Forest Health Technology Enterprise Team

TECHNOLOGY TRANSFER

Sampling Methods

Sampling Methods for Forest and Shade Tree Insects of North America

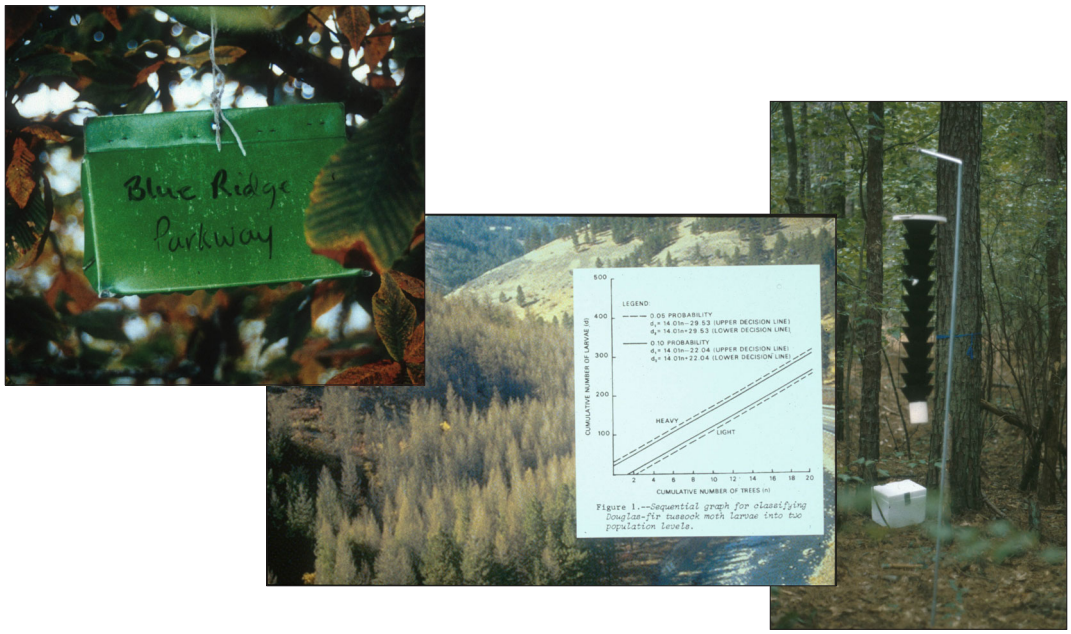

Figure 1.--Sequential graph for classifying Douglas-fir tussock moth larvae into two population levels.

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Sampling Methods for Forest and Shade Tree Insects of North America

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Preface

In a shade tree pest management course taught at Virginia Polytechnic Institute and State University, one of us (Scott M. Salom) was explaining the importance of sampling as an essential component of any integrated pest management (IPM) program. This explanation was followed by a presentation of some of the more common examples of sampling methods used for estimating insect populations. A student then asked if there was access to a compilation of this information for all forest and shade tree insect pests. The response was "no," that information for individual pests is in the scientific literature, much of it inaccessible to the average forester or arborist, either logistically or through the technical or scientific jargon used in the article that is likely unfamiliar to the general practitioner.

This exchange demonstrated a need to bring together all the information available on sampling methods for forest and shade tree insects, and to make it accessible in an unambiguous and comprehensive manner. The objectives of compiling this publication were to provide a valuable tool for natural resource professionals who are involved in pest management decision-making, and to identify key forest pests for which this type of information is lacking, and for which further research is warranted.

Although we searched the literature for three years, we inevitably were unable to locate all sampling papers, and perhaps missed others entirely. To fill these gaps, we are simultaneously developing a web site that will allow users to search for sampling procedures for individual pests. Our hope is to continually update the web site to provide a current resource detailing available sampling methods for forest insect pests (www. everest.ento.edu/~salom/Samplemeth).

We are pleased to present the results of our efforts, and hope you will find this text a useful resource for managing forest and shade tree insect populations.

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INTRODUCTION

Introduction

The forester or arborist that suspects significant pest activity may attempt to diagnose the problem by identifying the causal agent or its damage. According to integrated pest management principles, the mere presence of a pest does not warrant control. The population density of the pest or level of damage has to reach or exceed an action threshold before treatment is justified. This approach greatly reduces the amount of insecticide used and the cost of applying it or other tactics. However, a sampling plan must be developed to help individuals establish action thresholds and make accurate and judicious control decisions.

Management tools are constantly being developed for forest and shade tree pests; however, much of this information is scattered throughout the literature. Textbooks (Southwood 1978, Pedigo and Buntin 1994) and review articles (Strickland 1961, Kuno 1991) describe the theory and application of sampling techniques for estimating insect population densities and describing population distributions within a host habitat. Book chapters focus on types of sampling surveys used for forest and shade tree pests (Coulson and Witter 1984, Barbosa and Wagner 1989). Journal articles introduce the development of new sampling methods for estimating population densities and monitoring trends of individual species (Coffelt and Schultz 1994, Gargiullo and others 1983, Mason 1987, Stark 1952). Extension publications and conference proceedings often provide a how-to approach for individual sampling procedures that are used in pest management decision-making (Billings 1988, Fleischer and others 1992, McGraw and Hain 1979).

