuga caroliniana* Engelm.) on the east coast of the USA and Canada. Infestation by *A. tsugae* results in reduced production of new foliage, premature needle drop, branch dieback, thinning of the crown, and a general decline resulting in the death of the tree. Two parthenogenetic generations of *A. tsugae*, the sistentes and progredientes, occur each year. Eggs of both generations hatch into a mobile crawler stage that settles at the base of a needle to feed and mature. Sistentes are found on hemlock from mid-summer into spring. Progredientes occur for a brief period during late spring and early summer, giving rise to the next generation of sistentes that aestivates over the summer months and resumes feeding in the fall. Infestations may spread quickly, and *A. tsugae* is expected to spread throughout the range of eastern and Carolina hemlock.

Cutoff thresholds to stop sampling (i.e., stop thresholds) were developed for binomial sampling of adelgids based on the optimum sample sizes needed to reach a precision level of 0.25. This allows the detection of *A. tsugae* with 75% reliability in hemlock stands where less than 2% of the trees are infested (Table 1). The precision level for this plan is consistent for stands with at least 14% of the trees infested with adelgids. Lower infestation levels require more trees to be sampled with little additional information gained in return. No more than 100 trees need be sampled using this plan, and substantially fewer trees need be sampled if the infestation level is high within the stand.

**Sampling Procedure**

Roughly divide the stand into 4 blocks large enough to avoid overlap (ideally 1.6 hect-

ares each). Select trees that have branches within an arm's reach of the ground and avoid branches lacking needles. Arbitrarily select a tree as the initial sampling point in the center of the first block. Examine the underside of the terminal meter of one branch for evidence of ovisacs. Infestation is judged on the presence or absence of ovisacs and there is no need to count the number of ovisacs observed. If adelgids are present, mark the datasheet with a 1 to indicate the presence of adelgids. Consult the sampling datasheet for a list of semi-random cardinal directions and take 25 paces (2 strides per pace) in the designated direction to the next sampling point. Select the nearest suitable tree at the sampling point and examine it. If adelgids are found on the second tree, mark the datasheet with a 2. Re-enter the last tally number with 1 if no adelgids are found on the second tree. The datasheet uses a cumulative tally of all infested trees. Continue sampling until reaching the appropriate stop level or 25 trees have been sampled in that block.

If no adelgids are detected on the first tree, search another branch on the opposite side of the tree in the same manner. If no adelgids are detected on the second branch, mark the datasheet with a 0. Continue to the next tree using the semi-random cardinal directions on the datasheet as described above. If *A. tsugae* is not found on the first 8 trees, continue sampling trees until *A. tsugae* is found or 100 trees have been sampled. After *A. tsugae* is found, but the tally count is less than the stop threshold, continue sampling trees and adding new blocks as needed after each set of 25 trees. Stop sampling if 1) the tally count is below the stop threshold after sampling 100 trees or 2) the tally count is greater than the stop threshold.

Calculate the level of stand infestation as:

Percent infested trees = (number of infested trees) / (number of trees examined) X 100

**Notes**

The directions for determining stand infestation level are more appropriate for large stands of 4 ha or more, but they can be used for smaller stands with a smaller hemlock component. Stands do not need be divided into precise blocks and the semi-random cardinal directions listed on the datasheet do not have to be followed precisely. Small or narrow stands, or stands with few hemlocks, can be sampled in any pattern that provides a random, thorough sample.

There is no discrimination between dead or living *A. tsugae* when classifying a tree as infested using this plan. Dead *A. tsugae* indicates that the tree was previously infested and the infestation will likely persist in the area. Trees should be sampled when the ovisacs can be observed easily, from late October into mid-July.

Table 1. Maximum number of trees that must be examined to detect an infested tree by minimum detection threshold (minimum percent of infested trees) and reliability level (probability of finding a single infested tree). The shaded area encompasses the recommended 100-tree sample.

| Minimum % Infested Trees in Stand | Reliability Level (%) | | | |
|---|---|---|---|---|
| | 50 | 75 | 95 | 99 |
| 0.5 | 138 | 277 | 598 | 919 |
| 1 | 69 | 138 | 298 | 458 |
| 2 | 34 | 69 | 148 | 228 |
| 3 | 23 | 46 | 98 | 151 |
| 5 | 14 | 27 | 58 | 90 |
| 10 | 7 | 13 | 28 | 44 |
| 20 | 3 | 6 | 13 | 21 |

# Hemlock Woolly Adelgid Sampling Datasheet

Date: Location: Sampler: Comments on reverse side

| Path Direction | Tree | Sum HWA Trees | STOP≥ Threshold | Direction | Tree | Sum HWA Trees | STOP≥ Threshold | Direction | Tree | Sum HWA Trees | STOP≥ Threshold |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Block 1** | 1 | | n/a | SW | 35 | | 11 | N | 69 | | 13 |
| NE | 2 | | n/a | W | 36 | | 11 | N | 70 | | 13 |
| SE | 3 | | n/a | SW | 37 | | 11 | E | 71 | | 13 |
| N | 4 | | n/a | NW | 38 | | 11 | SE | 72 | | 13 |
| NW | 5 | | n/a | NW | 39 | | 11 | NE | 73 | | 13 |
| SW | 6 | | n/a | NE | 40 | | 11 | SE | 74 | | 13 |
| S | 7 | | n/a | N | 41 | | 12 | SW | 75 | | 13 |
| S | 8 | | 8 | SW | 42 | | 12 | **Block 4** | 76 | | 13 |
| SE | 9 | | 8 | W | 43 | | 12 | N | 77 | | 13 |
| SW | 10 | | 8 | NW | 44 | | 12 | E | 78 | | 13 |
| W | 11 | | 8 | SW | 45 | | 12 | N | 79 | | 13 |
| S | 12 | | 8 | W | 46 | | 12 | SE | 80 | | 13 |
| E | 13 | | 8 | SE | 47 | | 12 | SW | 81 | | 13 |
| E | 14 | | 8 | S | 48 | | 12 | S | 82 | | 13 |
| NE | 15 | | 8 | E | 49 | | 12 | SW | 83 | | 13 |
| SE | 16 | | 8 | S | 50 | | 12 | S | 84 | | 13 |
| NE | 17 | | 8 | **Block 3** | 51 | | 12 | W | 85 | | 13 |
| E | 18 | | 8 | NE | 52 | | 12 | N | 86 | | 13 |
| N | 19 | | 9 | E | 53 | | 12 | W | 87 | | 13 |
| NW | 20 | | 9 | S | 54 | | 12 | W | 88 | | 13 |
| N | 21 | | 9 | SE | 55 | | 12 | NE | 89 | | 13 |
| W | 22 | | 9 | SE | 56 | | 12 | N | 90 | | 13 |
| S | 23 | | 9 | S | 57 | | 13 | N | 91 | | 14 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| W | 24 | 10 | | W | 58 | 13 | | NW | 92 | 14 |
| W | 25 | 10 | | NW | 59 | 13 | | N | 93 | 14 |
| **Block 2** | 26 | 10 | | S | 60 | 13 | | SE | 94 | 14 |
| E | 27 | 10 | | NW | 61 | 13 | | NE | 95 | 14 |
| SE | 28 | 10 | | NE | 62 | 13 | | N | 96 | 14 |
| NE | 29 | 10 | | W | 63 | 13 | | E | 97 | 14 |
| SE | 30 | 10 | | NW | 64 | 13 | | SE | 98 | 14 |
| NE | 31 | 11 | | N | 65 | 13 | | E | 99 | 14 |
| E | 32 | 11 | | NE | 66 | 13 | | NE | 100 | 14 |
| N | 33 | 11 | | NE | 67 | 13 | | | STOP | |
| N | 34 | 11 | | W | 68 | 13 | | | | |

# Hemlock Woolly Adelgid

## *Adelges tsugae* Annand

### Hemiptera: Adelgidae

Fidgen, J. G.; Legg, D. E.; Salom, S. M. 2006. Binomial sequential sampling plan for hemlock woolly adelgid (Hemiptera: Adelgidae) sistens infesting individual eastern hemlock trees. Journal of Economic Entomology 99: 1500-1508.

**Objective**

To develop an efficient, cost-effective sampling method for determining the infestation level of *A. tsugae* on individual, high-value eastern hemlock trees.

**Abstract**

Hemlock woolly adelgid, *Adelges tsugae* (Annand), is a severe pest of eastern hemlock [*Tsuga canadensis* (L.) Carr.] and Carolina hemlock (*Tsuga caroliniana* Engelm.) on the east coast of the U.S. and Canada. Infestation by *A. tsugae* results in reduced production of new foliage, premature needle drop, branch dieback, thinning of the crown, and a general decline resulting in the death of the tree. Two parthenogenetic generations of *A. tsugae*, the sistentes and progredientes, occur each year. Eggs of both generations hatch into a mobile crawler stage that settles at the base of a needle to feed and mature. Sistentes are found on hemlock from mid-summer into spring. Progredientes occur for a brief period during late spring and early summer, giving rise to the next generation of sistentes that aestivates over the summer months and resumes feeding in the fall. Infestations may spread quickly, and *A. tsugae* is expected to spread throughout the range of eastern and Carolina hemlock.

A binomial sequential sampling plan was developed that samples the presence of sistentes on new shoots in a non-destructive manner. Sistentes are present on the tree for a longer period of time and are more easily observable than the progredientes. The plan requires examination of 20 to 80 new shoots on each tree to classify the tree as having a low, high, or indeterminate infestation level. Sampling took <2 min for each tree.

**Sampling Procedure**

Select eastern hemlocks that are in good health and exhibiting few symptoms of decline. Sample sistentes between October and May. Choose a threshold level appropriate for the objective: a 10% level is appropriate for maintaining aesthetics while a 30% level is appropriate if the goal is to maintain tree health.

Randomly select four branches in the lower crown of the tree. Branches do not need to be cut from the tree, but use pole pruners to reach the lower third of the crown if no live branches are available in the lower crown. There should be at least 20 new shoots on each branch sampled. Tally the number of the first five shoots on each branch that have at least one adelgid. Sum the number of infested shoots across all four branches (number of infested shoots out of 80 shoots sampled).

Check Table 1 for the upper and lower stop values associated with the threshold level chosen for your objective. Classify the tree as a low infestation if the tally of infested shoots is less than the lower stop value. Classify the tree as a high infestation if the tally of infested shoots is greater than the upper stop value.

If the tally falls between the lower and upper stop values, continue sampling the tree. Examine the next set of five shoots on each branch and tally the number of shoots with at least one adelgid on them. Add this cumulative tally to the first tally and refer to Table 1 again. If the cumulative tally for 40 samples is less than the lower stop value, classify the tree as a low infestation. If the cumulative tally for 40 samples is greater than the upper stop value, classify the tree as a high infestation. If the tally falls between the lower and upper stop values listed for 40 samples, count the number of infested shoots within the third set of five shoots on each branch. Continue in this manner until the tree is classified as either a low or high infestation or a total of 80 shoot samples have been examined. If the tree cannot be classified as a low or high infestation after examining a total of 80 shoot samples, then classify the tree as intermediate. Trees classified as low or intermediate using this plan may not require a pest management action.

**Notes**

Densities of *A. tsugae* on new shoots did not differ between the lower crown and the middle crown of infested trees in this study. This sampling plan is appropriate for building populations of *A. tsugae* but before infested trees are in decline. Sampling trees already in decline or sampling the progredientes stage has not been validated statistically and will likely produce inconsistent results.

Table 1. Stop boundaries for binomial sequential sampling of A. tsugae infesting eastern hemlock at the 10 and 30% of new shoots infested with at least one sistens thresholds

| Threshold (%) | Sample no. | Stop boundaries | | |
|---|---|---|---|---|
| | | Lower stop value | | Upper stop value |
| 10 | 20 | Low infestation | Continue sampling | High infestation |
| | 40 | | | |
| | 60 | | | |
| | 80 | | | |
| 30 | 20 | | | |
| | 40 | | | |
| | 60 | | | |
| | 80 | | | |

**Table 1 reproduced with permission from the Journal of Economic Entomology, granted April 2, 2009.**

# Black Larch Aphid

## *Cinaria laricifex* (Fitch)

### Hemiptera: Aphididae

Webster, R. 1993. Sample collection method and sequential sampling plan for mites (*Oligonychus ununquis*) and aphids (*Cinaria laricifex*) on tamarack. Tech. Note No. 278. Forestry Canada, Maritimes Forest Research Center; 5 p.

**Objective**

To propose a fixed precision sequential sampling plan to determine the optimal number of samples needed to monitor populations of *C. laricifex*.

**Abstract**

Black larch aphid, *Cinaria laricifex* (Fitch), is a common pest of new foliage on larch, *Larix* spp. Infested needles turn yellow and drop prematurely. High population densities may cause a loss of tree vigor. Infestations are a recurrent problem in seed orchards in New Brunswick.

A sequential sampling plan with fixed precision was developed for *C. laricifex* on larch. Depending on the desired level of precision, 12 to 50 trees need to be sampled using this plan. Known threshold levels can be applied to this sampling plan to determine how many branch samples are necessary to determine if control treatments are warranted.

**Sampling Procedure**

Randomly select at least 25 larch trees in each stand being surveyed. Sample one branch per tree, beating each branch with a 60-cm long padded stick ten times in rapid succession to dislodge any aphids present into a 30 x 20 x 8 cm container held under the branch. Wash the aphids out of the collection container with 35–40 ml of Oudeman's solution (8.7 L of 70% alcohol, 0.5 L glycerine, 0.8 L glacial acetic acid to make 10 L of solution) and into a 50-ml screw cap vial. Oudeman's solution kills and preserves all aphids in the sample, allowing for identification at a later date.

Remove needles, large pieces of debris, and excess Oudeman's solution from the sample. Pour the remainder into a petri dish set on a 1 cm grid to facilitate counting. It takes about 2–4 minutes to prepare each sample for counting.

Referencing Fig. B, count the cumulative number of aphids in each sample until the stop line is crossed for the desired level of sampling precision. A precision level of 0.25 is generally

sufficient for most purposes. For higher levels of precision, more samples should be taken from >25 trees, especially if aphids are present at low densities.

**Note**

This is a proposed sampling plan that still requires validation. Use with caution

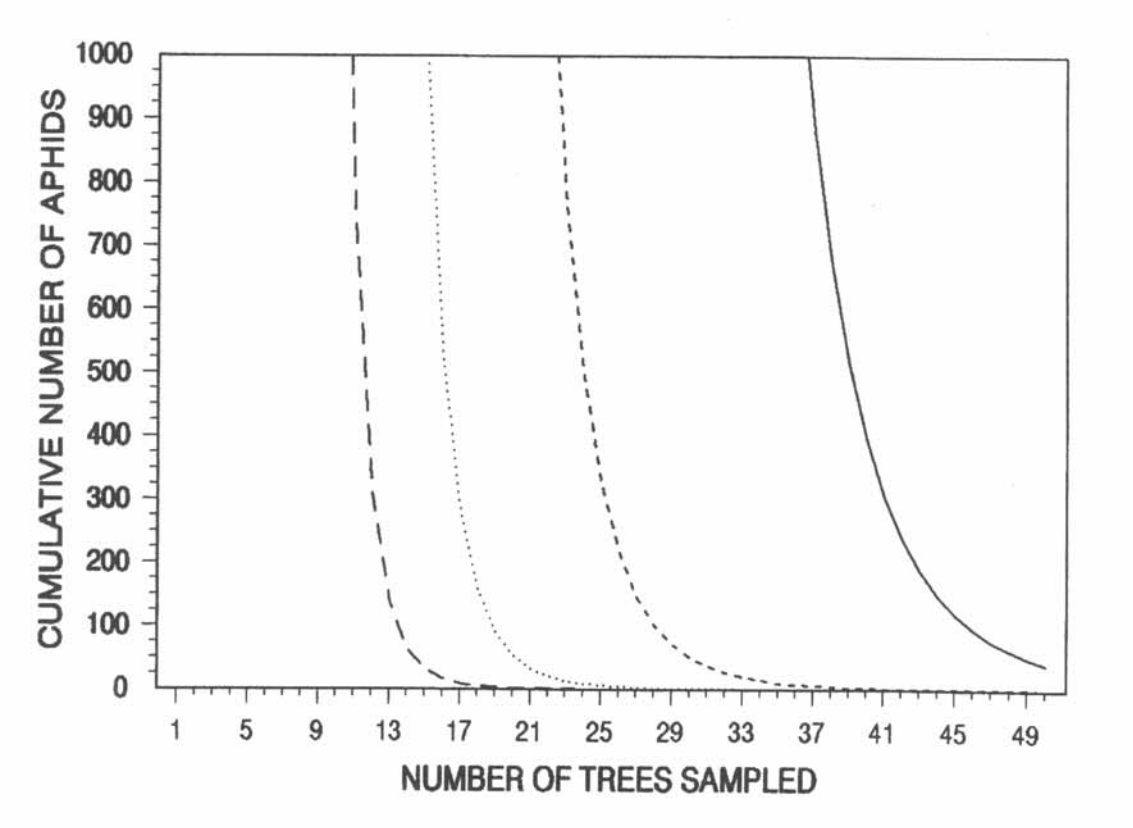


Figure B. Sequential sampling plan for aphids (*Cinaria* sp.) on larch based on Taylor's power law. The sequential sample stop lines were calculated from the formula of Green (1970) based on the regression from Taylor's (1961) power law. Sequential sample stop lines are given for precision levels of D = 0.20, 0.25, 0.30, and 0.35.

# Balsam Twig Aphid

## *Mindarus abietinus* Koch

### Hemiptera: Aphididae

Fondren, K. M.; McCullough, D. G. 2003. Phenology and density of balsam twig aphid, *Mindarus abietinus* Koch (Homoptera: Aphididae) in relation to bud break, shoot damage, and value of fir Christmas trees. Journal of Economic Entomology 96: 1760-1769.

**Objective**

To determine an appropriate spray period for *M. abietinus* based on pest phenology.

**Abstract**

Balsam twig aphid, *Mindarus abietinus* Koch, causes distortion, needle loss, and reduced growth on balsam fir, *Abies balsamea* (L.) Mill., and Fraser fir, *Abies fraseri* (Pursh) Poir. Both tree hosts are grown as Christmas trees with high economic value. The aesthetic or economic damage produced by *M. abietinus* has not been studied and the true impact of this pest may be over-estimated, leading to the unnecessary applications of insecticides for control.