To compile the existing information on sampling procedures for forest and shade tree insect pests of North America, we conducted an exhaustive library search that yielded over 300 publications. Of these, we considered 123 appropriate for inclusion here, using the criterion that the publication had to describe a sampling procedure for use in pest management decision-making. This publication contains reviews of those 123 papers.

Using This Publication

The papers reviewed in this report have been categorized by five insect feeding groups:

Bud, shoot, and root insects
Defoliating insects
Piercing and sucking insects and mites
Seed and cone insects
Wood- and bark-boring insects

Within each group, the species are organized in alphabetical order, by order, family, and genus, with the common name listed first. For an individual species, a review of one or several original publications may be provided. Each review usually contains a citation, objective, abstract, sampling procedure, tables or figures, notes, and references. The objective provides a brief description of the objectives stated in the original publication, and describes the reasons why the study was conducted. The sampling methods used may not be explicitly stated in the objective if they simply served as a tool to achieve other objectives. The abstract provides a brief description of the pest, but focuses on the data collected and development of the sampling procedure in the original publication. The sampling procedure provides a detailed step-by-step description of how to employ the sampling method within a given habitat. Tables or figures may be included to help illustrate the procedure, and have either been taken directly from the original publication or redrawn. The original table and figure numbers have been retained for ease of comparison should you choose to consult the original publication. Notes may be included to put the paper in perspective in relation to other publications or to offer caveats concerning appropriate use or limitations of a procedure. When applicable, a references section completes the review. References beginning with an asterisk (*) are reviewed in this publication, and can be located using the alphabetical index at the end of this text. The publication concludes with a brief glossary of forestry and entomological terms that might be useful. If you encounter difficulties understanding or using certain sampling techniques, we recommend you refer to the original publication for further clarification.

References

Barbosa, P.; Wagner, M. R. 1989. Introduction to forest and shade tree insects. San Diego: Academic Press, Inc.; 639 p.

Billings, R. F. 1988. Forecasting southern pine beetle infestation trends with pheromone traps. In Payne, T. L.; Saarenmaa, H., editors. Integrated control of Scolytid bark beetles: proceedings of IUFRO Working Party and International Congress of Entomology Symposium; 1988 July 4; Vancouver, BC, Canada; 295-306.

Coffelt, M. A.; Schultz, P. B. 1994. Within-tree distribution and a fixed-precision-level sampling plan for the orangestriped oakworm (Lepidoptera: Saturniidae). Journal of Economic Entomology 87: 382-388.

Coulson, R. N.; Witter, J. A. 1984. Forest entomology—ecology and management. New York: John Wiley and Sons Inc.; 669 p.

Fleischer, S.; 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.

Gargiullo, P. M.; Berisford, C. W.; Pienaar, L. V. 1983. Two-stage cluster sampling for pine tip moths. Environmental Entomology 12: 81-90.

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

McGraw, J. R.; Hain, F. P. 1979. Spruce spider mite sampling system. Forest Research Notes. North Carolina State University; 6 p.

Pedigo, L. P.; Buntin, G. D. 1994. Handbook of sampling methods for arthropods in agriculture. Boca Raton, FL: CRC Press Co.; 714 p.

Southwood, T. R. E. 1978. Ecological methods with particular reference to the study of insects populations. New York: Chapman & Hall Corp.; 524 p.

Stark, R. W. 1952. Sequential sampling of the lodgepole needleminer, *Evagora milleri*. Journal of Economic Entomology 55: 491-494.

Strickland, A. H. 1961. Sampling crop pests and their hosts. Annual Review of Entomology 6: 201-220.

BUD, SHOOT, AND ROOT INSECTS

Pales Weevil

Hylobius pales (Herbst)
Coleoptera: Curculionidae

Fettig, C. J.; Salom, S.M. 1998. Comparisons of two trapping methods to *Hylobius pales* (Coleoptera: Curculionidae) in Virginia. Environmental Entomology 27: 572-577.

Objectives

To determine if standard pit traps attract more *H. pales* than PVC traps; and if weevil density is related positively to weevil-induced seedling damage, thus providing a tool to predict future stand risks.

Abstract

The pales weevil, *Hylobius pales* (Herbst), is a major regeneration pest of Christmas tree plantations in the eastern USA. The development of an effective, easily implemented sampling strategy to detect when serious infestations are imminent is highly desirable, but does not exist currently in Virginia. A study was conducted during 1994 and 1995 in white pine, *Pinus strobus* L., Christmas tree farms in Floyd and Montgomery Co., Virginia. Most trees were of harvestable age (5-8 yr), and had no history of insecticide application during the previous five years. Methods were evaluated for trapping walking *H. pales* and for their potential at forecasting seedling damage.