The authors investigated the phenology of *M. abietinus* and resulting plant injury on balsam fir grown in commercial Christmas tree fields. Development of fundatrices and sexuparae was correlated with accumulated degree-days (DD) above a base temperature of 10˚C. Fundatrices began reproducing by ≈83DD and sexuparae appeared ≈83-111DD, suggesting that chemical controls should be applied for *M. abietinus* between 56-83DD. Fundatrice density was not a good predictor of sexuparae density or subsequent shoot damage. In addition, the authors attempted to establish an aesthetic injury level for *M. abietinus* on balsam fir grown as Christmas trees, but most polled consumers appeared to accept light to moderate injury on the trees. In such cases, slight economic loss may not warrant the cost of chemical control for *M. abietinus*. This differs from the results of Kleintjes et al. (1999), who reported that chemical control was warranted on trees with densities of two or more *M. abietinus* fundatrices.

**Sampling Procedure**

Beginning in March, monitor degree-day accumulation above the base threshold of 10˚C. Consider spraying for *M. abietinus* between 56-83DD, when eggs have completed hatching but before fundatrices begin reproducing. Management decisions should take into consideration such factors as expected economic value of trees at harvest, expense of treatments, and consumer acceptance of damaged trees.

**Reference**

* Kleintjes, P. K.; Lemoine, E. E.; Schroeder, J.; Solensky, M. J. 1999. Comparison of methods for monitoring *Mindarus abietinus* (Homoptera: Aphididae) and their potential damage in Christmas tree plantations. Journal of Economic Entomology 92: 638-643.

# Woolly Pine Needle Aphid

## *Schizolachnus piniradiatae* (Davidson)

### Hemiptera: Aphididae

Kulman, H. M. 1967. Within-tree distribution and winter mortality of eggs of the woolly pine needle aphid, *Schizolachnus piniradiatae*. Annals of the Entomological Society of America 60: 384-387.

**Objective**

To develop a sampling method for overwintering *S. piniradiatae* eggs as a means of predicting subsequent infestation levels on individual trees.

**Abstract**

Woolly pine needle aphid, *Schizolachnus piniradiatae* (Davidson), occurs on numerous species of pine (Pinus spp.). It is widespread in Canada but has also become a pest in the USA. A study conducted on 5-year-old, plantation-grown red pines (*Pinus resinosa* Ait.) in West Virginia indicated that trees can be classified as moderately or severely infested by *S. piniradiatae* based on the percentage of needles bearing egg masses. The percentage of needles infested by *S. piniradiatae* described the infestation level more accurately than the number of eggs per needle. Severely infested red pines had at least twice the percentage of infested needles than moderately infested trees. No oviposition preference was observed for new, 1-yr., or 2-yr. needles. This sampling method may aid managers in making control decisions for *S. piniradiatae*.

**Sampling Procedure**

Select red pines separated by at least 15.24 m in mid-March, before egg hatch begins. From both the middle and lower crown, randomly select two branches on opposite sides of each tree (four branches per tree). Examine needles on the branches for *S. piniradiatae* egg masses. Classify individual trees as moderately or severely infested based on the percentage of needles bearing egg masses.

| Percentage of needles bearing eggs | Infestation level |
|---|---|
| 10.1–20% | moderate |
| >20% | severe |

**Note**

The described infestation levels and aphid distributions may differ among other pine species, trees of different age classes, or trees not grown in plantings. This method should be used with caution until validate for other pine hosts in other regions.

# Saratoga Spittlebug

## *Aphrophora saratogensis* (Fitch)

### Hemiptera: Cercopidae

Wilson, L. F. 1971. Risk-rating Saratoga spittlebug damage by abundance of alternate-host plants. Res. Note NC-10. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 4 p.

**Objective**

To describe a risk-rating system for *A. saratogensis* damage based on the abundance of alternate host plants.

**Abstract**

Saratoga spittlebug, *Aphrophora saratogensis* (Fitch), is a pest of red pine, *Pinus resinosa* Ait, in the Great Lakes region of North America, and occasionally of jack pine, *Pinus banksiana* Lamb., and Scots pine, *Pinus sylvestris* L.. Adult *A. saratogensis* feed on host pine shoots, favoring young trees under 5 m tall. Feeding injury results in dead branches, deformed trees, topkill, and mortality. Nymphs feed on alternate hosts near host pines, with sweet fern, *Comptonia peregrina* (L.), being the favored host plant (Table 1).

Potential damage by *A. saratogensis* on red pines can be predicted by the abundance of sweet fern and alternate host plants within the stand. Stands can be evaluated either before planting or after establishment. Young host trees are more susceptible to damage, and trees >3 m tall are considered resistant to damage by *A. saratogensis*. Protect stands rated as moderate or heavy in areas where *A. saratogensis* occurs by removing sweet fern and other alternate host plants.

**Sampling Procedure**

The risk-rating procedure assumes that *A. saratogensis* is either present in the stand or in the surrounding areas, that the stand is stocked with >500 trees per hectare, and the site index is ≥50. In general, stands with red pine >3 m tall are not susceptible to damage by *A. saratogensis*.

Stands with uniform vegetative ground cover can be rated as one contiguous patch. Stands with very patchy vegetation should be divided into smaller areas for rating; in such cases, consider rating each 0.2 hectares. Estimate the percentage of ground in the stand covered by sweet fern. Estimate the percentage of ground covered by other hosts accepted by *A. saratogensis* (Table 1). Do not include non-host plants or bare soil. To determine the risk of

feeding injury by *A. saratogensis* in the rated area, compare the percentage of ground in the stand covered by sweet fern to the percentage of ground covered by other host plants using Figure 3. Stands can be classified as having light, moderate or heavy potential injury, which are described below:

| Potential injury rating | Extent of potential injury |
|---|---|
| Light | No visible symptoms of feeding other than scars beneath bark. |
| Moderate | Some stunting and deformation, with occasional flagging. |
| Heavy | Most pines stunted and deformed; many with flagging, topkill, or dead. |

Stands can be rated before planting or after establishment. Reduce or remove the alternate host plants in stands rated as moderate or heavy as soon as possible before populations of A. saratogensis reach outbreak levels. Once outbreaks occur, damaging populations of A. saratogensis may persist for up to 10 years. Densely planted, vigorous stands of red pine should be less susceptible to *A. saratogensis* damage as the closing canopy will produce too much shade for most of the alternate host plants.

**Note**

This risk-rating method was developed for use in the Great Lakes region of North America and may not be applicable in other areas. Use with caution until validated in other regions.

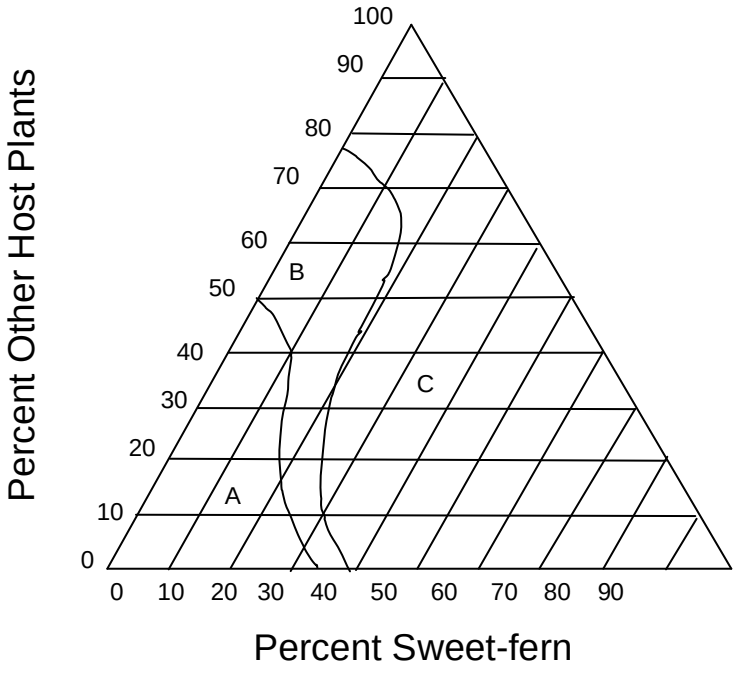


Figure 3. Spittlebug risk-rating triangle showing regions of light (A), moderate (B), and heavy (C) risk. To determine potential injury level, plot the percentage of ground occupied by sweet-fern against the percentage of ground occupied by other suitable hosts. (Modified from the original figure in the publication.)

Table 1. Spittlebug nymphal hosts and non-hosts commonly found in Lake States red pine plantations.

| Vegetational group | Common name | Scientific name |
|---|---|---|
| Primary host | Sweet fern | *Comptonia peregrina* (L.) Coult. |
| Secondary hosts[1] | Blackberry, raspberry | *Rubus* spp. |
| | Orange hawkweed | *Hieracium aurantiacum* L. |
| | Strawberry | *Fragaria virginiana* Dus. |
| | Bracken fern | *Pteridium aquilinum* (L.) Kuhn |
| | Blueberry | *Vaccinium* spp. |
| | Sand cherry | *Prunus pumila* L. |
| | Goldenrod | *Solidago* spp. |
| | Sheep sorrel | *Rumex acetosella* L. |
| | Cinquefoil | *Potentilla* spp. |
| | Wintergreen | *Gaultheria procumbens* L. |
| | Sumac | *Rhus* spp. |
| Non-hosts | Grasses | Gramineae |
| | Sedges | *Carex* spp. |
| | Mosses | *Lycopodium* spp. |
| | Lichens | *Cladonia* spp. |

[1]This group contains perhaps 200 species of plants that include herbs, ferns, woody shrubs, and young broadleaf trees.

# Obscure Scale

## *Melanaspis obscura* (Comstock)

### Hemiptera: Diaspidae

Potter, D. A.; Jensen, M. P.; Gordon, F. C. 1989. Phenology and degree-day relationships of the obscure scale (Homoptera: Diaspididae) and associated parasites on pin oak in Kentucky. Journal of Economic Entomology 82: 551-555.

**Objective**

To determine the first hatch of *M. obscura* crawlers on pin oak using degree-day accumulation.

**Abstract**

Obscure scale, *Melanaspis obscura* (Comstock), is a native armored scale that attacks oaks, *Quercus* spp., maples, *Acer* spp., hickories, *Carya* spp., and other hardwoods in the eastern USA. Stressed trees, such as those in the urban setting, are more susceptible to attack by *M. obscura*. Infestations may result in branch dieback and a weakened condition, but infested trees rarely die from *M. obscura* alone.

When necessary, insecticide sprays can be applied against the overwintering stage or the newly-eclosed crawlers of *M. obscura*. Land managers can forecast the eclosion of *M. obscura* crawlers on pin oak, *Quercus palustris* Muenchhausen, used as street trees in Kentucky, using degree-day accumulation. Crawlers begin hatching at a mean accumulation of 1,521 ±22 degree-days (DD) ºC, which corresponds to late June-early July in northern Kentucky. Chemical applications applied during this time period should be effective against the crawler stage.

**Sampling Procedure**

Begin monitoring degree-day accumulations from 1 January using a base threshold of 4.44°C. Consider applying insecticides against *M. obscura* crawlers after 1,521 ± 22DD have accumulated.

**Notes**

While the mean degree-day accumulation of 1,521 ± 22DD gave a close prediction of crawler hatch in other states, this model should be used with caution outside of northern Kentucky until it has been validated with local temperature data.

The peak activity period of the primary parasites of *M. obscura* is also in July. Application of chemical controls against *M. obscura* crawlers will have a negative impact on these parasites. Consider reserving insecticide controls for trees in stressed conditions, but refraining from treating otherwise healthy trees in order to conserve natural enemies.

# Birch Aphids

## *Betulaphis brevipilosa* Börner

## *Callipterinella calliptera* (Hartig)

## *Euceraphis betulae* (Koch)

### Hemiptera: Drepanosiphidae

Hajek, A. E.; Dahlsten, D. L. 1988. Distribution and dynamics of aphid (Homoptera: Drepanosiphidae) populations on *Betula pendula* in northern California. Hilgardia 56: 1-33.

**Objective**

To develop a collective aesthetic injury level for the aphids *B. brevipilosa*, *C. calliptera*, and *E. betulae* on European white birch, *Betula pendula*, in northern California.

**Abstract**

The aphids *Betulaphis brevipilosa* Börner, *Callipterinella calliptera* (Hartig), and *Euceraphis betulae* (Koch) feed on European white birch, *Betula pendula* Roth., which is often planted as an ornamental tree in North America. Large populations of these aphids produce copious amounts of honeydew that supports the growth of sooty mold, and attacked leaves may senesce prematurely. Homeowners who find the honeydew and mold unsightly may use chemical applications as preventive treatments to avoid this problem.

A collective aesthetic injury level was calculated for these aphids on *B. pendula* within the urban landscape in northern California. The authors estimated that 40 aphids per 100 cm of branch terminal or 88 aphids per 100 leaves warranted control measures if homeowners considered feeding damage by the aphids to be unsightly. Sample sizes necessary to estimate population density were determined using the coefficients of Taylor's Power Law. Sampling effort depends on aphid density and the desired level of reliability in estimating aphid density. Overall, the aggregated distribution of these aphids requires large numbers of samples from each tree even if only a low level of reliability is desired. Higher aphid densities require smaller sample sizes and less time is spent sampling each tree, thus sampling cost is also lower than if aphid densities were low. Sampling in the spring, when aphid populations were high, took <2 minutes per branch while sampling in the summer, after populations fell, required <1.5 minutes per branch. Few aphids were found in the upper third of the canopy, therefore sampling effort should concentrate on the lower two-thirds of the tree.

**Sampling Procedure**

The sampling unit consists of all the leaves found on a new long terminal shoot, plus the leaves on any short shoots occurring along the previous year's twig growth of a length equal

to the terminal shoot. Examine leaves and shoots closely for immature and adult aphids. Record the number of aphids found on leaves and on the branch separately. Average the number of aphids per 100 cm branch terminal or per 100 leaves. If feeding damage, honeydew production, or sooty mold accumulation is undesirable, consider insecticide treatment when aphid populations reach 40 aphids per 100 cm of branch terminal or 88 aphids per 100 leaves.

To estimate aphid densities on groups of trees, randomly sample 5 branches per tree throughout the lower two-thirds of the canopy when aphid populations are low (approximately 5 aphids per 100 leaves) and 3 branches per tree when aphid populations are high (approximately 40 aphids per 100 leaves). Refer to Fig. 1 for the number of trees to sample to estimate aphid populations at either low or high aphid densities using a 70% confidence limit. Sampling costs in person-hours are illustrated in Fig. 2 for both low and high aphid densities with a 70% confidence limit.

Use Table 5 to determine the total number of branch samples necessary to estimate aphid densities on individual trees. For example, 174 branch terminals should be taken from each tree to estimate aphid density when aphids are estimated to be 10 per 100 cm branch length and 30% reliability is desired (Table 5).

**Note**

These recommendations are based on data collected in northern California and may not apply to other aphid species on different host birch species in other regions. Use these recommendations with caution until validated in other locations.

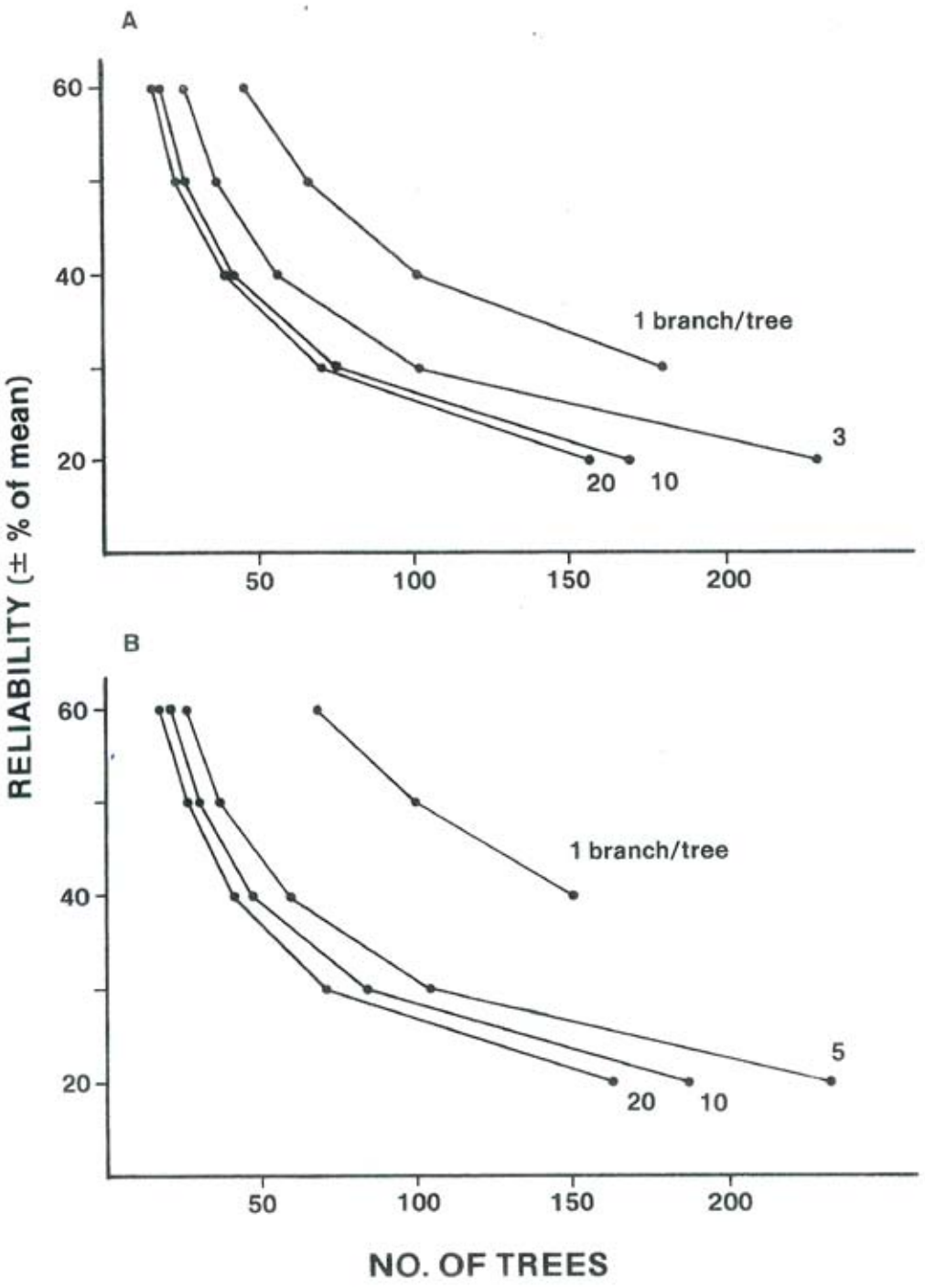


Fig. 1. Numbers of trees to sample for estimation of aphid populations on *Betula pendula* with varying levels of reliability and numbers of branches per tree (70 percent confidence limits). (A) 40 aphids/100 leaves; (B) 5 aphids/100 leaves.