Weevil gender, trap rotation and density of ground cover did not explain a significant proportion of the variation in trap catch. Standard pit traps baited with a white pine billet and 5:1 mixture of 95% ethanol: turpentine caught significantly more weevils than PVC traps baited only with a 5:1 mixture of 95% ethanol: turpentine. Trap catch was related positively to seedling damage and wound surface area (mm^2) in 1995 ($Y = -6.62 + 0.087X$, $R^2 = 0.98$, $P < 0.002$; $Y = -422.69 + 4.80X$, $R^2 = 0.99$, P = 0.011), but not in 1994. Although catches of both trap types are related positively, PVC pitfall traps did not detect the large initial peak that occurred in early summer. In addition, early season catch trends varied between the two methods at a time when weevil monitoring would have the greatest implication on management decisions. For these reasons, the use of pit traps for monitoring weevil populations in Virginia is recommended.

Sampling Procedure

Pit traps: One freshly-cut white pine billet, 8-12 cm in diameter and 30 cm long, is treated with a registered insecticide to prevent weevil escape. A shallow depression is made in the ground within 20 cm of a healthy tree and the billet is placed firmly within the shallow depression. A 25-ml vial containing a 5:1 ethanol: turpentine mixture (62.1%-pinene, 20.1% camphene, 10.8%-pinene, 2.6% limonene, 1.8% benzene, and 1.3% 3-carene) (Klean Strip SD-81, W. M. Barr. Memphis, TN) is then placed adjacent to the billet. Cover the trap with a black tile and fresh white pine foliage to reduce desiccation. Place traps at a density of approximately 12 per hectare. Weevils should be collected and baits replaced biweekly.

PVC pitfall traps: The basic pitfall trap design has been described in detail by Rieske and Raffa (1993). The only pertinent difference is that the 5:1 ethanol: turpentine mixture is released from a single, 25-ml vial.

Notes

The strong positive relationship between trap catch and seedling damage is based solely on four data points. Therefore, these results should be interpreted with caution.

Reference

*Rieske, L. K.; Raffa, K. F. 1993. Potential use of baited pitfall traps in monitoring pine root weevil, *Hylobius pales*, *Pachylobius picivorus*, and *Hylobius radicis* (Coleoptera: Curculionidae) populations and infestation levels. Journal of Economic Entomology 86: 475-485.

Mangini, A.; Carlton, C.; Perry, R. W.; Hanula, J. L. 1994. Seed, cone, regeneration, and defoliating insects in forest ecosystem management. Gen. Tech. Rep. 50. U.S. Department of Agriculture, Forest Service; 154-161.

Objective

To determine if *H. pales* posed any significant threat to regeneration in Phase II treatment stands.

Abstract

The pales weevil, *Hylobius pales* (Herbst), is a major regeneration pest of Christmas tree and commercial pine plantations in the eastern USA. This pest has also been implicated as a vector of pathogenic tree fungi. As part of the Phase II Ecosystem Management Research conducted on the Ouachita and Ozark National Forests, the Arthropod and Microbial Communities Study Group completed a survey of *H. pales*. Pitfall traps baited with 2 ml of turpentine (52.5% α-pinene, 41.4% β-pinene, 2% β-phellandrene and 1.1% limonene) and 2 ml of 95% ethanol caught *H. pales*. Adequate sampling accuracy was obtained by establishing three transects of 10 traps each per site. Traps were spaced on 12-m intervals.

Sampling Procedure

Use one 2-ml vial of turpentine and one 2-ml vial of 95% ethanol in each PVC pitfall trap (for a description of the trap see Hunt and Raffa 1989). Remove all trap contents, clean and re-bait each trap weekly.

Reference

*Hunt, D. W. A.; Raffa, K. F. 1989. Attraction of *Hylobius radicis* and *Pachylobius picivorus* (Coleoptera: Curculionidae) to ethanol and turpentine in pitfall traps. Environmental Entomology 18: 351-355.

Pales Weevil

Hylobius pales (Herbst)
Coleoptera: Curculionidae

Raffa, K. F.; Hunt, D. W. A. 1988. Use of baited pitfall traps for monitoring pales weevil, *Hylobius pales* (Coleoptera: Curculionidae). Great Lakes Entomology 21: 123-125.

Objective

To determine if ethanol and turpentine baited pitfall traps are an effective tool for monitoring *H. pales* populations.