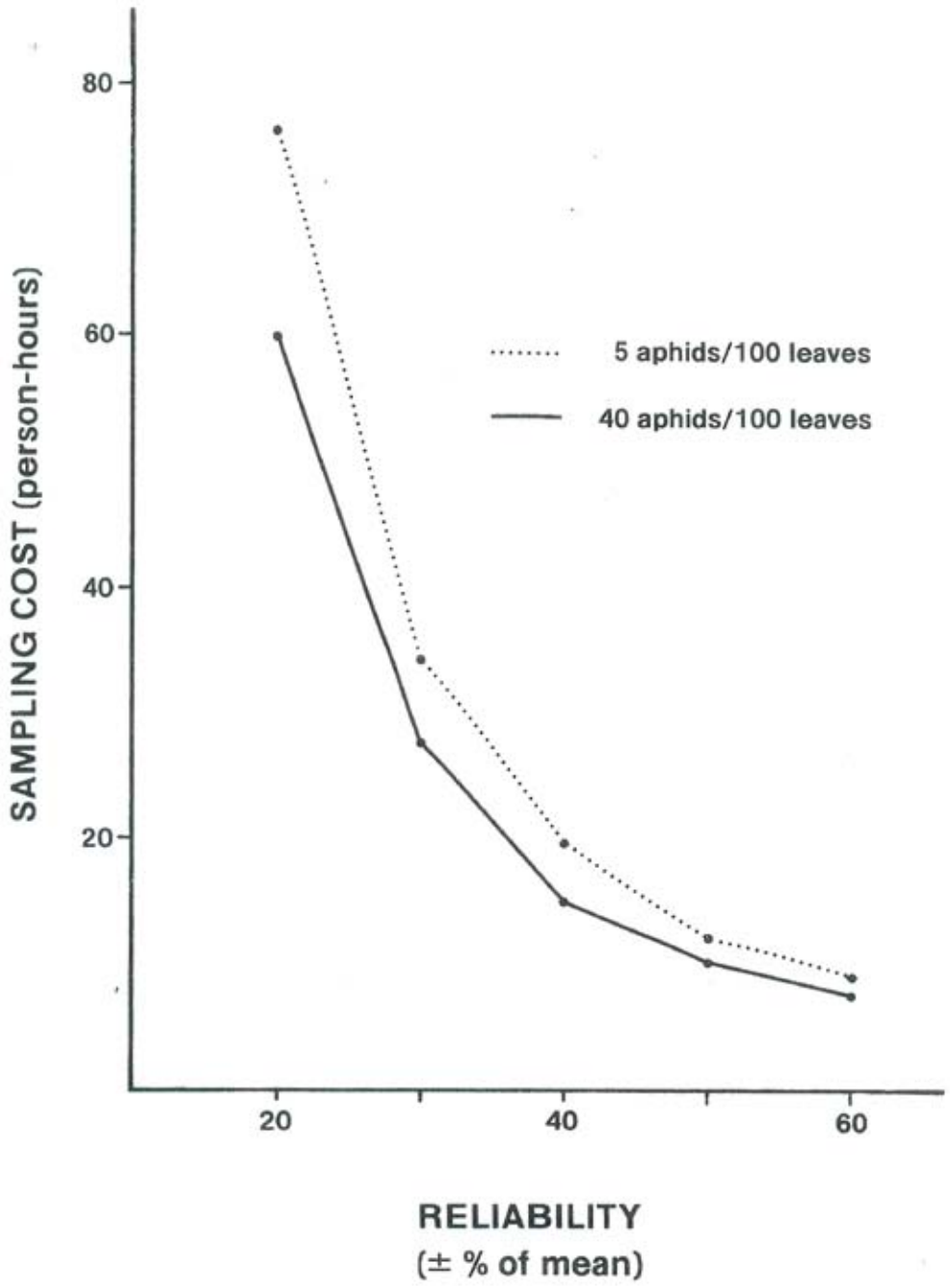


Fig. 2. Sampling costs (in person-hours) to optimally estimate aphid population densities on *Betula pendula* for varying levels of reliability (70 percent confidence limits).

Table 5. Sample size in number of branches for estimation of aphid populations on individual Betula pendula trees at varying levels of reliability and aphid population densities.

| Mean aphid density | Reliability with 70% confidence intervals (± % of the mean) | | | | |
|---|---|---|---|---|---|
| | 20% | 30% | 40% | 50% | 60% |
| (/100 *cm*) | *(number of branches)* | | | | |
| 10 | 391 | 174 | 98 | 63 | 43 |
| 20 | 320 | 142 | 80 | 51 | 36 |
| 30 | 285 | 126 | 71 | 46 | 32 |
| 40 | 262 | 116 | 65 | 42 | 29 |
| 50 | 245 | 109 | 61 | 40 | 27 |

# Sycamore Lace Bug

## *Corythucha ciliata* (Say)

### Hemiptera: Tingidae

Horn, K. F.; Farrier, M. H.; Wright, C. G.; Nelson, L. A. 1983. A sampling method for estimating egg and first-instar densities of the sycamore lace bug, *Corythucha ciliata* (Say). Journal of the Georgia Entomological Society 18: 37-49.

**Objective**

To develop fixed precision estimation plans for eggs and first-instar nymphs of *C. ciliata* on individual trees using Taylor's power law.

**Abstract**

The sycamore lace bug is a minor pest of sycamore, *Platanus occidentalis* L. In 1983, the importance of *C. ciliata* in Europe, where it is an exotic pest, was increasing. A sequential estimation plan was devised for eggs and first-instar nymphs to aid in basic research on this insect.

Both plans were based on Taylor's power law. Log variance was related positively to *C. ciliata* eggs (log variance = log 19.11 + 1.393log mean; $r^2 = 0.94$) and first-instar nymphs (log variance = log 7.831 + 1.594log mean; $r^2 = 0.92$). This information was used to develop sequential estimation plans for eggs and first-instar nymphs at the 0.20 and 0.25 levels of fixed precision. Control measures were recommended if densities of *C. ciliata* exceeded 2 eggs/$cm^2$.

**Sampling Procedure**

Select sycamore trees at random. Sample an equal number of similar-sized leaves from each cardinal direction from the lower (≤3.5 m) part of the canopy. The third to fifth leaves from the terminal leaf were used in this study. On the underside of each leaf, count the number of eggs or first instars per leaf. Average the densities among all leaves sampled from one tree. If the leaf appears to have more than 100 eggs on it, count the number of eggs on one half of the leaf divided by the midvein and then double the tally for the estimate of that leaf. Stop sampling leaves when the mean number of eggs or first instars per leaf crosses the desired level of fixed precision at either of the t-values (probability that the mean is within the level of fixed precision) (see Figs. 2 & 3 for eggs or nymphs, respectively). Trees are classified as lightly or heavily infested if the density of eggs is <1.0 or >2.0 eggs per $cm^2$ of leaf area, respectively. However, leaf area must also be sampled to use this threshold. Allow at least 2 weeks to pass after sampling eggs before sampling first instars to allow all eggs to hatch.

**Notes**

The authors did not specify infestation levels for first instars; use the infestation levels given for eggs with caution. This sampling plan was developed from samples on relatively few trees in one location. Thus, variation in mean and variance among different populations of *C. ciliata* was not addressed in this study. Please use this plan with caution if sampling lace bugs in locations other than Raleigh, NC.

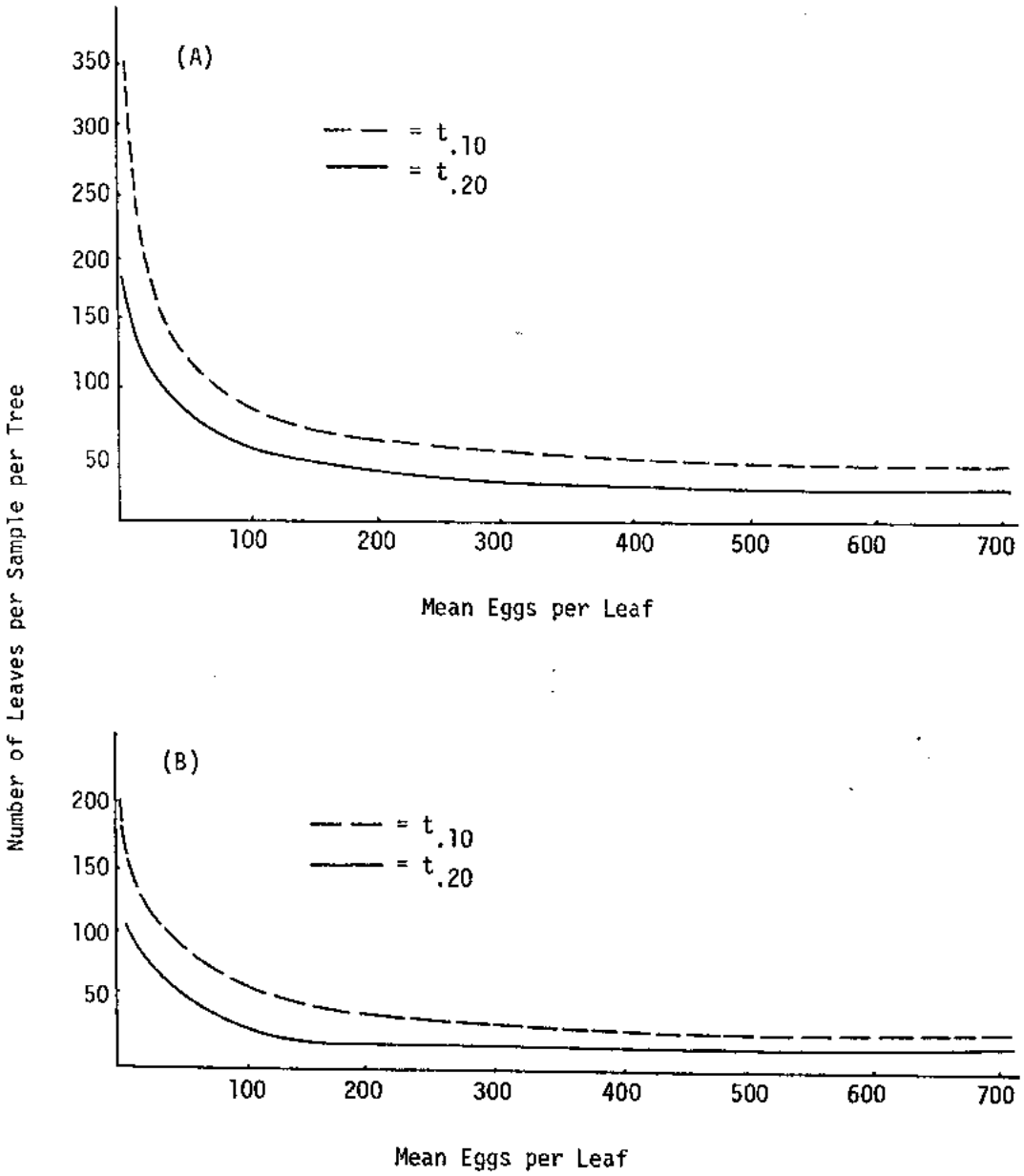


Fig. 2. Number of leaves needed to estimate the mean Corythucha ciliata egg density within a tree with a given level of accuracy and reliability (A) D = .20 and (B) D = .25. Dashed and solid lines represent the critical t-statistics at the 0.1 and 0.2 probability levels (two-tailed), respectively.

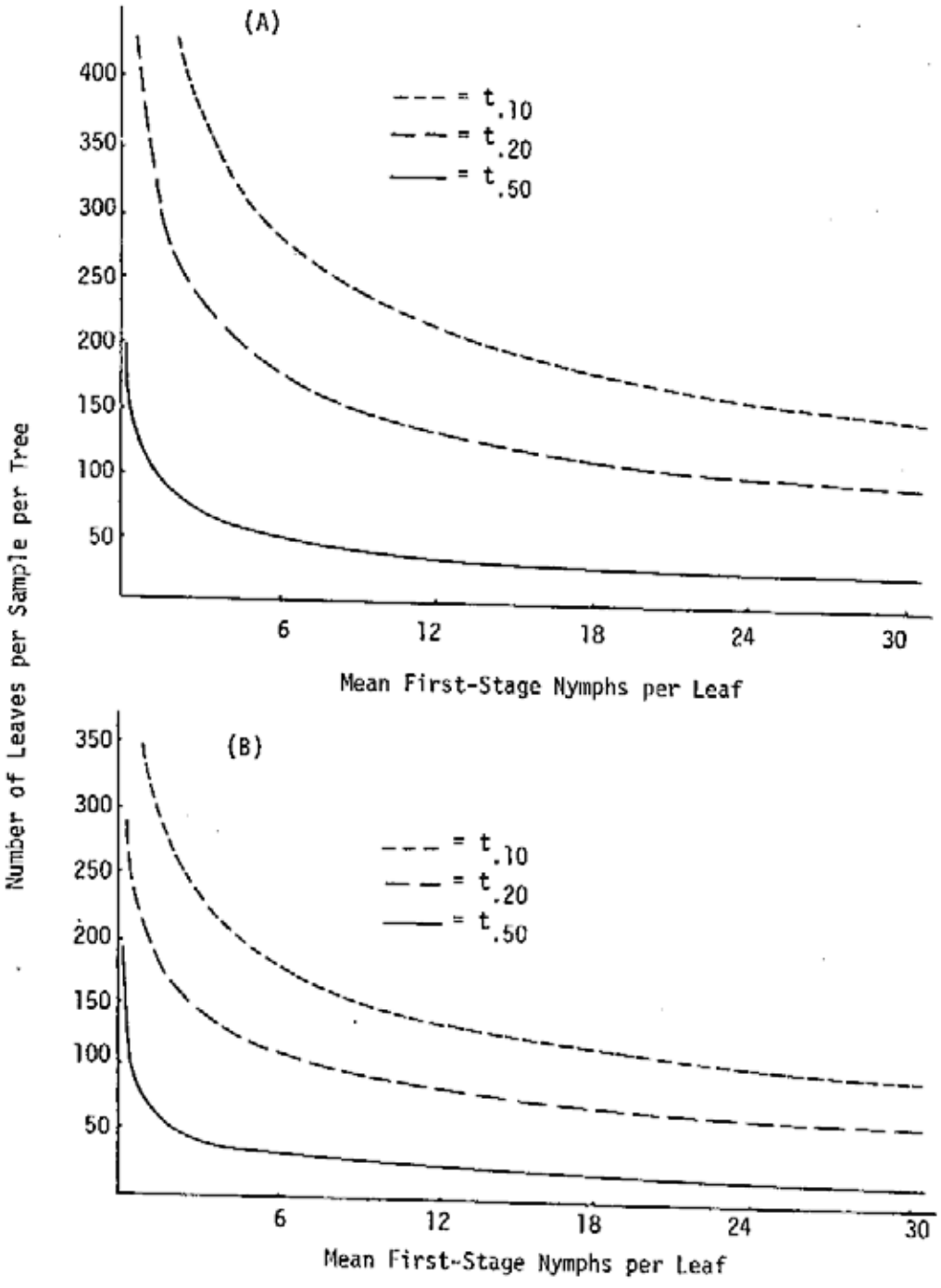


Fig. 3. Number of leaves needed to estimate the mean Corythucha ciliata first-instar density within a tree with a given level of accuracy and reliability (A) D = .20 and (B) D = .25. Dotted, dashed, and solid lines represent the critical t-statistics at the 0.1, 0.2, and 0.5 probability levels (two-tailed), respectively

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# SEED AND CONE INSECTS

# Spiral Spruce Cone Borer

## *Strobilomyia neanthracina* (Michelsen)

# Spruce Seed Moth

## *Cydia strobilella* (L.)

### Diptera: Anthomyiidae

Ruth, D. S.; Miller, G. E.; Sutherland, J. R. 1982. A guide to common insect pests & diseases in spruce seed orchards in British Columbia. Inf. Rep. BC-X-231. Environment Canada, Canadian Forestry Service, Pacific Forest Research Centre; 28 p.

**Objective**

To provide a rough treatment threshold for spruce conelets, *Picea* spp., infested by *C. strobilella* and *S. neanthracina*.

**Abstract**

Spruce seedmoth, *Cydia strobilella* (L.), is an important pest of spruce (*Picea* spp.) seeds. Larvae feed inside seeds where the damage is cryptic. Spruce cone maggot, *Strobilomyia neanthracina* Michelsen, is a major pest of spruce cones and seeds. Larvae tunnel within cones in a characteristic spiral manner, consuming seeds developing at the base of scales. Primary hosts of both pest species include white spruce, *Picea glauca* (Moench) Voss, Engelmann spruce, *Picea engelmannii* Parry, and other *Picea* spp. Both pest species can cause substantial seed loss in seed orchards in Canada and USA.

Random sampling of 5–10% of the cone-bearing spruces in an orchard can provide a rough estimate of seed loss by *C. strobilella* and *S. neanthracina*. Ten conelets should be taken from each sampled tree and examined visually for eggs. A seed loss of 10–20% can be expected at harvest if eggs of either species are found on two conelets from each tree, thus control measures are warranted if more than one cone per tree is infested.

**Sampling Procedure**

Immediately after pollination in the spring, randomly select 5–10% of the cone-bearing spruces in an orchard. Collect 10 conelets throughout the canopy of each selected tree. Using a hand lens, examine each conelet for the presence of *C. strobilella* and *S. neanthracina* eggs. If two conelets from each tree are found to have eggs of either pest species on them, a seed loss of 10–20% can be expected at harvest. Managers should consider control measures if more than 1 conelet per tree is infested and the majority of conelets in the orchard are closed and are turning downwards. Seed loss may have already occurred by the time conelets are pendant

# Western Conifer Seed Bug

## *Leptoglossus occidentalis* Heidemann

### Hemiptera: Coreidae

Blatt S. E.; Borden, J. H. 1996. Distribution and impact of *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae) in seed orchards in British Columbia. Canadian Entomologist 128: 1065-1076.

**Objective**

To determine the distribution of *L. occidentalis* in coastal Douglas-fir and lodgepole pine seed orchards.

**Abstract**

Western conifer seed bug, *Leptoglossus occidentalis* Heidemann, feeds on seeds developing within the cones of coastal Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and several species of pine (*Pinus* spp.). It is considered a serious pest in seed orchards in the USA and British Columbia. Studies on the distribution of *L. occidentalis* in coastal Douglas-fir seed orchards in British Columbia indicated that this species has a patchy distribution as the nymphs feed in aggregations. Thus, whole tree counts may be more appropriate than sampling a set number of branches when population densities are low. This species was not observed on trees without cones, suggesting that coneless trees can be excluded from sampling. X-ray analysis of seeds indicated that *L. occidentalis* was responsible for <5% and ≈14% seed loss in coastal Douglas-fir and lodgepole pine, *Pinus contorta* var. *latifolia* Engelm., respectively. Seed loss was not related to *L. occidentalis* density on either host species. The authors concluded that current populations of *L. occidentalis* in seed orchards in British Columbia are not large enough to warrant control measures on either coastal Douglas-fir or lodgepole pine.

**Sampling Procedure**

Tree sampling: Randomly select trees bearing cones in mid-July. Visually select three cone-bearing branches from each tree from a distance, then examine each selected branch for adult and nymphs of *L. occidentalis*. Use a ladder or bucket truck as needed. Given the aggregation behavior of *L. occidentalis* nymphs, whole tree counts are probably more appropriate for nymphs than just sampling three branches from a tree.

Seed sampling: Randomly select 25 cones from trees at harvest. Dry cones in paper bags, then extract and winnow seeds before x-ray analysis. Examine radiographs to categorize

seeds as full, empty, or partially full. Douglas-fir seeds may also be categorized as infested by the Douglas-fir seed chalcid, *Megastigmus spermotrophus* Wachtl.

The number of *L. occidentalis* causing 5, 10, 15, and 20% seed loss over a 120-day feeding period is given in Table 2. Populations of *L. occidentalis* in British Columbia are probably not large enough to exceed the acceptable seed loss of <5%.

**Reference**

Hanson, P. D. 1984. Comparison of damage to Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seed, by each life stage of *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae). Vancouver: University of British Columbia; B.Sc. thesis. 28 p.

Table 2. Calculated numbers of Leptoglossus occidentalis required to cause 5–20% damage to coastal Douglas-fir and lodgepole pine seed based on Hansen's (1984) feeding rate of one seed bug per day, and extended over an estimated 120 days of favorable weather for feeding from 1 May to 31 August in British Columbia. Estimates of cones per tree and filled seed per cone based on data supplied by D. Reid and B. Barber, B.C. Forest Service, Saanichton and Victoria, respectively, who obtained records from the Tree Seed Centre, B.C. Forest Service, Surrey, B.C.

| Species | Source of seed | Cones per tree | Filled seed per cone | Filled seed produced | Percentage damage | Seed damaged | Insects required per tree |
|---|---|---|---|---|---|---|---|
| Douglas-fir | Seed orchard | 3,000 | 40 | 120,000 | 5 | 6,000 | 50 |
| | | | | | 10 | 12,000 | 100 |
| | | | | | 15 | 18,000 | 150 |
| | | | | | 20 | 24,000 | 200 |
| | Wild stand | 2,800 | 14 | 39,200 | 5 | 1,960 | 17 |
| | | | | | 10 | 3,920 | 33 |
| | | | | | 15 | 5,880 | 49 |
| | | | | | 20 | 7,840 | 66 |
| Lodgepole pine | Seed orchard | 2,000 | 15 | 30,000 | 5 | 1,500 | 13 |
| | | | | | 10 | 3,000 | 25 |
| | | | | | 15 | 4,500 | 38 |
| | | | | | 20 | 6,000 | 50 |
| | Wild stand | 8,300 | 20 | 166,600 | 5 | 8,300 | 70 |
| | | | | | 10 | 16,600 | 139 |
| | | | | | 15 | 24,900 | 208 |
| | | | | | 20 | 33,200 | 277 |

**Table 2 modified and reproduced with the permission of the authors, granted April 2, 2009.**

# Western Conifer Seed Bug

## *Leptoglossus occidentalis* Heidemann

### Hemiptera: Coreidae

Bates, S. L.; Lait, C. G.; Borden, J. H.; Kermode, A. R. 2002. Measuring the impact of *Leptoglossus occidentalis* (Heteroptera: Coreidae) on seed production in lodgepole pine using an antibody-based assay. Journal of Economic Entomology 95: 770-777.

**Objective**

To improve the detection of damage caused by *L. occidentalis* in harvested lodgepole pine seed using an immunoassay.

**Abstract**

Western conifer seed bug, *Leptoglossus occidentalis* Heidemann, feeds on developing seeds within the cones of lodgepole pine, *Pinus contorta* var. *latifolia* Engelm. This seed bug occurs throughout western North America but appears to be spreading into eastern Canada and the USA. Adult male and female *L. occidentalis* can damage 1.4 and 2.0 seeds per day, respectively, in late cone development. Seed loss due to *L. occidentalis* can be difficult to calculate, as seed damaged by pest feeding cannot be distinguished from aborted seed at harvest unless examined using x-rays. Seed loss estimates are based typically on exclusion studies or caged feeding trials. A new method has been developed using an antibody marker for a salivary protein deposited by *L. occidentalis* while feeding on seeds (Lait et al. 2001). Managers interested in using this immunoassay are strongly encouraged to consult the original publication for detailed information regarding this technique. This method accurately detects seeds damaged by *L. occidentalis*, but traditional radiograph techniques are necessary to estimate the percentage of empty seeds aborted due to other causes.

**Sampling Procedure**

Collect cones at harvest and store at ≈18°C until processing. Boil cones in water for ≈90 s to remove the resin seal, then bake at 50°C for 8 h. Remove seeds from cones by shaking them vigorously in a container for 90 s. Seeds not dislodged during this procedure are classified as being fused to the cone scales.

Grind individual seeds in 150 µl of a buffer made of 62.5 mM Tris-HCL (pH 6.8), 2% sodium dodecyl sulfate (wt:vol), and 10% glycerol (vol:vol). Load 15 µl of each seed sample on a 15% acrylamide resolving gel and separate the proteins using sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) under reducing conditions with 2 µl

β-mercaptoethanol per sample. Transfer separated proteins onto nitrocellulose with a Western blot. Block overnight in Tris-buffered saline (TBS) made with 5% nonfat milk powder. Incubate Western blots for 2 h at room temperature with affinity-adsorbed primary polyclonal antibody (1:5000) to *L. occidentalis* salivary protein (Lait et al. 2001). Positive binding of the antibody can be demonstrated by using a secondary antibody conjugated to alkaline phosphatase (1:10000) with 5-bromo-4-chloro-3-indoyly phosphate and nitro blue tetrazolium, which react together and form a colored product. Seed samples with this colored product are classified as damaged by *L. occidentalis* feeding. Seeds fused to cone scales should also be considered as being damaged by *L. occidentalis* feeding from early in the season. Managers must use their experience and the estimated size and value of the expected seed crop to decide if the seed loss determined by this method warrants control measures for *L. occidentalis* the following year.

**Notes**

The authors did not suggest a minimum number of cones to sample, but they should be collected from a sufficient number of randomly selected trees to adequately assess feeding damage throughout the orchard.

The authors noted that some seeds exposed to *L. occidentalis* early during seed development may be empty when harvested but not test positive for *L. occidentalis* feeding. Also, feeding by *L. occidentalis* on cones early in the season increased the number of seeds fused to the cone scales. The fused seeds, remaining in the cone after the extraction process, are often overlooked as feeding injury on the seed crop. The authors noted that not all fused seeds, when removed from the cones and tested with the immunoassay, produced the colored product indicating *L. occidentalis* feeding damage despite their association with *L. occidentalis*. In both cases, these false-negative results may be due to assimilation of the salivary proteins by the developing ovule or degradation of the proteins over time before harvest. For this reason, the immunoassay is not wholly accurate in detecting *L. occidentalis* damage that may occur early in the season.

**Reference**

Lait, C. G.; Bates, S. L.; Kermode, A. R.; Morrissette, K. K.; Borden, J. H. 2001. Specific biochemical marker-based techniques for the identification of damage to Douglas-fir seed resulting from feeding by the western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hemiptera: Coreidae). Insect Biochemistry and Molecular Biology 31: 739–746.

# Western Conifer Seed Bug

## *Leptoglossus occidentalis* Heidemann

### Hemiptera: Coreidae

Bates, S. L.; Borden, J. H. 2005. Life table for Leptoglossus occidentalis Heidemann (Heteroptera: Coreidae) and prediction of damage in lodgepole pine seed orchards. Agricultural and Forest Entomology 7: 145-151.

**Objective**

To predict damage caused by *L. occidentalis* on harvested seed yield in lodgepole pine seed orchards in British Columbia.

**Abstract**

Western conifer seed bug, *Leptoglossus occidentalis* Heidemann, feeds on developing seeds within the cones of lodgepole pine, *Pinus contorta* var. *latifolia* Engelm. Feeding damage by *L. occidentalis* represents a significant economic loss for seed orchards in British Columbia as lodgepole pine seed is valued at $1,000–5,000 per kg (Strong et al. 2001). In this study the authors estimated that one *L. occidentalis* per tree early in the season will result in approximately 310 seeds lost to feeding damage at harvest. This damage reflects feeding by both a founding bug and the expected offspring. In the absence of any predation or parasitism, approximately 434 seeds per tree lost to feeding damage can be expected at harvest. This damage prediction is based on the population dynamics of the bug over the season as well as feeding studies conducted by Bates et al. (2002). Adult male and female *L. occidentalis* can damage 1.4 and 2.0 seeds per day, respectively (Bates et al. 2002).

**Sampling Procedure**

Early in the season when nymphs are present, beat lodgepole pines thoroughly using a beat stick and a tray or a drop cloth. Sample as much of the canopy as possible. Examine the tray or drop cloth and count the number of *L. occidentalis* nymphs and adults present. The authors did not suggest a minimum number of trees to sample, but the density of *L. occidentalis* within an orchard should be averaged over a sufficient number of randomly selected trees. Managers must use their experience and the estimated size and value of the expected seed crop to decide if the expected seed loss produced by 0.5 to 2.5 bugs per tree early in the season warrants control measures (see Fig. 1 in original publication).

The authors recommend sampling throughout the season as adult populations, and associated seed losses, may rise quickly late in the season. Sample for *L. occidentalis* nymphs and adults as described above, but count male and female adults separately. The damage predic-

tion for seed loss due to adult feeding late in the season is based on the numbers of adults present and days to harvest, but not the effect of potential offspring. Use Table 6 (refer to original publication) to predict the number of damaged seeds per tree based on the developmental stage, sex, density of bugs per tree, and the number of days remaining to harvest. Again, managers must use their experience and the estimated size and value of the expected seed crop to decide if the predicted seed loss warrants control measures before harvest.

**Notes**

Refer to the original publication for Figure 1 and Table 6, which could not be reprinted here due to the immoderate charges requested by the publisher for copyright clearance.

The authors noted that first instar *L. occidentalis* were difficult to sample as they tended to be tossed into the air rather than dropping onto the tray or drop cloth when trees were beaten. *L. occidentalis* occurs throughout western North America but appears to be spreading into eastern Canada and the U.S. Damage predictions established for *L. occidentalis* in western Canada may not be applicable for *L. occidentalis* in its newly expanded range in eastern North America.

**References**

# Bates, S. L.; Lait, C. G.; Borden, J. H.; Kermode, A. R. 2002. Measuring the impact of *Leptoglossus occidentalis* (Heteroptera: Coreidae) on seed production in lodgepole pine using an antibody-based assay. Journal of Economic Entomology 95: 770-777.

Strong, W. B.; Bates, S. L.; Stoehr, M. U. 2001. Feeding *by Leptoglossus occidentalis* (Hemiptera: Coreidae) reduces seed set in lodgepole pine (Pinaceae). Canadian Entomologist 133: 857-865.

# Western Conifer Seed Bug

***Barbara colfaxiana* (Kearfott), Lepidoptera: Tortricidae**

***Contarinia oregonensis* Foote, Diptera: Cecidomyiidae**

***Dioryctria abietivorella* (Grote), Lepidoptera: Pyralidae**

***Lepesoma lecontei* (Casey), Coleoptera: Circulionidae**

***Megastimus spemotrophus* (Wachtl), Hymenoptera: Torymidae**

Dombrosky, S. A.; Schowalter, T. D. 1988. Inventory monitoring for estimating impact of insects on seed production in a Douglas-fir seed orchard in western Oregon. Journal of Economic Entomology 81: 281-285.

## Objective

To develop a fixed precision enumerative sampling plan that estimates infestation levels of multiple species of seed and cone insects attacking cones and seeds of coastal Douglas-fir.

## Abstract

Genetically improved Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, is commonly grown in orchards in the Pacific Northwest to aid reforestation efforts in the coastal region. The value of harvested seed ranged from $650-2,200/kg in the 1980's, and any damaged seed is considered an economic loss. A number of important insect pests have been reported from Douglas-fir cones, feeding on the cone and developing seeds within the cone.

A study conducted in western Oregon examined the distribution of Douglas-fir cones and insects attacking the cones, as stratified within crowns and among trees in a seed orchard. The number of trees and the number of cones per tree or the number of cones per crown level (bottom, mid, and upper) was determined for sampling multiple cone pests at the 0.10 and 0.20 standard errors (SE) of the mean. In general, 12 cones collected randomly throughout the canopies of each of 100 trees should be adequate to estimate seed losses due to biotic or abiotic factors with a standard error of the mean of 0.20, but stratified sampling among crown levels is recommended for more precise estimates of potential cone and seed yields. Sampling large numbers of trees is necessary due to the high level of variation among trees. Orchard managers should select a sampling plan that balances the desired level of precision with an acceptable cost of sampling.

## Sampling Procedure

For non-stratified sampling of biotic and abiotic factors contributing to cone and seed losses, collect 12 cones randomly throughout the canopy of each of 100 trees selected at random in a seed orchard. This should be sufficient to estimate seed losses at the 0.20 standard error level

of precision. Examine cones and seeds to determine mortality, total seeds per cone, the number of healthy seeds, and seed loss due to insects, frost, unexplained failure to develop, etc.

Sample immature cones at the flowering stage in April or the pendant stage in June for the flightless weevil *Lepesoma lecontei* (Casey) (Coleoptera: Curculionidae). To sample *L. lecontei* at the 0.10 standard error of the mean, examine 584 cones throughout the crown from each of 781 trees (Table 4). Alternatively, partition the live crown of each of the 781 trees into thirds by counting the number of whorls present on each tree and dividing by three (Miller 1986a, b). Sample 92 cones from the bottom crown, 390 cones from the mid-crown, or 1,111 cones from the top crown of each tree.

To sample *L. lecontei* at the 0.20 standard error of the mean, examine 146 cones throughout the crown from each of 195 trees (Table 4). Alternatively, partition the live crown of each of the 195 trees into thirds by counting the number of whorls present on each tree and dividing by three (Miller 1986a, b). Sample 23 cones from the bottom crown, 98 cones from the mid-crown, or 278 cones from the top crown of each tree.

Sample mature cones in early September for the following insects that damage seeds:

| | | |
|---|---|---|
| Douglas-fir cone gall midge | *Contarinia oregonensis* Foote | Diptera: Cecidomyiidae |
| Douglas-fir cone moth | *Barbara colfaxiana* (Kearfot) | Lepidoptera: Tortricidae |
| Douglas-fir seed chalcid | *Megastimus spermotrophus* (Wachtl) | Hymenoptera: Torymidae |
| Fir coneworm | *Dioryctria abietivorella* (Grote) | Lepidoptera: Pyralidae |

Use Table 4 to determine how many trees, cones per tree, or cones per crown level should be sampled for each of these pests. For example, to sample *M. spermotrophus* at the 0.10 standard error of the mean, examine 49 cones throughout the crown from each of 620 trees. Alternatively, partition the live crown of each tree into thirds by counting the number of whorls present on each tree and dividing by three (Miller 1986a, b). Sample 15 cones from either the bottom or mid-crown of each tree, or 25 cones from the top crown of each tree. To sample *M. spermotrophus* at the 0.20 standard error of the mean, examine 12 cones throughout the crown from each of 158 trees. Alternatively, partition the live crown of each tree into thirds by counting the number of whorls present on each tree and dividing by three (Miller 1986a, b). Sample 4 cones from either the bottom or mid-crown of each tree, or 6 cones from the top crown of each tree.

Examine each cone for characteristic damage produced by insects attacking seeds and determine the percentage of healthy seeds or seeds damaged by each insect pest. When sampling *M. spermotrophus*, dissect each cone to remove the scales. X-ray the seeds that appear healthy to detect infestation by *M. spermotrophus* or other internal damage.

**Notes**

Table 4 was generated from a sample of ten trees at one site in one year. This information

should be used with caution until additional data can be collected to verify or adjust the numbers. Additional data collected from other seed orchards throughout the Pacific Northwest will greatly improve the predictive ability of this inventory monitoring system.

## References


* Miller, G.E. 1986a. Distribution of *Contarinia oregonensis* Foote (Diptera: Cecidomyiidae) eggs in Douglas-fir seed orchards and a method for estimating egg density. Canadian Entomologist 118: 1291-1295.