Abstract

The pales weevil, *Hylobius pales* (Herbst), is a serious pest of young pine, *Pinus* spp., plantations throughout eastern North America. Pitfall traps baited with 95% ethanol and turpentine (52.5% α-pinene, 41.4% β-pinene, 2% β-phellandrene, 1.1% limonene, 0.9% camphene and 0.7% myrcene) were used to monitor *H. pales* populations in Wisconsin. This study was carried out in a 15-year-old plantation of Scots pine, *Pinus sylvestris* L., which was already suffering high mortality from the pine root collar weevil, *Hylobius radicis* Buchanan. Male and female *H. pales* were attracted equally to this bait combination. Neither component alone showed any attractiveness. Approximately 75% of all weevils were trapped during July, with the remainder collected in August. Future studies are aimed at estimating the relationship between trap catch and tree damage, mainly to facilitate the integrated pest management (IPM) of *H. pales*.

Sampling Procedure

Use sections of 20 cm long by 10 cm diameter plastic PVC pipe (see Tilles and others 1986). Drill eight 6-mm entrance holes around the circumference of each trap, 4 cm from the top. Coat the inside of each trap with liquid Teflon (DuPont de Nemours, Wilmington, DE, USA) to prevent *H. pales* escape. Use a combination of 95% ethanol and turpentine (Sunnyside Corp., Wheeling, IL, USA) as bait. Place each bait component separately in 12 by 35-mm (0.5 dram) glass vials. Drill two 2-mm holes below the entrance holes and attach a small wire through the 2-mm holes. Suspend each bait in the trap from this wire. Cap both ends of each trap, and drill two holes in the bottom cap to allow water drainage. Bury each trap in the ground so that the entrance holes are flush with the soil surface. Coat the above-ground portion of each trap with black paint in order to simulate a stump. Empty each trap and replace baits weekly.

Note

Space eight traps uniformly across the area to be treated.

Reference

Tilles, D. A.; Sjodin, K.; Nordlander, G.; Eidman, H. H. 1986b. Synergism between ethanol and conifer host volatiles as attractants for the pine weevil, *Hylobius abietis* (L.) (Coleoptera: Curculionidae). Journal of Economic Entomology 79: 970-973.

Rieske, L. K; Raffa, K. F. 1993. Potential use of baited pitfall traps in monitoring pine root weevil, *Hylobius pales*, *Pachylobius picivorus*, and *Hylobius radicis* (Coleoptera: Curculionidae) populations and infestation levels. Journal of Economic Entomology 86: 475-485.

Objective

To determine the predictive potential of this monitoring system for use in an Integrated Pest Management (IPM) program for *H. pales*.

Abstract

Plantation pine, *Pinus* spp., production in the Lake States is often limited by the feeding of adult pales weevil, *Hylobius pales* (Herbst), which can cause extensive seedling mortality and disfigurement of young trees. Population fluctuations of *H. pales* were monitored in five Wisconsin Christmas tree plantations of 5-year-old Scots pine, *Pinus sylvestris* (L.). Trees were spaced 1.8 m apart, and had not received insecticide treatment. Pitfall traps were baited with 2 ml of turpentine (46% α-pinene, 42% β-pinene, 2% β-phellandrene, 1% limonene, 0.9% camphene and 0.8% myrcene) and 2 ml of 95% ethanol in separate vials and tested at 6, 18 and 32 traps per 432 m^2 to determine their ability to detect weevil activity.

The lowest trap density (6 traps) had the best correlation between trap catch and damage indices, and was the least expensive sample to obtain. The 1988 trap catch of female *H. pales* was correlated positively with infestation level and infestation severity in 1988, 1989 and 1990. This trapping method could be used to forecast *H. pales* density and predict damage, but more work is needed to confirm these relationships.

Sampling Procedure

Pitfall traps: Use 17 cm long by 10 cm wide sections of plastic PVC pipe (see Tilles and others 1986). Drill eight 7-mm entrance holes around the perimeter of each trap, 6 cm from the top end. Coat the inside of each trap with liquid Teflon (DuPont de Nemours, Wilmington, DE, USA), which will prevent weevil escape. Drill an additional two 2-mm holes in the trap wall and attach a 14-gauge wire. Place a 2 ml vial of 95% ethanol and a 2 ml vial of turpentine (Mantz Paint, Madison, WI, USA) in each trap by suspending each from the 14-gauge wire. The vials will then be approximately 4 cm below ground level. Cap both ends of the trap, and drill two 2-mm holes in the bottom cap to allow water drainage. Coat the aboveground cap and the exposed portion of the PVC pipe with flat black paint in order to resemble a tree trunk. Bury each trap until the entrance holes are flush with the soil surface level.

Space traps evenly within a 432 m^2 block (i.e., 8-9 m). Monitor all traps weekly throughout the activity period of *H. pales*. Remove all weevils and replenish the baits during each sample collection.

To estimate infestation levels and the condition of tree foliage, take a subsample of trees within the 432 m^2 and look for the following:

Infestation levels: Examine the root collar of 12 trees per block for larval tunneling to a depth of 12 cm into the soil. Calculate two indices of infestation based on this data:

1. infestation level = # trees infested/# trees in subsample
2. infestation severity = (the sum of the proportion of damaged stem perimeters/# subsampled trees) x 100.