* Miller, G.E. 1986b. Damage prediction for *Contarinia oregonensis* Foote (Diptera: Cecidomyiidae) in Douglas-fir seed orchards. Canadian Entomologist 118: 1297-1306.


Table 4. Minimum number of trees and cones required for seed loss estimates within a predetermined standard error (SE), based on data from 10 study trees at the Beaver Creek Seed Orchard, 1984.

| Factor | Trees *(n)* | Cones/tree *(n)* | Cones/tree level | | |
|---|---|---|---|---|---|
| | | | Bottom *(n)* | Middle *(n)* | Top *(n)* |
| **SE = 0.10** | | | | | |
| Healthy seeds | 565 | 52 | 15 | 22 | 28 |
| Undeveloped seeds | 73 | 2 | 1 | 1 | 2 |
| Gall midge | 312 | 51 | 59 | 13 | 19 |
| Seed chalcid | 620 | 49 | 15 | 15 | 25 |
| Cone moth | 605 | 895 | 52 | 945 | 627 |
| Coneworm | 1,020 | 706 | 368 | 468 | 523 |
| Other | 207 | 148 | 33 | 124 | 75 |
| Weevil | 781 | 584 | 92 | 390 | 1,111 |
| Other cone mortality | 379 | 157 | 133 | 198 | 758 |
| **SE = 0.20** | | | | | |
| Healthy seeds | 144 | 13 | 4 | 6 | 6 |
| Undeveloped seeds | 21 | 0.5 | 0.25 | 0.25 | 0.5 |
| Gall midge | 79 | 13 | 15 | 3 | 5 |
| Seed chalcid | 158 | 12 | 4 | 4 | 6 |
| Cone moth | 151 | 224 | 13 | 236 | 157 |
| Coneworm | 255 | 177 | 92 | 117 | 131 |
| Other | 52 | 37 | 8 | 31 | 19 |
| Weevil | 195 | 146 | 23 | 98 | 278 |
| Other cone mortality | 95 | 39 | 33 | 50 | 190 |

# Multiple Seed and Cone Insects

Fogal, W. H.; Larocque, G. 1992. Development of flowers, cones, and seeds in relation to insect damage in two white spruce communities. Forest Ecology and Management 47: 335-348.

**Objective**

To determine the optimal time to sample seed and cone pests of white spruce, *Picea glauca*, based on the temporal relationship between seed and cone development and the occurrence of pest damage.

**Abstract**

Seed- and cone-feeding insects of white spruce, *Picea glauca* (Moench) Voss, can cause substantial seed loss in seed orchards. Trees are frequently sprayed for seed and cone pests after the upright cones turn to a pendant position to avoid interfering with pollination while cones are upright (Fogal and Plowman 1988). However, research on the temporal relationship between seed and cone development of white spruce and the occurrence of damage by seed and cone insect pests indicated that spruce budworm, *Choristoneura fumiferana* (Clem.), spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munroe, and spruce seedmoth, *Cydia strobilella* (L.), damaged some cones before they assumed the pendant position. Waiting until cones have turned to a pendant position before applying insecticides may be too late to prevent some losses by these pests.

Depending on the life cycle of the species of pest to be controlled, insecticides should be applied before or soon after pollination to limit seed loss. Insecticides should be applied before pollination against *C. fumiferana* and most likely *D. reniculelloides* as these larvae feed on microstrobili and megastrobili before fertilization occurs. Systemic insecticides against *C. strobilella* and other insects that oviposit directly into seed cones after pollination should be applied before or soon after pollination to allow the translocation of the material into the cones. However, avoid any canopy sprays that interfere with pollination.

The efficacy of insecticide applications can be assessed by sampling insect damage. Sample developing cones no earlier than mid-July to maximize sampling effort. Waiting until mid-July helps avoid underestimating seed losses due to late-season insect pests or overestimating seed yield due to seed abortion or cones dropping prematurely later in the season. Managers may consider canceling the harvest if heavy damage to cones and seeds is found (Dobbs et al. 1976). Damage detected at this sampling date cannot be abated by the use of insecticide applications this late in the season, but large populations of seed and cone insects in the samples

may signal the need for insecticide application the following season to protect the next crop.

**Sampling Procedure**

Sample developing cones no earlier than mid-July for the following insects that damage seeds and cones:

| Insect | Type of feeding damage |
|---|---|
| Spruce budworm, *Choristoneura fumiferana* (Clem.) | Curled, distorted cones |
| Spruce cone-axis midge, *Dasineura rachiphaga* Tripp | One or more larvae in silken cocoons in cone-axis gallery |
| Spruce cone maggot, *Strobilomyia neanthracina* Michelsen | Reddish-brown tunnels filled with resin around cone axis. |
| Spruce coneworm, *Dioryctria reniculelloides* Mutuura and Munroe | Cone-axis gallery filled with frass, silk |
| Spruce seed chalcid, *Megastigmus piceae* Rohwer | Larvae in seed |
| Spruce seed midge, *Mayetiola carpophaga* (Tripp) | Larvae in seed |
| Spruce seedmoth, *Cydia stobilella* (L.) | Seeds filled with frass; one or more larvae in cone-axis gallery |

Cones infested by *C. fumiferana* and *D. reniculelloides* can be distinguished by the characteristic damage patterns made by the larvae. Examine longitudinal sections of cones and seeds under a dissecting microscope to identify the other insect species present. Larvae in seed were recorded as seed-inhabiting insects in the study and were not identified to species.

Sampling after mid-July will ensure that insects damaging cones and seeds late in the season are included in the assessments and that a more accurate assessment of seed loss is noted. For example, trees may abscise cones attacked by *C. fumiferana*, *S. neanthracina*, or *C. strobilella* in mid-season so that late season assessments may underestimate damage by these pests. However, damage by *D. rachiphaga* and seed pests such as *M. carpophaga* and Megastigmus piceae is less evident early in the season and may be overlooked if assessments are made too early. Sampling seed and cone pests after mid-July offers a good compromise in terms of maximizing sampling efforts, but multiple samples made over the season are preferable to a single sample.

**References**

Dobbs, R. C.; Edwards, D. G. W.; Konishi, J.; Wallinger, D. 1976. Guidelines to collecting cones of B.C. conifers. Joint Rep. No. 3. Victoria, B.C.: Canadian Forest Service, British Columbia Forest Service; 98 p.

Fogal, W. H.; Plowman, V. C. 1989. Systemic insecticides for protecting northern spruce and pine seed trees. Inf. Rep. PI-X-92. Chalk River, Ont.: Natural Resources Canada, Canadian Forest Service, Petawawa National Forestry Institute; 17 pp.

# Multiple Seed and Cone Insects

Kozak, A. 1964. Sequential sampling for improving cone collection and studying damage by cone and seed insects in Douglas fir. Forestry Chronicle 40: 210-218.

**Objectives**

To develop a sequential sampling plan for cone and seed insects on individual Douglas-fir trees; to develop a sequential sampling plan for determining the percentage of Douglas-fir cones with adequate filled seeds for collection.

**Abstract**

Seed- and cone-feeding insects of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] can cause substantial seed loss in seed orchards. Common pests include Douglas-fir cone pyralid (*Dioryctria abietella* Denis & Schiffermüller), Douglas-fir seed chalcid [*Megastigmus spermotrophus* (Wachtl)], Douglas-fir cone gall midge (*Contarinia oregonensis* Foote) and Douglas-fir cone moth [*Barbara colfaxiana* (Kearfott)]. These insects were monitored on Douglas-fir cones in a study conducted in British Columbia and a sequential sampling plan was developed for these pests on individual trees. Testing of this plan showed that an individual tree could be classified in terms of filled seed as poor, medium, or good within 30 minutes and usually by sampling <50 cones. The sampling plan is based on the collective damage produced by seed- and cone-feeding insects and does not require the identification of which species produced the damage, making it very useful to land managers without specialized training in entomology.

This technique is recommended for lightly to moderately infested trees.

**Sampling Procedure**

To sample damaged cones from individual Douglas-fir trees: Randomly select trees for sampling in mid-August or when damage produced by common species of cone- and seed-feeding insects is visible to the naked eye. Randomly select cones throughout the canopy of selected trees if at all possible. Slice each cone in half longitudinally (Winjum and Johnson 1960) and count the number of filled and empty seeds found on one cut surface (one half of the cone). Refer to Table II to determine how many cones should be sampled based on the undamaged filled seed found on the cut surface of each cone. Continue sampling until the tree can be classified as poor, medium, or good.

The relationship between the number of undamaged filled seed on the cut surface of a cone (X) and the number of undamaged filled seed per cone (Y) can be expressed using the formula $Y = 3.04X - 0.33$ (Kozak et al. 1963).

To sample damaged cones from a stand of Douglas-fir (not from individual trees): Randomly select trees for sampling in mid-August or when damage produced by common species cone- and seed-feeding insects is visible to the naked eye. Randomly select four cones from a maximum of 50 trees. Slice each cone in half longitudinally and count the number of filled and empty seeds found on one cut surface (one half of the cone). In general, cones with at least four filled seeds on the cut surface of one half of the cone are considered satisfactory for economical seed extraction. Using the formula $Y = 3.04X - 0.33$ as described above, 35.2 L of cones (approximately 1,000 cones) should produce at least 11,830 seeds if at least 4 filled seeds are found on the cut surface of each cone. Land managers can use this crude estimate to judge whether a stand should be harvested for seed or not.

**Notes**

This sampling plan does not require differentiation among the insect species damaging seeds and cones. However, see the original publication for sequential graphs for sampling Douglas-fir cone gall midge and Douglas-fir seed chalcid separately.

The original article also contains a procedure for determining the number of cones that should be sampled in order to classify a stand as having sufficient cone quality to justify seed extraction. Sampling heavily infested stands using this procedure may not be economical as, on average, more than 100 trees should be sampled before the classification can be made due to inter-tree variation. The effort required to classify a stand makes it unattractive for operational use and was not considered practical by the authors, thus it is not presented in this summary.

**References**

Kozak, A.; Sziklai, O.; Griffith, B. G.; Smith, J. H. G. 1963. Variation in cone and seed yield from young open-grown Douglas firs on the U.B.C. Research Forest. Res. Paper 57. Vancouver, BC: University of British Columbia, Faculty of Forestry; 8 p.

Winjum, J. K.; Johnson, N. E. 1960. A modified knife cone cutter for Douglas fir seed studies. Journal of Forestry 58: 487-488.

Table 2. Sequential table for sampling undamaged filled seeds.

| No. of Cones Examined | Cumulative Number of Undamaged Filled Seeds | | | |
|---|---|---|---|---|
| | Porr vs. Medium | | Medium vs. Good | |
| | Upper Limit of Poor | Lower Limit of Medium | Upper Limit of Medium | Lower Limit of Good |
| 1 | – | – | – | 32 |
| 2 | – | – | – | 38 |
| 3 | – | – | – | 43 |
| 4 | 1 | – | – | 49 |
| 5 | 4 | – | – | 54 |
| 6 | 6 | – | – | 60 |
| 7 | 9 | – | – | 65 |
| 8 | 11 | – | – | 71 |
| 9 | 14 | – | – | 76 |
| 10 | 16 | – | – | 82 |
| 11 | 19 | – | – | 87 |
| 12 | 21 | – | – | 93 |
| 13 | 23 | – | – | 98 |
| 14 | 26 | – | – | 104 |
| 15 | 28 | – | – | 109 |
| 16 | 21 | – | – | 115 |
| 17 | 33 | – | – | 120 |
| 18 | 36 | – | – | 126 |
| 19 | 38 | – | – | 131 |
| 20 | 41 | – | – | 137 |
| 21 | 43 | – | – | 142 |
| 22 | 45 | – | – | 148 |
| 23 | 48 | 65 | 99 | 153 |
| 24 | 50 | 67 | 105 | 159 |
| 25 | 53 | 70 | 110 | 164 |
| 26 | 55 | 72 | 115 | 170 |
| 27 | 58 | 75 | 121 | 175 |
| 28 | 60 | 77 | 126 | 180 |
| 29 | 63 | 80 | 132 | 186 |
| 30 | 65 | 82 | 137 | 191 |

CONTINUE SAMPLING

CONTINUE SAMPLING

**Table 2 reproduced with permission from the Forestry Chronicle, granted April 22, 2009.**

# WOOD- AND BARK-BORING INSECTS

# Bronze Birch Borer

## *Agrilus anxius* Gory

### Coleoptera: Buprestidae

Akers, R. C.; Nielsen, D. G. 1984. Predicting *Agrilus anxius* Gory (Coleoptera: Buprestidae) adult emergence by heat unit accumulation. Journal of Economic Entomology 77: 1459-1463.

**Objective**

To develop a degree-day model of adult *A. anxius* emergence to improve the timing of treatment applications.

**Abstract**

Bronze birch borer, *Agrilus anxius* Gory, is a severe pest of white-barked birches, *Betula* spp., in North America. Stressed trees in urban settings are particularly susceptible to *A. anxius*, but infestations also occur in forests. Larvae, known as flathead borers, tunnel into the trunks of trees and consume the cambium and phloem before emerging as adults from D-shaped exit holes. Infestations result in the girdling of the cambium and symptoms include a gradual progression of canopy thinning and branch dieback from the upper crown towards the base of the tree. Severely weakened trees die, but some may survive with reduced aesthetic value.

Pheromone traps are not available for *A. anxius* or other buprestids. Management of buprestid species typically consists of insecticide sprays applied in the spring, based on calendar date, to the bark of susceptible trees before the adult females oviposit. Larval *A. anxius* chew through the chorion directly into the wood beneath, so insecticides must be applied to the trunks before oviposition to exploit this small window of larval vulnerability. However, insecticide applications based on calendar date do not consider unusually cool or warm spring weather that may alter adult emergence. The timing of spray applications against *A. anxius* can be improved through the use of a degree-day (DD) model with a base temperature of 10ºC that predicts adult emergence. Research conducted in Ohio, USA, indicated that 10% of adult *A. anxius* emerge when the mean degree-day accumulation reaches 235.7DD. Insecticides should be applied at that time for this pest.

**Sampling Procedure**

Begin monitoring degree-day accumulation on 1 April using a base temperature of 10ºC. Expect 10% of adult *A. anxius* to emerge when the mean degree-day accumulation reaches 235.7DD. Insecticide treatments should be applied to the bark of white-barked birches when temperatures reach this threshold.

**Note**

This model was developed for use in Ohio, U.S.A., and may not be accurate for other regions. Use with caution until validated in other areas.

# Emerald Ash Borer

## *Agrilus planipenis* Fairmaire

### Coleoptera: Buprestidae

Crook, D. J.; Khrimian, A.; Francese, J. A.; Fraser, I.; Poland, T. M.; Sawyer, A. J.; Mastro, V. C. 2008. Development of a host-based semiochemical lure for trapping emerald ash borer *Agrilus planipennis* (Coleoptera: Buprestidae). Environmental Entomology 37: 356-365.

**Objective**

To improve detection of *A. planipennis* using pheromone-baited prism traps.

**Abstract**

Emerald ash borer is an established, exotic woodborer attacking healthy green (*Fraxinus pennsylvanica* Marsh.), black (*F. nigra* Marsh.), and most importantly, white ash (*F. americana* L.) in northern North America. Tree mortality is high and rapid. Attempts at eradication appear to be failing, but nonetheless a useful survey system is required for this pest.

Research has shown that *A. planipennis* are attracted to the color purple and a purple box trap baited with ash logs was developed by Francese et al. (2005) (see our review in this volume) to detect adult populations. Further research indicates that purple, three-sided prism traps baited with volatiles found in ash bark distillates catch significantly more *A. planipennis* per m2 of trapping surface than the original four-sided box trap baited with ash logs. No differences in trap catch were found among five sizes of the prism trap. Placing the purple prism traps in the mid-canopy of ash trees appeared to enhance their efficacy in attracting *A. planipennis* adults. Prism traps baited with Phoebe oil, a steam distillate from Brazilian walnut (*Phoebe porosa* Mez.), caught significantly more beetles than unbaited traps or traps baited with Manuka oil, a distillate from New Zealand tea tree (*Leptospermum scoparium* J.R. and G. Forst). Phoebe oil contains 7-epi-sesquithujene and an unidentified compound not found in Manuka oil, along with four sesquiterpenes shared with Manuka oil and also identified from green ash bark. These commercial oils are readily available and offer a viable alternative to the difficult and expensive option of synthesizing single or multiple component sesquiterpene lures for *A. planipennis* adults.

**Sampling Procedure**

Purple panels are the most efficient color in trapping adult *A. planipennis* (Francese et al. 2005). Tie three 35 x 60 cm panels of corrugated purple plastic (0.26 cm thick; Coroplast, Dallas, TX) together to form an open-ended prism with a 0.63 m2 surface area, or fold a

single sheet of plastic to these dimensions. Coat the outside of each panel with insect trapping glue (The Tanglefoot Company, Grand Rapids, MI).

Use lures formulated in polypropylene "bubble cap" or "pouch" devices (Synergy Semiochemicals, Burnaby, BC, Canada) to deliver a release rate of 50 mg Phoebe oil/day. Individual release rates of the identified components in Phoebe oil are approximately as follows:

| Identified component | Release rate per day |
|---|---|
| α-cubene | 0.2 mg |
| α-copaene | 3.0 mg |
| Trans-β-carophyllene | 0.5 mg |
| α-humulene | 0.8 mg |
| 7-*epi*-sesquithujene | 0.75 mg |

Hang each Phoebe oil lure from a black carabiner (5.6 cm long) from a hole punched in the bottom of one of the trap panels. Place traps 13 m above ground, preferably within the canopy of ash trees where adults are active (Francese et al. 2007). Traps should be separated by 40 m. Check traps weekly for adults. Replace lures after 4 weeks.

**References**

Francese, J. A.; Fraser, I.; Lance, D. R.; Mastro, V. C. 2007. Developing survey techniques for emerald ash borer: the role of trap height and design. In: Mastro, V. C.; Lance, D.; Reardon, R.; Parra, G. editors. Proceedings of the Emerald ash borer research and Asian longhorned beetle research and development review meeting. October 29– November 2 2006; Cincinnati, OH. FHTET-2007-04. Morgantown, WV: U.S. Department of Agriculture, Forest Service; 72–73.

# Francese, J. A.; Mastro, V. C.; Oliver, J. B.; Lance, D. R.; Youssef, N.; Lavallee, S. G. 2005. Evaluation of colors for trapping *Agrilus planipennis* (Coleoptera: Buprestidae). Journal of Entomological Science 40: 93-95.

# Emerald Ash Borer

## *Agrilus planipennis* Fairmaire

### Coleoptera: Buprestidae

Francese, J. A.; Mastro, V. C.; Oliver, J. B.; Lance, D. R.; Youssef, N.; Lavallee, S. G. 2005. Evaluation of colors for trapping *Agrilus planipennis* (Coleoptera: Buprestidae). Journal of Entomological Science 40: 93-95.

**Objective**

To evaluate trap color as an attractant for flying *A. planipennis* in detection surveys.

**Abstract**

Emerald ash borer is an established, exotic woodborer attacking healthy green (*Fraxinus pennsylvanica* Marsh.), black (*F. nigra* Marsh.), and most importantly, white ash (*F. americana L.*) in northern North America. Tree mortality is high and rapid. Attempts at eradication appear to be failing, but nonetheless a useful survey system is required for this pest. There is evidence that other *Agrilus* spp. use color, sound, and semiochemicals to locate potential hosts. This study reports the effect of trap color and placement height on catch rates of adult *A. planipennis*.

Purple sticky traps caught significantly more borers than all other colors tested at both the 1.8 m and 6.1 m placement heights of the traps. Moreover, significantly greater numbers of borers were caught at the 1.8 m height than at the 6.1 m height with purple-colored traps. Therefore, purple-colored traps suspended at the 1.8 m height should be sufficient at detecting borers until useful semiochemicals are developed for this pest. This type of detection survey is useful because flying adult borers are recovered before large numbers of borer exit holes and crown dieback are detected in host trees.

**Sampling Procedure**

Purple panels are the most efficient color in trapping adult *A. planipennis*. Using plastic cable ties, tie four 37.5 x 60 cm corrugated plastic panels (0.26 cm thick; Coroplast, Dallas, TX) together to form an open-ended box. Attach a stainless steel umbrella rig (Zing Products, Westport, MA) to each open end of the box to maintain the shape of the trap. Attach two ash logs, 3.8 cm in diameter and 50 cm long, to the steel spreaders inside the box as an attractant. Bait logs should be enclosed entirely by the box trap. Suspend the trap 1.8 m above ground from the crown of an ash tree. Coat the outside of each panel with Pestick insect trapping glue (Hummert International, Earth City, MO). Check traps bi-weekly for adults.

**Notes**

No information was provided regarding the spacing of box traps within a given area.

An improved trap consisting of a three-sided prism of corrugated purple plastic and baited with attracted volatiles is now recommended for detection of *A. planipennis* (Crook et al. 2008; see our review in this volume), but the original box trap baited with ash logs may be useful for some surveys. Also see our review of Francese et al. (2008) in this volume for additional information regarding trap placement for *A. planipennis*.

**References**

# Crook, D. J.; Khrimian, A.; Francese, J. A.; Fraser, I.; Poland, T. M.; Sawyer, A. J.; Mastro, V. C. 2008. Development of a host-based semiochemical lure for trapping emerald ash borer *Agrilus planipennis* (Coleoptera: Buprestidae). Environmental Entomology 37: 356-365.

# Francese, J. A.; Oliver, J. B.; Fraser, I.; Lance, D. R.; Youssef, N.; Sawyer, A. J.; Mastro, V. C. 2008. Influence of trap placement and design on capture of the emerald ash borer (Coleoptera: Buprestidae). Journal of Economic Entomology 101: 1831-1837.

# Emerald Ash Borer

## *Agrilus planipenis* Fairmaire

### Coleoptera: Buprestidae

Francese, J. A.; Oliver, J. B.; Fraser, I.; Lance, D. R.; Youssef, N.; Sawyer, A. J.; Mastro, V. C. 2008. Influence of trap placement and design on capture of the emerald ash borer (Coleoptera: Buprestidae). Journal of Economic Entomology 101: 1831-1837.

**Objective**

To evaluate horizontal and vertical trap placement for flying *A. planipennis* in detection surveys; to evaluate trap color within and outside of an ash woodlot; to evaluate the efficacy of trap design.

**Abstract**

Emerald ash borer is an established, exotic woodborer attacking healthy green (*Fraxinus pennsylvanica* Marsh.), black (*F. nigra* Marsh.), and most importantly, white ash (*F. americana* L.) in northern North America. Tree mortality is high and rapid. Attempts at eradication appear to be failing, but nonetheless a useful survey system is required for this pest. There is evidence that other *Agrilus* spp. use color, sound, and semiochemicals to locate potential hosts. This study reports the effect of trap design, color, and placement height and distance in relation to an ash woodlot on catch rates of adult *A. planipennis*.

Purple traps caught significantly more *A. planipennis* than red or white traps. Purple traps caught significantly more *A. planipennis* in fields and along edges of woodlots than inside woodlots. Four-sided box traps caught more *A. planipennis* than crossvane traps, while two-panel traps and three-sided prism traps caught as many beetles as the other trap designs. The box, panel, and prism traps caught more beetles per square meter of flat trap surface than the crossvane traps. In general, the authors recommend the use of the prism trap for sturdiness, ease of construction, and economy. Prism traps hung at 13 m caught more beetles than those hung at 6 m, and traps hung at 13 and 6 m caught more beetles than those set at 1.5 m. Greater captures in traps hung at canopy height (13 m) likely reflect the adult activity of *A. planipennis* occurring predominately in the canopy. Placing traps at canopy height requires additional effort (e.g., the use of a bucket truck or tree-climbing equipment), but increases the chances of detecting the presence of *A. planipennis* within a stand.

**Sampling Procedure**

Purple is the most efficient color in trapping adult *A. planipennis*. Three-sided prism traps are recommended for sturdiness, ease of construction, and economy. Construct traps out of

corrugated plastic panels (0.26 cm thick; Coroplast, Dallas, TX) (Fig. 2; also described in our review of Crook et al. 2008 in this volume). Attach a three-arm modified stainless steel umbrella rig spreader (Zing Products, Westport, MA) to the top of each trap using plastic cable ties (Fig. 2). Coat the outside of each panel with Pestick insect trapping glue (Hummert International, Earth City, MO). Set each prism trap at a height of 13 m in the midcrown of an ash tree. Traps can be checked easily if hung from a rope attached to the umbrella spreader and using a pulley attached to an upper branch. Space traps by 15 m. Deploy traps before adult flight activity during the summer (or before June) and remove trapped adults each week.

Purple panel traps may be useful if traps are set at heights of 3 m or lower. Attach two 15.2 cm wide by 91.4 cm tall panels of corrugated purple plastic (0.26 cm thick; Coroplast, Dallas, TX) to a steel rebar pole (1.27 cm diam.) (Fig. 1). The top of the first panel should be hung at 0.91 m above ground and the top of the second panel should be hung above the first on the same pole at 3.0 m above ground, with 2.1 m in between the two panels. Coat each side of both panels with insect trapping glue. Set purple panel traps outside of woodlots containing ash trees, either along the edges of the woodlot or in adjacent fields. Deploy traps before adult activity during the summer (or before June) and remove trapped adults each week.

If using the four-panel box trap (described in our review of Francese et al. 2005 in this volume), hang traps at 1.5 m above ground using L-shaped steel rebar poles (1.27 cm diam.) in fields adjacent to woodlots. Coat the outside of each panel with Pestick insect trapping glue. Space traps by 15 m. Deploy traps before adult flight activity during the summer (or before June) and remove trapped adults each week.

**Notes**

Although not specified, consider deploying prism traps in the canopies of ash trees directly along the edges of a woodlot and not within the woodlot.

The results of a greater trap capture of *A. planipennis* at 13 and 6 m heights are in contrast with those of Francese et al. 2005, who reported that greater numbers of adults were caught at the 1.8 m height than at the 6.1 m height using purple-colored box traps (see our review in this volume).

**References**

# Crook, D. J.; Khrimian, A.; Francese, J. A.; Fraser, I.; Poland, T. M.; Sawyer, A. J.; Mastro, V. C. 2008. Development of a host-based semiochemical lure for trapping emerald ash borer *Agrilus planipennis* (Coleoptera: Buprestidae). Environmental Entomology 37: 356-365.

# Francese, J. A.; Mastro, V. C.; Oliver, J. B.; Lance, D. R.; Youssef, N.; Lavallee, S. G. 2005. Evaluation of colors for trapping *Agrilus planipennis* (Coleoptera: Buprestidae). Journal of Entomological Science 40: 93-95.

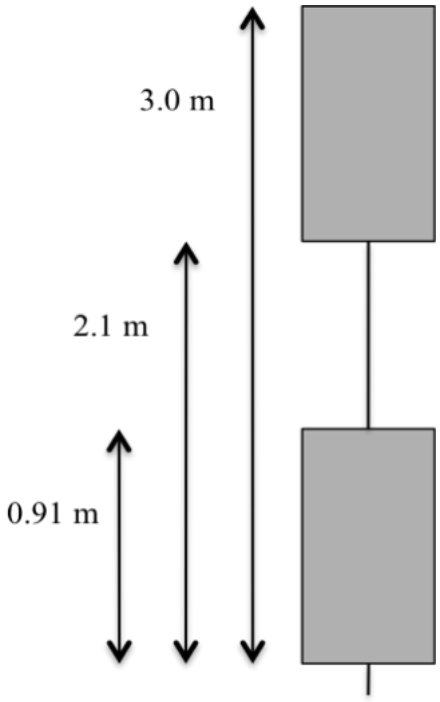


Fig. 1. Purple panel trap used for emerald ash borer. Figure modified from Fig. 1, Francese et al. 2008, Journal of Economic Entomology 101: 1831–1837.

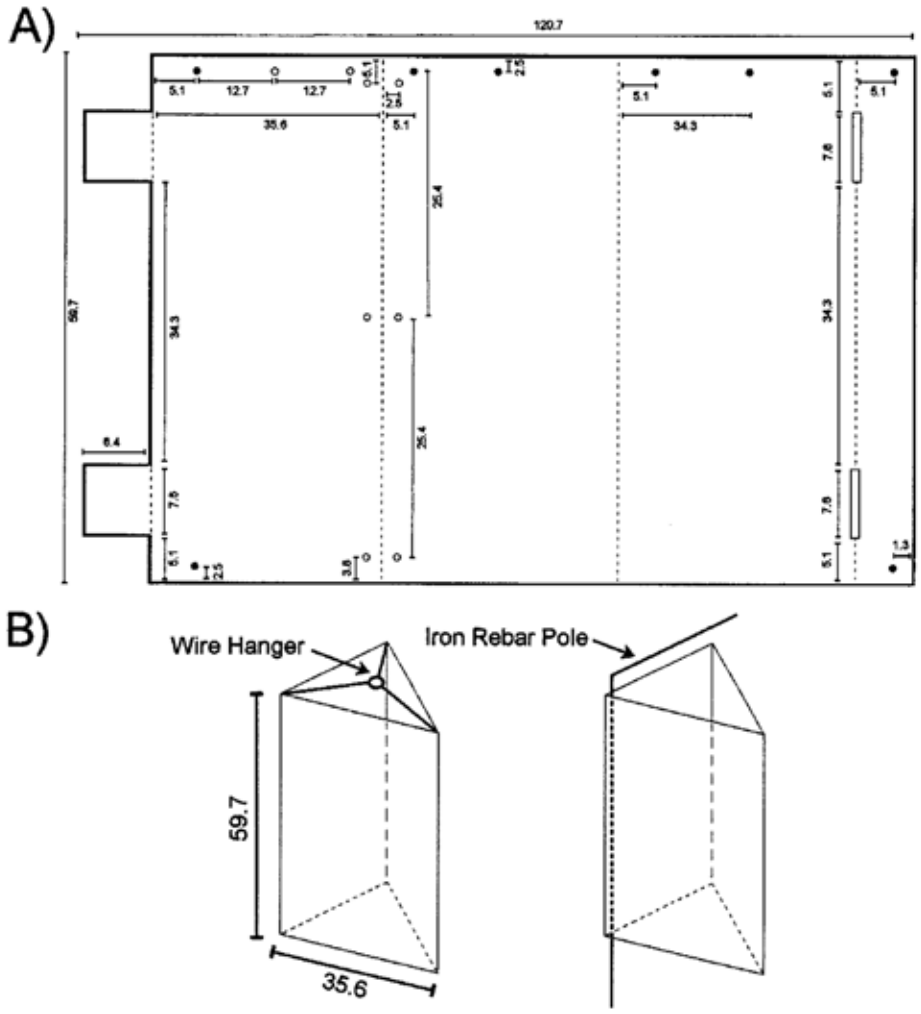


Fig. 2. Emerald ash borer prism trap used in 2006 and 2007. (A) Schematic of a prism trap cut from a single sheet of corrugated plastic. White circles represent holes to be used for attachment points to an iron rebar pole if the trap is to be hung at ground level. Black circles represent holes to be used for attachment points to a wire trap hanger if the trap is to be hung from a tree or other high place. (B) Diagram of the assembled trap showing both a high setup (left) and a low setup (right). All units are in centimeters.

**Fig. 2 reprinted as fair us under 17 USC § 107.**

# Red Oak Borer

## *Enaphalodes rufulus* Haldeman

### Coleoptera: Cerambycidae

Crook, D. J.; Fierke, M. K.; Mauromoustakos, A.; Kinney, D. L.; Stephen, F. M. 2007. Optimization of sampling methods for within-tree populations of red oak borer, *Enaphalodes rufulus* (Haldeman) (Coleoptera: Cerambycidae). Environmental Entomology 36: 589-594.

**Objective**

To develop a systematic sampling procedure that accurately estimates within-tree population densities of *E. rufulus* in northern red oak using a minimal number of samples.

**Abstract**

Red oak borer, *Enaphalodes rufulus* Haldeman, is a serious native pest of red oak, *Quercus rubra* L., and has been recently associated with oak decline, particularly in the Ozark National Forest in Arkansas. This cerambycid can kill stressed trees, such as those affected by oak decline. An accurate method of estimating *E. rufulus* populations through destructive sampling has been developed (Fierke et al. 2005a), but it is labor intensive. A nondestructive, rapid estimation survey procedure has also been developed to classify tree populations of *E. rufulus* during epidemics (Fierke et al. 2005b).

Another sampling plan has been developed based on the minimum number of samples determined necessary for statistical accuracy while substantially reducing the labor requirement of Fierke et al. (2005a). This plan differs from Fierke et al. (2005b) in that it is also useful for non-epidemic population levels. Systematic sampling of seven bolts cut from boles of trees infested with *E. rufulus* produced root mean square errors below the 25% threshold of the measured parameters of current generation galleries and live *E. rufulus*. This plan is recommended as an optimal sampling method to monitor *E. rufulus* densities with acceptable statistical accuracy, but requiring fewer samples and reduced labor.

**Sampling Procedure**

Fell selected northern red oaks. Assess the presence of *E. rufulus* attack and emergence holes along the trunk to determine the height of infestation on each tree. Cut each trunk into seven 0.5-m sample bolts starting at 1.5–2.0 m high and continuing at 20, 40, 50, 60, 80, and 90% of the infested tree bole. Dissect bolts to determine the number of current generation galleries in the phloem and the density of live *E. rufulus* present in the tree. Bolts should be refrigerated at 2°C until dissection.

**Note**

The authors suggest that a more appropriate sampling method might be determined from their data tables for studies needing a higher level of statistical precision or when other population parameters, such as emergence holes in the bark or previous generation galleries in the heartwood, are being assessed. See the original publication for details.

**References**

# Fierke, M. K.; Kinney, D. L.; Salisbury, V. B.; Crook, D. J.; Stephen, F. M. 2005a. A rapid estimation procedure for within-tree populations of red oak borer (Coleoptera: Cerambycidae). Forest Ecology and Management 215: 163-168.

Fierke, M. K.; Kinney, D. L.; Salisbury, V. B.; Crook, D. J.; Stephen, F. M. 2005b. Development and comparison of intensive and extensive sampling methods and preliminary within-tree population estimates of red oak borer (Coleoptera: Cerambycidae) in the Ozark Mountains of Arkansas. Environmental Entomology 34: 184-192.

# Red Oak Borer

## *Enaphalodes rufulus* Haldeman

### Coleoptera: Cerambycidae

Donley, D. E.; Rast, E. 1984. Vertical distribution of the red oak borer, *Enaphalodes rufulus* (Coleoptera: Cerambycidae), in red oak. Environmental Entomology 13: 41-44.

**Objective**

To develop a sampling method for *E. rufulus* based on its vertical distribution during attacks in immature stands of red oak (*Quercus* spp.).

**Abstract**

Red oak borer, Enaphalodes rufulus Haldeman, attacks both red and white oak tree groups (*Quercus* spp.) in the eastern USA and southeastern Canada. Larvae feed on the phloem and sapwood of host trees and cause large economic losses in oak-hickory forests. Initial attacks are difficult to detect as only pinhole wounds are found on the bark, but emerging adults leave noticeable exit holes measuring 10–14 mm in diameter. Evaluation of damage and execution of control measures for *E. rufulus* have been based on sampling the 5 m basal section of trees between 10 and 30 cm dbh as this pest attacks trees at a uniform height and dbh. There is a need to develop a sampling method that will determine the *E. rufulus* population from the vertical distribution in immature oak trees, since attack density is inversely related to size for trees of this age.

Infested red oaks (*Quercus rubr*a L., *Q. coccinea* Muench., and *Q. velutina* Lam.) in immature stands in Indiana and Pennsylvania were examined for infestation by moderate populations of *E. rufulus*. Attack density, attacks per tree, and attacks per unit of bark surface were measured on cut trees among nine dbh classes (10.0, 12.5, 15.0, 17.5, 20.0, 22.5, 25.0, 27.5, and 30.0 cm). Attack height, attacks per tree, or attacks per unit of bark surface area did not vary between the two locations. Trees with 10–30 cm dbh had suitable wood for infestation from the ground line (0.06 m) to 22.4 m high, but *E. rufulus* attacked stems only between 0.07–17 m. Only 6 attacks were observed on limbs. Attack density decreased with tree size but attack height increased with dbh class. The authors concluded that at least 75% of *E. rufulus* attacks occur in the economically important basal 5 m of red oaks.