Incidence of foliar symptoms: Grade all trees in block on the basis of needle color. Trees with green (visibly healthy), yellow (intermediate degradation), and red or brown (dead) needles are given a 1, 2 and 3, respectively. Use this data to determine four indices of foliar symptoms:

1. symptom level = proportion of symptomatic trees
2. foliar severity = sum of foliar grades/# trees in replicate
3. proportion of yellow trees
4. proportion of red trees

These indices will help predict population density as well as provide an indication of damage levels.

Note

Better damage estimates may be obtained if pitcheating weevil, *Pachylobius picivorus* (Germar), pine root collar weevil, *Hylobius radicis* Buchanan, and *H. pales* are treated as a complex rather than trying to estimate damage separately for each individual species.

Reference

Tilles, D. A.; Sjödin, K.; Nordlander, G.; Eidmann, H. H. 1986. Synergism between ethanol and conifer host volatiles as attractants for the pine weevil, *Hylobius abietis* (L.) (Coleoptera: Curculionidae). Journal of Economic Entomology 79: 970-973.

Hunt, D. W. A.; Raffa, K. F. 1989. Attraction of *Hylobius radicis* and *Pachylobius picivorus* (Coleoptera: Curculionidae) to ethanol and turpentine in pitfall traps. Environmental Entomology 18: 351-355.

Objectives

To determine if *H. radicis* preferentially selects pitfall traps baited with red pine, *Pinus resinosa* Aiton, stems, turpentine, ethanol, or a combination of these baits; and if the number of *H. radicis* caught in traps is related positively to host damage.

Abstract

The pine root collar weevil, *Hylobius radicis* Buchanan, is an important pine, *Pinus* spp., pest in the northeastern USA and southeastern Canada. Larvae develop in the root collars of living hosts, which severely weakens and sometimes kills the host. The relative attractiveness of pitfall traps baited with red pine shoots, turpentine (52.5% α-pinene, 41.4% β-pinene, 2% β-phellandrene and 1.1% limonene), 95% ethanol, or a combination of these baits, was tested for capturing adult *H. radicis*. This study was conducted in five Wisconsin Christmas tree plantations of 5-year old Scots pine, *Pinus sylvestris* L.

Hylobius radicis adults were trapped from May through August 1987. Traps baited with a 2-ml vial of turpentine (Sunnyside Corp., Wheeling, IL, USA), and a 2-ml vial of ethanol, at release rates of 200 mg and 40 mg per day (at 22°C), respectively, were most effective for catching *H. radicis*. The sex ratio (% males) of *H. radicis* caught in the traps was 10%, suggesting that this bait combination is highly attractive to females. The number of *H. radicis* (*Y*) captured in pitfall traps was related positively to foliar damage (*X*) ($Y = 3.2 + 3.4X$; $R^2 = 0.87$, $P < 0.05$).

Sampling Procedure

Use 10 cm wide and 20 cm long sections of PVC pipe. Drill eight 6-mm entrance holes, at 4 cm intervals, around the circumference of each trap 4 cm from the top. Apply Fluon (DuPont de Nemours, Wilmington, DE, USA) to the inside walls of each trap to prevent weevil escape. Drill two 2-mm holes just below ground level and attach a small wire through the holes. Attach each of the trap baits to this wire. Place a cap on the ends of each trap, and drill two 2-mm holes in the bottom cap to permit water drainage. Bury each trap 16 cm deep so that the entrance holes are flush with the soil surface. Paint the upper cap, and exposed portion of each trap, black in order to resemble the silhouette of a stump. Traps were positioned within tree rows midway between every second tree, for a trap spacing of 3.4 m. Plots were at least 30 m from adjacent plots and the edge of the plantation.

Notes

Forty traps were used for each treatment in this study. No information is provided on the minimum number of traps needed to monitor weevil populations.

Pine Root Collar Weevil

Hylobius radicis Buchanan
Coleoptera: Curculionidae

Wilson, L. F.; Millers, I. 1983. Pine root collar weevil—its ecology and management. Tech. Bull. No. 1675. Washington, DC: U.S. Department of Agriculture, Forest Service; 34 p.

Objectives

To provide a comprehensive review of the survey methods used to detect the presence and population density of *H. radicis* as well as assess techniques used to determine damage caused by this forest pest.

Abstract

The pine root collar weevil, *Hylobius radicis* Buchanan, is an important pest of pine, *Pinus* spp., plantations in the northeastern USA. Larvae cause most of the damage as they feed below ground and bore into the inner bark. As they grow larger, *H. radicis* larvae also damage xylem tissues. Signs of infestation include pitch-soaked soil adjacent to the root collar of attacked trees, reduced shoot vigor, chlorosis and windthrow. Several types of surveys can be conducted by forest landowners to detect, evaluate, and predict weevil populations or damage. Three direct surveys that look for the presence of *H. radicis* and two indirect surveys that assess damage caused by its feeding were presented. A hazard-rating system was also presented to guide in the establishment of new pine plantations.

Sampling Procedure

The first three surveys deal with estimation of *H. radicis* presence and population levels whereas the last two surveys deal with estimation of damage.

Detection survey: First, look for obvious symptoms of weevil damage including yellowing or red foliage, or windthrown trees typical of heavy infestations. Second, examine the root collars of damaged trees for girdling by pulling the soil away with a shovel to look for blackened, pitch-soaked soil sticking to the bark. If this sign is present, remove more soil out to 15 cm from the root collar and look for larvae or pupae in the outer bark tissues. Stop sampling once *H. radicis* is found or continue with an appraisal survey.

Immature weevil appraisal survey: This survey determines the proportion of trees with immature weevils and should be conducted in stands with trees 5-13 cm diameter at ground level or trees 1-5 m in height. Sampling for immature weevils should be carried out between mid-June and mid-July when the greatest number of large immature weevils are present. Identify these specimens to confirm they are *H. radicis.*

Determine the parts of the stand that will be sampled and conduct the survey systematically. Only live, standing trees should be sampled. Use the following chart to determine the sampling intensity:

Table 1. Recommended sampling intensity based on stand area.

Stand size		Sample trees	
Acres	Hectares	Number per acre (0.4 ha)	Total
1	0.4	20	20
3	1.2	7	21
5	2.0	4	20
10	4.0	3	30
>20	>8.0	2	40

Sampling: Cut off one or more lower branches to expose the base of the tree. Remove the needle litter from the trunk out to about 30 cm. Dig a small trench around the tree 15 cm away from the trunk and 15 cm into the soil. Section the soil and examine each section by removing the soil and crumbling it to search for pitch and damage to the root collar. If there is no pitch present after digging around the tree, then record the tree as uninfested and move to the next tree. If pitch is present, then begin searching the soil for *H. radicis* larvae, pupae and callow adults (light- to reddish-brown weevils in pupal cells). Record the tree as either infested or uninfested based on the presence or absence of weevils, respectively, and move to the next tree. After sampling the minimum number of trees for the acreage in question, determine the proportion of infested trees. If the proportion of infested trees is >75%, then the infestation is severe enough to cause high mortality and control is warranted.

Adult appraisal survey: This survey determines the proportion of trees with adult *H. radicis* and should be conducted in stands with trees 5-13 cm in diameter at ground level or 1-5 m in height. The best time to conduct this survey is from mid-May through to the end of June when most adult weevils are close to the root collar for mating and oviposition. Be certain that any adult weevils found are *H. radicis* because several other weevil species may be found.

Determine the parts of the stand that will be sampled and conduct the survey systematically. Only live, standing trees should be sampled. See Table 1 for recommended sampling intensity.

Sampling: Cut off one or more lower branches to expose the base of the tree. Carefully search the interface between the organic layer and soil layer for adults, as well as the root collar out to about 46 cm. Be sure to examine bark crevices for hiding weevils. If one live *H. radicis* is found, then record the tree as infested and move to the next tree. If no weevils are found, then continue searching the soil around the root collar by digging down to a depth of 10 cm. If no weevils are found at this point, then record the tree as uninfested. After sampling the minimum number of trees for the acreage in question, determine the proportion of infested trees. If the proportion of infested trees is >40%, then the infestation is severe enough to cause tree mortality.

Damage appraisal survey: If tree mortality and windthrow have already occurred in the stand, then a nondestructive damage appraisal survey should be carried out. The number of freshly attacked trees is an accurate estimate of tree losses to occur the following year, assuming a rising or stable infestation.

Sampling: Sample a cluster of trees every 20 m along transect lines throughout the stand. In each cluster, record the number of living and dead trees. Calculate the percentage of dead trees but make sure the dead trees were attacked and killed by *H. radicis* (see Detection Survey). If 3-

5% of trees were recently killed, then approximately 95% of apparently healthy trees are likely infested.

Stand damage index: This survey is a destructive but detailed assessment of *H. radicis* damage that is used primarily for research purposes. This technique is also useful in practical field application when a precise estimate of damage is needed. Randomly select trees 1-3 m in height to be surveyed.