**Sampling Procedure**

Identify infested red oaks by inspecting the bark from the ground up to ≈23 m. Number each tree before cutting it down and sectioning the trunk into transportable pieces. In the lab, debark all sections with diameters of ≥7.5 cm outside the bark, which is the wood habitable by

*E. rufulus*. Record the height of each attack from the original groundline. Record the total attacks per tree and the vertical distance (height) of each infestation in the stem to the original groundline for each dbh class. Calculate the cumulative frequency of attack heights from all dbh classes by plotting attack height against the cumulated percentage of attacks.

**Notes**

Red oak stands were selected for this study based on the presence of moderate *E. rufulus* populations that warranted control measures, and the results of this study may differ from stands with low or high populations. No significant differences were detected in the number of *E. rufulus* attacks between peeled and unpeeled trunk sections, so managers may consider leaving the bark on the trunk sections to save time. Trees between 10–30 cm dbh are considered brood trees (Donley 1981) and are removed for control of *E. rufulus*.

**References**

Donley, D. E. 1981. Control of the red oak borer by removal of infested trees. Journal of Forestry 79: 731-733.

# Red Oak Borer

## *Enaphalodes rufulus* Haldeman

### Coleoptera: Cerambycidae

Fierke, M. K.; Kinney, D. L.; Salisbury, V. B.; Crook, D. J.; Stephen, F. M. 2005a. A rapid estimation procedure for within-tree populations of red oak borer (Coleoptera: Cerambycidae). Forest Ecology and Management 215: 163-168.

**Objective**

To develop a nondestructive procedure that quickly estimates the population levels of red oak borer in northern red oak, *Quercus rubra* L., during epidemics.

**Abstract**

Red oak borer, *Enaphalodes rufulus* Haldeman, is a serious native pest of red oak, *Quercus rubra* L., and has been recently associated with oak decline, particularly in the Ozark National Forest in Arkansas. This cerambycid can kill stressed trees, such as those affected by oak decline. An accurate method of estimating *E. rufulus* populations through destructive sampling has been developed (Fierke et al. 2005b), but it is labor intensive. A rapid estimation survey procedure was therefore developed to classify tree populations of *E. rufulus* during epidemics.

Overall, the nondestructive rapid estimation survey procedure correctly classifies red oak borer populations in ≥85% of sampled trees. Tree crown condition and red oak borer emergence holes on the basal 2 m of tree bole are used to classify trees into one of three categories ranging from Class 1 (low infestation) to Class III (high infestation). This plan requires <2 minutes to conduct on each tree, whereas the procedure of Fierke et al. (2005b) required >100 hours per tree.

**Sampling Procedure**

Assess the percentage of crown dieback on an individual tree using the procedures described by Starkey et al. (2000) and in USDA (2001). Assign a crown condition class (CCC) to the tree following the rating scale for percent defoliation in the crown as presented in Table 1. Count the number of red oak borer emergence holes in the first 2 m of height on the tree bole. Assign a basal emergence hole (BEC) class to the tree based on the number of tallied emergence holes following the scale presented in Table 1. Sum the CCC and BEC to obtain the rapid estimation index (REI), which ranges in value from 0¬–7. Reference Table 1 to determine the rapid estimation procedure (REP) class for the individual tree based on the calculated REI value. Class I and Class II trees are considered to have a low and moderate

infestation level, respectively. Class III trees have a high infestation of *E. rufulus* with dead or mostly dead crowns, numerous emergence holes, and imminent tree mortality. Land managers can use these REP classes to estimate *E. rufulus* population levels and the extent of the infestation throughout stands of red oak, and base management decisions on this information.

**Notes**

This procedure is useful for rapidly estimating populations of red oak borer in a tree during epidemics. However, the authors caution against using it with endemic populations as Class I trees in this study had greater numbers of *E. rufulus* than expected given the levels previously reported in the literature for endemic conditions. Further work is required to determine the number of trees needed to sample in a stand or forest in order to estimate red oak borer populations at specified levels of fixed precision. See Crook et al. (2007) in this volume for information regarding a sampling plan for *E. rufulus* using a minimal number of samples.

**References**

# Crook, D. J.; Fierke, M. K.; Mauromoustakos, A.; Kinney, D. L.; Stephen, F. M. 2007. Optimization of sampling methods for within-tree populations of red oak borer, *Enaphalodes rufulus* (Haldeman) (Coleoptera: Cerambycidae). Environmental Entomology 36: 589-594.

# Fierke, M. K.; Kinney, D. L.; Salisbury, V. B.; Crook, D. J.; Stephen, F. M. 2005b. Development and comparison of intensive and extensive sampling methods and preliminary within-tree population estimates of red oak borer (Coleoptera: Cerambycidae) in the Ozark Mountains of Arkansas. Environmental Entomology 34: 184-192.

Starkey, D.; Mangini, S.; Oliveria, F.; Clarke, S.; Bruce, B.; Kertz, R.; Menard, R. 2000. In: Forest Health Evaluation of Oak Mortality and Decline on the Ozark National Forest, 1999. Alexandria, LA: U.S. Department of Agriculture, Forest Service, Forest Health Protection.

(USDA) U.S. Department of Agriculture, Forest Service. 2001. Forest inventory and analysis Southern Research Station Field Guide. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Table 1. Rapid estimation procedure variables assessed in the field include crown condition and number of basal emergence holes.

| Crown condition | CCC | Emergence holes <2m | BEC | REI | REP class |
|---|---|---|---|---|---|
| <1% dieback | 0 | 0 | 0 | 0, 1 | Class I |
| 1–33% dieback | 1 | 1–5 | 1 | | |
| 34–66% dieback | 2 | 6–20 | 2 | 2, 3, 4 | Class II |
| 67–99% dieback | 3 | >20 | 3 | | |
| Dead | 4 | | | >4 | Class III |

Summation of these variables yields indices that were used to classify trees into REP infestation history classes. Abbreviations: CCC, crown condition class; BEC, basal emergence hole class; REI, rapid estimation index (CCC + BEC).

**Table 1 reprinted with permission from Elsevier Limited, granted June 8, 2009.**

# Mountain Pine Beetle

## *Dendroctonus ponderosae* Hopkins

### Coleoptera: Curculionidae

Safranyik, L.; Linton, D. A. 2002. Line transect sampling to estimate the density of lodgepole pine currently attacked by mountain pine beetle. Inform. Rpt. BC-X-392. Victoria, B. C.: Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre; 10 p.

**Objective**

To develop an efficient line transect method for estimating densities of trees infested by *D. ponderosae*, as judged by signs of recent beetle activity.

**Abstract**

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is a serious pest of lodgepole pine, *Pinus contorta* Dougl. ex Loud, in western North America. Other hosts include ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., sugar pine, *Pinus lambertiana* Dougl., and western white pine, *Pinus monitcola* Dougl. ex D. Don. Generally *D. ponderosae* will attack host pines stressed by mechanical or fire damage, growing on poor sites, attacked by pathogens or other insect pests, or are overmature or overcrowded. During outbreaks of *D. ponderosae*, even healthy trees may be attacked and extensive tree mortality may occur.

Regression analysis was used to determine the probability of correctly identifying lodgepole pines attacked by *D. ponderosae* located at varying distances from a transect line. Two cruisers independently walked and counted all infested trees along 36 50-m transects. Fixed plots were established over the center of each transect and all trees within each plot were examined for infestation. Prism sampling was also conducted at three locations along the transect line.

The relationship between the probability of detecting an infested tree and the perpendicular distance of an infested tree from the transect line was used to construct a detection curve (i.e. , numbers of infested trees observed along the transect vs. the distance of observed trees from the transect). The detection curve was used to estimate $\hat{u}$ using the following equation:

$$\hat{A} = n/2L\hat{u}$$

where $\hat{A}$ = the general estimator of infested trees per unit area, $n$ = the number of trees observed with an active infestation, $L$ = transect length in meters, and $\hat{u}$ = an estimate of one half of the effective strip width about the line transect. Line transects conducted in southern British Columbia indicated that the density of currently infested lodgepole pines per hectare could be determined as $\hat{A} = 10{,}000nb/La^2$, where $b$ and $a$ are the slope and intercept of the

detection curve and the other variables are defined as above. The estimate of $\hat{A}$ did not differ from estimates from the fixed plots and prism plots, but the line transect method took only 2–3 minutes on a 50-m line compared to approximately 15 minutes for conducting fixed or prism plots along the same ground. While experience in recognizing recently infested trees did not appear to affect the average density of infested trees identified in this study, each cruiser should develop a personal detection curve and equation for estimating infested trees using this method. If cruisers work in pairs, the detection curve data for each pair can be combined into a single curve.

**Sampling Procedure**

Each cruiser should develop a personal detection function by conducting preliminary transect surveys. The total length of the preliminary transect should be long enough that a cruiser sights a minimum of 200 infested trees, but this minimum can be divided among separate transects.

Set a transect by pulling a 50-m tape taut on the ground. Walk along the length of this transect and tally all trees with signs of recent *D. ponderosae* activity on one side of the transect. Keep to a walking pace without stopping to examine any trees in detail. When a suspected infested tree is seen along the transect, record the distance of the tree along the 50-m tape from the start of the transect line. At the end of the transect, return to the starting point and proceed along the other side in the same manner.

Count and record the number of recently infested trees and their distances from the starting point on both sides of the transect, then measure and record the perpendicular distance of each observed tree from the transect line. Examine each observed tree to confirm that it is currently infested or not. Determine the maximum distance that a confirmed, attacked tree was observed from along the transect. Add 2 m to this distance to calculate the half-width of a fixed plot to be centered over the transect length. Examine each tree within the fixed plot and record whether it has a current infestation or not. Make note of all trees that cruisers did not observe from the transect.

Calculate the number of currently infested and noninfested trees per hectare using the fixed plot data. Sort the transect data into total trees per 2-m wide strips up to a maximum distance of 20 m from the transect line. Calculate the average proportions of confirmed infested trees, infested trees not observed from the transect, and trees misidentified as infested.

Construct a histogram for the mean number of confirmed, currently infested lodgepole pine trees detected by a cruiser along the transect (Y) against the distance of the trees from the transect line in 2-m increments (X). Estimate the value of $\hat{u}$ by integrating the detection curve from zero to a perpendicular distance equal to the x-intercept of a linear regression.

To use this method in practice, randomly establish transect lines through the area of interest and record the number of observed infested trees and the distance walked along the transect

for each observation. The appropriate total length of a transect line ($L$) can be estimated using the following formula:

$$L = (c/CV^2)(L_1/n_1)$$

where $c$ = the number of observed infested trees, $CV^2$ = the desired coefficient of variation, $L_1$ = the length of a preliminary walk along $L$, and $n_1$ = the number of observed infested trees along $L_1$.

Estimate the value of $\hat{u}$ as the integral from 0 to the point where the regression line intercepts the x-axis ($X = a/b$), with $a$ = the intercept and $b$ = the slope from the linear regression of the developed detection curve, so that $\hat{u} = a^2/2b$. Estimate the density of infested trees ($\hat{A}$) per hectare using the equation $\hat{A} = 10{,}000n/2L\hat{u}$, where $n$ = the number of currently infested trees observed along the transect, including any trees that might prove to be uninfested with later examination, and $L$ = the length of the transect.

**Note**

If trees are tallied on only one side of the transect, use the formula $\hat{A} = [n/2L\hat{u}]2$. Refer to the original publication for more detail on creating the detection curve and its use in estimating $\hat{u}$. A logistic regression may provide a better fit than a simpler linear regression.

# Mountain Pine Beetle

## *Dendroctonus ponderosae* Hopkins

### Coleoptera: Curculionidae

Wulder, M. A.; Dymond, C. C.; Erickson, B. 2004. Detection and monitoring of the mountain pine beetle. Info. Rpt. BC-X-398. Victoria, B.C.: Natural Resources Canada, Pacific Forestry Centre; 24 p.

**Objective**

To describe a method of estimating the population trend and overwintering mortality for *D. ponderosae*.

**Abstract**

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is a serious pest of lodgepole pine, *Pinus contorta* Dougl. ex Loud, in western North America. Other hosts include ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), sugar pine (*Pinus lambertiana* Dougl.), and western white pine (*Pinus monitcola* Dougl. ex D. Don). Generally *D. ponderosae* attacks host pines stressed by mechanical or fire damage, growing on poor sites, attacked by pathogens or other insect pests, or are overmature or overcrowded. Even healthy trees may be attacked and extensive tree mortality may occur during outbreaks of *D. ponderosae*.

Fixed-size bark samples offer a statistically valid means of determining the population trend and overwintering mortality of *D. ponderosae* within a stand (Shore 1985). Typically bark samples are 900 $cm^2$ and sample plots are <1 ha in size. The number of eggs and larvae, pupae and adults, and galleries present in the sample are used to calculate the average trend ratio within a stand of a given number of sampled trees. Stands can be classified as having an increasing, decreasing, or static population. Trend ratios from the fall and the spring can be used to determine the overwintering mortality of *D. ponderosae* occurring within a stand. Trend ratios should be used only to support the findings of aerial or ground surveys, but not replace them.

**Sampling Procedure**

Of particular interest are newly infested green trees near red attacked trees. These green attacked trees currently hold brood and will serve as the source of new infestations. Green attack trees should be located through ground surveys by starting near red trees and using a prism or strip cruising technique. These surveys should be done between September and October, and later again the subsequent spring. As potential brood trees are found in stands, remove a fixed size area of bark (ca. 900 $cm^2$) from each tree. Tally the number of eggs and

larvae, pupae and adults, and galleries present in the bark sample. Calculate the average trend ratio (*r*) for each stand using the following formula

$$r = \frac{\sum_{t}((y + o)/ g)}{t}$$

where *y* = the number of eggs and larvae, *o* = the number of pupae and adults, *g* = the number of galleries present in each sample, and *t* = the number of sampled trees. If *r* >4.0, then the population is increasing. If *r* <2.6, the population is decreasing. If 4.0 < *r* >2.6, then the population is static. Use the estimated trend ratio to support data collected in aerial and ground surveys, but not as a definitive infestation estimate for a given population.

If of interest, determine the percent of overwintering mortality (*r*) in each stand using the following equation:

$$r = \frac{(r\_fall - r\_spring)x100}{r\_fall}$$

where *r* = the average trend ratio, *r*_fall = *r* determined in the fall, and *r*_spring = *r* determined in the spring.

**Note**

The average trend ratio and percent of overwintering mortality should be used to support the interpretation of aerial and ground surveys of *D. ponderosae* infestations. They should not be used as the primary technique of assessing infestations. Ground crews doing brood survey work should be trained well and their work should be checked periodically for consistency and accuracy.

**Reference**

Shore, T. 1985. Forest insect and disease survey, Pacific Region: general instruction manual. Victoria, B.C.: Government of Canada, Canadian Forestry Service, Pacific Forest Research Center; 125 p.

# Douglas-fir Beetle

## *Dendroctonus pseudotsugae* Haldeman

### Coleoptera: Curculionidae

Negrón, J. F.; Schaupp, W. C.; Johnson, E. 2000. Development and validation of a fixed-precision sequential sampling plan for estimating brood adult density of *Dendroctonus pseudotsugae* (Coleoptera: Scolytidae). Canadian Entomologist 132: 119-133.

**Objective**

To develop a sequential estimation plan for the assessment of *D. pseudotsugae* population trends.

**Abstract**

The Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, is a serious insect pest of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, in western North America. Large populations of this bark beetle can destroy vast areas of Douglas-fir. Sampling procedures for Douglas-fir beetle attacking Douglas-fir are time-consuming. A sequential estimation procedure was developed to address this issue.

Log variance was related positively to log mean *D. pseudotsugae* brood adults (log variance = 0.491 + 1.687(log mean); $r^2 = 0.54$). The intercept and slope from this equation was fitted into the equation given by Green (1970) to produce the sequential sampling stop lines at the 0.1, 0.2, and 0.3 levels of fixed precision. The number of samples required to estimate *D. pseudotsugae* populations, across all beetle densities, was 91, 20, and 8 at the 0.1, 0.2, and 0.3 levels of fixed precision, respectively.

**Sampling Procedure**

Identify the stand or area to be sampled. Throughout the stand, randomly select trees successfully attacked by *D. pseudotsugae* and with a diameter of at least 25.4 cm. Remove a vertically oriented sample of bark 30.5 long by 15.25 cm wide from the south side of the tree. Collect samples at 1.37 m above ground. Chill samples until they can be processed. Dissect and examine each bark sample and tally all brood adults and gallery starts present in the sample. Reference Fig. 2 and continue sampling additional trees until the line of the desired level of fixed precision is crossed, at which point sampling is stopped. A precision level of 0.2 may be adequate for monitoring *D. pseudotsugae* populations in order to make management decisions.

After sampling has stopped, calculate the emergence ratio for the stand using the following formula:

$$\text{Stand emergence ratio} = \frac{\text{cumulative number of brood adults}}{\text{(cumulative number of gallery starts x 2 beetles)}}$$

Land managers should consider management strategies for *D. pseudotsugae* when increasing emergence ratios signal the presence of growing pest populations.

**Note**

Data were collected from a few sites in Colorado. Use this plan with caution until it can be validated with data from other areas where *D. pseudotsugae* is present.