Sampling: Sample 20 to 30 trees systematically throughout the plantation or portion of the plantation to be surveyed. Dig around the root collar to root depth looking for larval injury. If no injury is found, then record the tree as uninfested. If injury is found, then cut the tree and remove the stump portion. Saw each stump in cross section across the area that appears to have the worst external damage. On one face of the cross section, calculate the degree of damage "d" by the formula:

$$d = \frac{Go_1 + Go_2 + \ldots + Go_n + Gi_1 + Gi_2 + Gi_n}{Co_1 + Co_2 + \ldots + Co_n + Ci_1 + Ci_2 + Ci_n}$$

where Go, Gi are measurements of girdled outer and inner bark (cm or inches) for each root collar; Co, Ci are circumferences (cm or inches) for the outer and inner bark, and "n" represents the sample size. The damage index (DI) is calculated by multiplying the total damage (d), by the proportion of trees infested (p) and a constant (k) (i.e., DI = dpk, where k = 1,000). Three damage classes were developed:

1. Light - DI <100: Contains pines with <40% of the root collars scarred by larval feeding and no abnormal growth or off-color symptoms.
2. Moderate - 100<DI<300: Contains pines with 30-85% of the root collars scarred by larval feeding and >10% with shortened terminal growth.
3. Heavy - DI>301: Contains pines with 80-100% of the root collars scarred by larval feeding and from a few to many trees leaning, off-color, or dead.

Hunt, D. W. A.; Raffa, K. F. 1989. Attraction of *Hylobius radicis* and *Pachylobius picivorus* (Coleoptera: Curculionidae) to ethanol and turpentine in pitfall traps. Environmental Entomology 18: 351-355.

Objectives

To determine if *P. picivorus* preferentially selects red pine, *Pinus resinosa* (Aiton), stems, volatiles of turpentine and ethanol, or a combination of these baits, placed in pitfall traps; and if the number of *P. picivorus* caught in traps is related positively to host damage.

Abstract

The pitcheating weevil, *Pachylobius picivorus* (Germar), feeds nocturnally on the inner bark of pine twigs, and can cause widespread mortality in newly planted stands. Pitfall traps were placed in a 5-year-old plantation of Scots pine, *Pinus sylvestris* (L.), in Waushara Co., Wisconsin, to evaluate the relative attractiveness of red pine stems, turpentine (52.5% α-pinene, 41.4% β-pinene, 2% β-phellandrene and 1.1% limonene) (Sunnyside Corp., Wheeling, IL, USA) and 95% ethanol to adult weevils.

One trap per 72 m^2 was most effective at catching *P. picivorus* if baited in the spring with 2 ml each of ethanol and turpentine released from separate vials. Slightly more female than male *P. picivorus* were attracted to the traps. Because the peak activity period *of H. radicis* occurred earlier than *P. picivorus,* it is suspected that the initial wounding of trees by *H. radicis* attracts *P. picivorus*, thereby increasing risk to young host trees. No significant relationships were found between the number of *P. picivorus* caught in the pitfall traps and subsequent tree damage. However, the presence of high numbers of *H. radicis*, which is suspected to precondition tree hosts for *P. picivorus*, could be useful in defining damage thresholds.

Sampling Procedure

Use 10 cm wide and 20 cm long PVC pipe as the trap body. Drill eight 6-mm entrance holes at 4 cm intervals 4 cm from the top of each trap. Apply liquid Teflon or Fluon (Dupont de Nemours, Wilmington, DE, USA) to the inside walls of each trap to prevent weevil escape. Drill two 2-mm holes into the trap wall, below the eight 6-mm holes and attach a small wire through the holes. Hang bait(s) from this wire. Place a plastic cap on both ends of the trap, and drill two 2-mm holes in the bottom cap to drain water. In each plot, bury eight traps horizontally until entrance holes are flush with the soil surface. Traps should be within tree rows midway between every second tree such that the trap spacing is 3.4 m. Plots should be spaced 30 m apart. Empty the contents of each trap and replenish baits weekly.

Pitcheating Weevil

Pachylobius picivorus (Germar)
Coleoptera: Curculionidae

Mangini, A.; Carlton, C.; Perry, R. W.; Hanula, J. L. 1994. Seed, cone, regeneration, and defoliating insects in forest ecosystem management. Gen. Tech. Report 50. U. S. Department of Agriculture, Forest Service; 154-161.

Objective

To determine if *P. picivorus* posed any significant threat to regeneration in Phase II treatment stands.

Abstract

The pitcheating weevil, *Pachylobius picivorus* (Germar), is a major regeneration pest of pine stands, *Pinus* spp., throughout the eastern USA. Adults feed nocturnally on the inner bark of seedlings and tree shoots, and oviposit in the roots and root collars of stressed or dying pine trees, as well as other coniferous hosts. As part of the Phase II Ecosystem Management Research conducted in the Ouachita and Ozark National Forests, the Arthropod and Microbial Communities Study Group completed a survey of *P. picivorus.* Pitfall traps baited with 2 ml of turpentine (52.5% α-pinene, 41.4% β–pinene, 2% β-phellandrene and 1.1% limonene) and 2 ml of 95% ethanol caught *P. picivorus*. Adequate sampling accuracy was obtained by establishing three transects of 10 traps each per site. Traps were spaced on 12 m intervals.