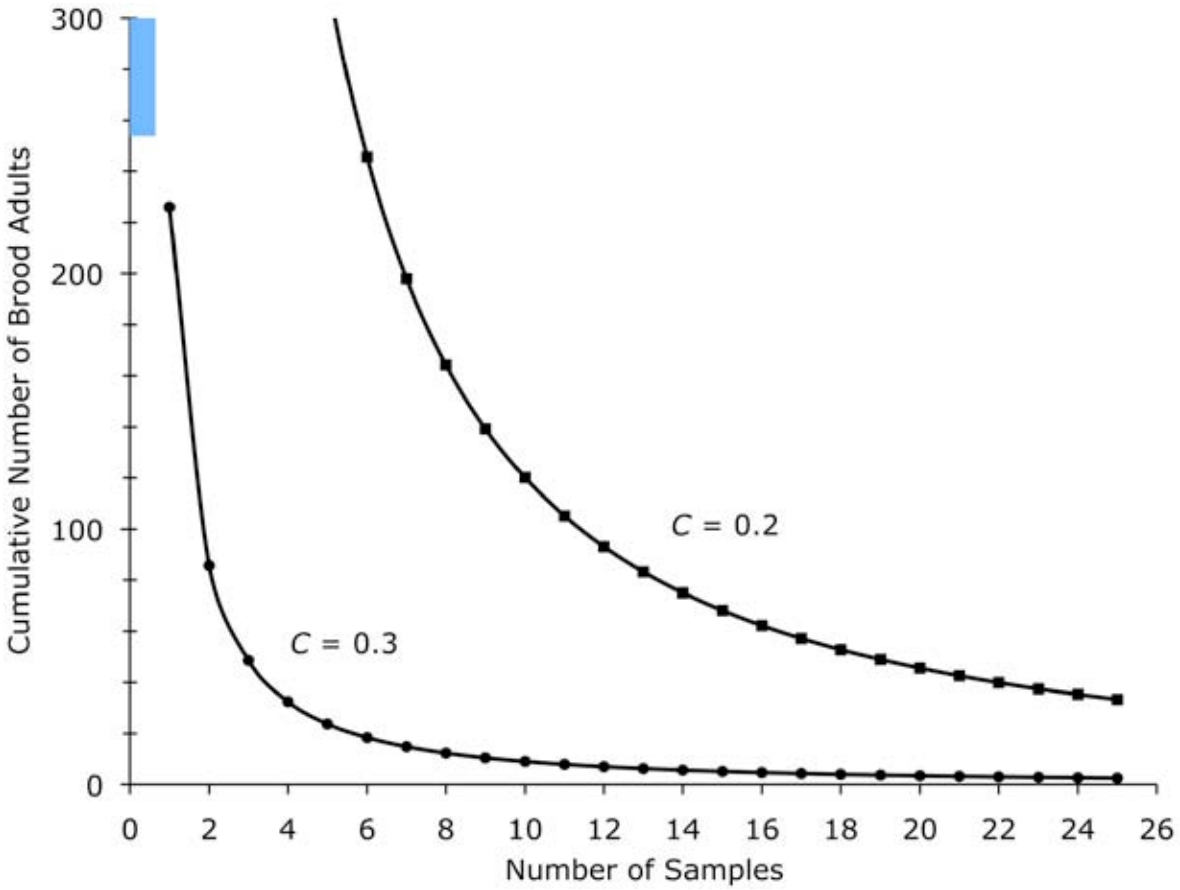


Fig. 2. Sequential sampling stop lines for Dendroctonus pseudotsugae brood adults in 30.5 cm x 15.2 cm (0.046 m2) samples with precision levels (C) of 0.2 and 0.3, Pike-San Isabel National Forest, Colorado, 1997–1998.

**Figure 2 modified and reproduced with permission by the authors, granted April 16, 2009. The C = 0.1 level of fixed precision, found in the original publication, has been omitted due to the large sample sizes required to estimate densities of brood adults.**

# Spruce Beetle

## *Dendroctonus rufipennis* (Kirby)

### Coleoptera: Curculionidae

Fiddick, R. L. 1978. Use of felled trap trees as a supplementary technique for reducing spruce beetle infestation. Information Rpt. BC-P-23. Victoria, B. C.: Environment Canada, Forestry Service, Pacific Forest Research Centre; 2 p.

**Objective**

To describe a method of predicting increased attacks by *D. rufipennis*.

**Abstract**

Spruce beetle, *Dendroctonus rufipennis* (Kirby), is a serious pest of spruce trees (*Picea* spp.) in North America. Englemann spruce (*Picea engelmannii* Parry ex Engelm.), white spruce [*Picea glauca* (Moench) Voss] and Sitka spruce (*Picea sitchensis* Carr.) are commonly attacked. Large-diameter, mature trees are preferred hosts. The life cycle of *D. rufipennis* typically takes two years to complete, but can be accelerated if summers are long, hot, and dry. Outbreaks of *D. rufipennis* may last 2–5 years and can produce high levels of mortality in mature spruce trees. Felled trap trees can be used to predict an increase in attacks by *D. rufipennis*, especially during hot, dry years that accelerate brood development. If pupae and adults represent >50% of the brood found in 20–25 trap trees, there is an increased chance of *D. rufipennis* attacking more trees the subsequent spring.

**Sampling Procedure**

Locate and identify infested spruce stands with ground surveys. In the fall, examine brood development on 20–25 spruce trees by removing 0.05 m2 of bark on each tree and tallying the percentage of *D. rufipennis* in each life stage present (i.e., larva, pupa, or adult). If pupae and adults represent >50% of the brood present on 20–25 trees, there is an increased chance of more trees being attacked the subsequent spring. Hot, dry summers tend to accelerate beetle development and favor building populations the following year.

# Spruce Beetle

## *Dendroctonus rufipennis* (Kirby)

### Coleoptera: Curculionidae

Hansen, E. M.; Bentz, B. J.; Munson, A. S.; Vandygriff, J. C.; Turner, D. L. 2006. Evaluation of funnel traps for estimating tree mortality and associated population phase of spruce beetle in Utah. Canadian Journal of Forest Research 36: 2574-2584.

**Objective**

To relate trap capture of *D. rufipennis* to tree mortality within a given area and predict the size of a local population.

**Abstract**

Spruce beetle, *Dendroctonus rufipennis* (Kirby), is a serious pest of spruce trees (*Picea* spp.) in North America. Englemann spruce (*Picea engelmannii* Parry ex Engelm.), white spruce [*Picea glauca* (Moench) Voss] and Sitka spruce (*Picea sitchensis* Carr.) are commonly attacked. Large-diameter, mature trees are preferred hosts. The life cycle of *D. rufipennis* typically takes two years to complete, but can be accelerated if summers are long, hot, and dry. Outbreaks of *D. rufipennis* may last 2–5 years and can produce high levels of mortality in mature spruce trees.

Researchers in Utah related captures of *D. rufipennis* in Lindgren funnel traps (Lindgren 1983) to population phase and a relative measure of tree mortality for the current and subsequent year in Englemann spruce. Populations of *D. rufipennis* could be separated into endemic (<2 mass-attacked trees per ha) or epidemic (≥2 mass-attacked trees per ha) phases based on total trap capture. Capture of ≈842 beetles from a single trap over a flight period is considered a threshold delineating the endemic and epidemic phases of *D. rufipennis* for the current and subsequent year relative to trap use. The epidemic phase is further indicated by the presence of spillover attacks on susceptible host trees within 10 m of the funnel traps. Total trap capture was not useful in predicting the number of trees that were attacked, nor could suboutbreak populations *D. rufipennis* be distinguished using this technique. Land managers can use the population phase of *D. rufipennis* and associated level of tree mortality predicted by total trap capture as an aid in making management decisions.

**Sampling Procedure**

Bait each 16 unit Lindgren funnel trap with a two-component lure consisting of racemic frontalin and +5/–95 α-pinene (PheroTech, Inc., Delta, B.C.). Load frontalin and α-pinene

separately in 400 µL and a 1.8 mL centrifuge tubes, respectively. Release rates for frontalin and α-pinene should be 2.8 and 1.3 mg per day at 20°C, respectively. Include an insecticidal strip in each trap to kill any beetles attracted to the trap.

Multiple funnel traps should be installed in stands of Engelmann spruce, with >800 m between traps to avoid inter-trap bias. Hang traps so the trap cup is 1.5 m above ground and >0.25 m from any bole. Service traps weekly during the operational period. Traps should remain in place throughout the entire flight period of *D. rufipennis*, approximately late May through mid-August. Replace α-pinene lures in mid-summer.

Total trap capture of under ≈842 beetles per trap indicates that the population is in an endemic phase, whereas a trap capture of ≈842 beetles or more indicates that the population is in an epidemic phase. The relative density of mass-attacked trees and the predicted level of tree mortality associated with endemic and epidemic populations of *D. rufipennis* are provided below:

| Total trap capture over flight period | Population phase | Associated density of mass-attacked trees | Predicted host tree mortality |
|---|---|---|---|
| >842 beetles per trap | Endemic | <2 mass-attacked trees per ha | Few, if any, trees within 10 ha infested in current or subsequent year |
| <842 beetles per trap | Epidemic | ≥2 mass-attacked trees per ha | Substantial tree mortality within a 10 ha area in the subsequent year, if not the current year |

At the end of the flight period, examine susceptible host trees within 10 m of the funnel trap for evidence of mass-attack by *D. rufipennis*. Spillover attacks within 10 m of the funnel trap are a further indication of an epidemic population phase.

**Note**

Not all populations of *D. rufipennis* may respond in similar ways to the combination of lures and trap type used in this study. The recommendation made from this study should be used with caution until verified in other regions.

**Reference**

# Lindgren, B. S. 1983. A multiple funnel trap for scolytid beetles (Coleoptera). Canadian Entomologist 115: 299-302.

# Scolytid Beetles

## Coleoptera: Curculionidae

Lindgren, B. S. 1983. A multiple funnel trap for scolytid beetles (Coleoptera). Canadian Entomologist 115: 299-302.

### Objective

To evaluate the effectiveness of a multiple funnel trap in capturing scolytid beetles.

### Abstract

The multiple funnel trap, also known as the Lindgren funnel trap, revolutionized the trapping of ambrosia and bark beetles. The trap is constructed of suspended, vertically aligned funnels baited with pheromone lure and directing captured insects into a collection jar at the bottom of the trap. This design minimizes the loss of attracted beetles, a problem encountered with window flight traps when beetles resume flight after colliding with the vertical panes. Beetles were captured more easily by the funnel trap than the perforated entrances of stovepipe traps. Furthermore, the multiple funnel trap collected beetles in a jar at the bottom of the trap, avoiding the need for the adhesive used in sticky traps. Traps are reusable and are serviced quickly, saving both time and money.

### Sampling Procedure

The multiple funnel trap is now available commercially, but was originally constructed of suspended, vertically aligned funnels (16 cm tall; 20 cm upper diameter; 3.5 cm lower diameter) made from 0.2 mm vinyl sheets. Funnels were stapled to three twill tapes (16 mm wide) at 7.5 cm intervals. Traps consisting of eight funnels provided 0.33 $m^2$ trapping surface, which could be adjusted as needed by adding or removing funnels, or by using funnels of a different size.

Each trap could be collapsed for portability. A pheromone lure was placed under an inverted plastic tray (30 cm diameter) set above the top funnel. The lid of a collection container was attached at the neck of the lowest funnel and the jar screwed onto it. The collection container could hold a killing substance and preservative, or filled with suitable material to hold live insects. A hole piercing the side of the collection container allowed excess rainwater to drain. Traps are hung from sturdy hooks welded to iron pipe or rods. Avoid installing traps under trees where leaves may fall and clog the funnels.

# GLOSSARY

# Glossary

| Terms | Definition |
|---|---|
| accuracy | The degree of closeness of a measured or calculated quantity to its actual (true) value. |
| aesthetic injury level | An action threshold for treatment based on aesthetic impacts on a plant |
| aestivate | To enter into diapause during a warm or dry season |
| apical dominance | In plants, the tendency of an apical bud to produce hormones that suppress the growth of the lateral buds below it on a stem. |
| beat sheet | A hand-held tool constructed of a square piece of light colored fabric and often supported by a cross frame which is used to catch insects when sampling. |
| binomial sampling | A sampling method that involves recording only the presence or absence of members of the population being sampled (such as an insect pest) on a sample unit (such as a leaf), rather than counting the numbers of individuals; presence/absence sampling. |
| chorion | The outer shell or covering of an arthropod egg. |
| coefficient of variation | A statistical measure of the dispersion of data points in a data series around the mean. It represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from each other. |
| components of variance | When factors being tested are random, a type II ANOVA model is used to determine how much of the variance in an experiment is due to difference in treatment means, and how much is due to random error about these means. |

| | |
|---|---|
| conspecific | An organism belonging to the same species of another |
| crown | Branches, leaves and reproductive structures extending from the trunk or main stems; highest point of tree. |
| cultivar | A cultivated variety or strain of a plant produced by horticultural techniques and not normally found in wild populations. |
| degree days | A measurement of thermal units required for growth and development of an arthropod, other cold-blooded animals, or plants. Daily Mean temperature - base development temperature provides degree-days for that day. Add degree-days over many days to get to an accumulated amount that can represent a certain stage of growth specific to that organism. |
| delta trap | A triangular shaped trap with a sticky catch surface often used to attract lepidopteran pest species with a pheromone lure. |
| density-dependent mortality | Rate of mortality that is influenced by increasing population density (either positively or negatively). Ex. The greater the population of a host, the higher the percentage of hosts parasitized by a parasitoid. |
| density-independent mortality | Rate of mortality that is not influenced by its density (either positively or negatively). Ex. Extreme weather factors can kill a percentage of a population regardless of the population size |
| diapause | A period of genetically controlled arrested development and reduced metabolic rate, during which growth, differentiation and metamorphosis cease. |
| eclose | For an insect to emerge from the cuticle of the pupa, the cocoon, or puparium; or in hemimetabolous insects, from the cuticle of the last nymphal instar. |
| economic injury level | The lowest population density of a pest that will cause economic damage; amount of pest injury, which will justify the cost of control. |

| | |
|---|---|
| economic threshold | The level of pest population or damage level one needs to treat at to prevent the reaching of the economic injury level. |
| endemic | Native or limited to a specific economic injury level. |
| enumerative sampling plan | A sampling plan that incorporated continuous values as sampling measures. |
| frass | Solid larval excrement exuded from the anus. |
| fundatrices | In aphids, the wingless parthnogenic female that emerges in the spring for overwintering eggs. |
| gall | Abnormal growth of plant tissues stimulated by animal or other biotic organism activity on or in the plant tissue. |
| hyperbolic curve | Any of a set of six functions related, for a real or complex vairable *x*, to the hyperbola in a manner analogous to the relationship of the trigonometric functions to a circle. |
| immunoassay | A technique that uses the binding of antibodies to antigens to identify and measure the presence of certain substances. |
| indicator plants | A species whose presence, absence, or relative well-being in a given environment is indicative of the health of its ecosystem as a whole. The phenological state of plant development can be used to time or synchronize with other biotic activites. |
| leaf plastochron index | Way of measuring the age of plants and leaves on a morphological rather than a temporal time scale. |
| linear regression | Models the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. The most common method for fitting a regression line is the method of least-squares. This method calculates the best-fitting line for the observed data by minimizing the sum of the squares of the vertical deviations from each data point to the line. |

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| logarithmic regression | Regression done on a log scale. Data may be transformed to a log scale when the variance of *Y* changes with changing values of *X*. |
| logistic regression | A regression modle for binomially distributed response/dependent variables that is useful for modeling the probability of an event occurring as a function of other factors. |
| operculum | A lid or cover. |
| oviposition | The act of laying eggs. |
| ovisacs | An egg-containing capsule. |
| parthenogenesis | An asexual form of reproduction found in females where growth and development of embryos occurs without fertilization by a male. |
| pheromone trap | Any of various containers baited with sexual scent, used to ure and entrap pest or disrupt mating habits. |
| precision | The degree to which further measurements or calcualtions show the same or similar results. |
| prism sampling | A point sampling method commonly used to inventory trees in which each tree has a given plot size in relation to its size. It is easily applied with an optical wedge prism and is appropriate for determining basal area and density, as well as for assessing volume and stand structure. |
| probit | A unit of measurement of statistical probability based on deviations from the mean of normal distribution. |
| progredientes | One of two generations of hemlock woolly adelgid found in late spring developing on hemlock trees. Progredients are comprised of both wingless (parthenogenic) and winged offspring (sexuparae), which develop simultaneously. |
| radiograph | A photographic image produced on a radiosensitive surface by radiation other than visible light. |

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| raster | A data structure for maps based on grid cells. |
| scouting | The monitoring of pest populations and crop development to help growers make sound pest management decisions through knowledge of the pest and natural enemy populations. If used carefully, scouting will help prevent crop damage while eliminating unnecessary pest control treatments. |
| semiochemical | Any substance, produced by an organism that provokes a response in individuals of the same or different species. |
| sequential estimation | A method of estimating a parameter by analyzing a sample just large enough to ensure a previously chosen degree of precision. The fundamental technique is to take a sequence of samples, the outcome of each sampling determining the need for another sampling. The procedure is terminated when the desired degree of precision is achieved. |
| sequential sampling | A sampling method in which the number of samples is not fixed in advance. |
| sessile | Attached or fastened, incapable of moving from place to place; attached directly without a stem or petiole. |
| sexuparae | A winged portion of the progredientes generation of hemlock woolly adelgid found on hemlock trees in late spring. Sexupara, when fully developed, will leave hemlocks in search of a spruce species on which to oviposit. No suitable species is present in North America so this portion of the population dies before sexual reproduction occurs. |
| sistentes | One of two generations of hemlock woolly adelgid found in autumn and winter following a summer aestivation. This is a wingless, parthenogenetic generation that gives rise to progredientes. |
| stand | An arbitrarily determined cohort of trees considered as a single management unit. |
| stratified sampling | Grouping members of the population into relatively homogeneous subgroups before sampling. |

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| strip cruising | Where the diameters at breast height (dbh) of all trees within a certain distance of a center line are tallied and the volume of wood on the area sampled and then on the total area of the forest stand are then calculated from these diameter measurements. |
| Taylor's power law | An equation used to related variance to the mean population size: $S^2 = a\mu^b$, where a and b are constants, a is a sampling parameter while b is an index of aggregation characteristic of the species, $s^2$ is the variance, $\mu$ is the mean. |
| terminal leader | The primary shoot of a plant. |
| transect | A path along which one records and counts occurrences of the phenomenon of study (e.g. plants noting each instance). |
| type I error | Rejection of the null hypothesis when it is in fact true. |
| type II error | Not rejecting the null hypothesis when it is false. |
| vector | Mathematicial: Mapping data, which is stored as points, lines and/or polygons. |
| whorl | An arrangement of three or more leaves, petals or branches radiating from a single node. |
| wing trap | A type of paper/cardboard based pheomone trap used for sampling insect pests. |

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