Sampling Procedure

Use one 2-ml vial of turpentine and one 2-ml vial of 95% ethanol in each PVC pitfall trap (for a description of the trap see Hunt and Raffa 1989). Remove all trap contents, clean and re-bait each trap weekly.

References

*Hunt, D. W. A.; Raffa, K. F. 1989. Attraction of *Hylobius radicis* and *Pachylobius picivorus* (Coleoptera: Curculionidae) to ethanol and turpentine in pitfall traps. Environmental Entomology 18: 351-355.

Rieske, L. K.; Raffa, K. F. 1993. Potential use of baited pitfall traps in monitoring pine root weevil, *Hylobius pales*, *Pachylobius picivorus*, and *Hylobius radicis* (Coleoptera: Curculionidae) populations and infestation levels. Journal of Economic Entomology 86: 475-485.

Objective

To investigate the predictive potential of this monitoring system for use in an integrated pest management (IPM) system for *P. picivorus*.

Abstract

Plantation pine, *Pinus* spp., production in the Lake States is often limited by the feeding of adult pitcheating weevils, *Pachylobius picivorus* (Germar), which can cause extensive seedling mortality and disfigurement of young trees. Population fluctuations of *P. picivorus* were monitored from 1988 to 1990 in five, 5-year-old Scots pine, *Pinus sylvestris* (L.), plantations in central Wisconsin. Trees were spaced 1.8 m apart and had not received insecticide treatment. Pitfall traps were baited with 2 ml of turpentine (46% α-pinene, 42% β-pinene, 2% β-phellandrene, 1% limonene, 0.9% camphene and 0.8% myrcene) and 2 ml of 95% ethanol and tested at 6, 18 and 32 traps per 432 m^2 to determine their ability to detect weevil activity.

The lowest trap density (6 traps) had the best correlation between trap catch and damage indices, and was the least expensive. Trap catch of *P. picivorus* was correlated significantly with 1988 to 1990 foliar symptoms, suggesting that either assessing population levels of *P. picivorus* or their damage may be useful at forecasting future population trends and damage levels.

Sampling Procedure

Pitfall traps: Use 17 cm long by 10 cm wide plastic PVC pipes (see Tilles and others 1986). Drill eight 7-mm wide entrance holes around the perimeter of each trap, 6 cm from the top end. Coat the inside of each trap with liquid Teflon (DuPont de Nemours, Wilmington, DE, USA) to prevent weevil escape. Drill two 2-mm holes in the trap wall just below the entrance holes. Attach a 14-gauge wire through these two holes. Place a 2-ml vial of 95% ethanol and a 2-ml vial of turpentine (Mantz Paint, Madison, WI) in each trap by suspending both vials from the wire approximately 4 cm below ground level. Cover each end of all traps with plastic caps. Drill two 2-mm holes in the bottom cap to drain water. Paint the above ground cap, and the exposed portion of the PVC pipe, black in order to resemble a tree trunk. Bury traps vertically until entrance holes are flush with ground level.

Space traps evenly within the 432 m^2 block (i.e., 8-9 m). Monitor all traps weekly throughout the activity period of *P. picivorus*. Remove all weevils and replenish all baits during each sampling interval.

To determine infestation levels and tree damage in each 432 m^2 block, sub-sample an appropriate number of trees and look for the following:

Infestation levels: Examine the root collar of 12 trees per block for larval tunneling to a depth of 12 cm into the soil. Calculate the following two indices of infestation based on this data:

1. infestation level = # trees infested / # trees in subsample
2. infestation severity = (the sum of the proportion of damaged stem perimeters / # subsampled trees) x 100.

Incidence of foliar symptoms: Grade all trees in block based on needle color. Trees with green (visibly healthy), yellow (intermediate degradation) and red or brown (dead) needles should be given a 1, 2 and 3, respectively. Use this data to determine four indices of foliar symptoms:

1. symptom level = proportion of symptomatic trees
2. foliar severity = sum of foliar grades / # trees in replicate
3. proportion of yellow trees
4. proportion of red trees

Note

Better damage estimates may be obtained if *P. picivorus,* pales weevil, *Hylobius pales* (Herbst.), and pine root collar weevil, *Hylobius radicis* Buchanan, are treated as a complex rather than trying to estimate damage separately for each of these closely related species.

Reference

Tilles, D. A., Sjödin, K.; Nordlander, G.; Eidmann, H. H. 1986. Synergism between ethanol and conifer host volatiles as attractants for the pine weevil, *Hylobius abietis* (L.) (Coleoptera: Curculionidae). Journal of Economic Entomology 79: 970-973.

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

Objective

To develop a sequential sampling plan for white grubs, *Phyllophaga* spp., which facilitates the estimation of population levels and helps determine if control measures are warranted.

Abstract

White grubs, *Phyllophaga* spp., feed on the roots of conifers in newly established plantations, causing crop failures in infested stands. A study was conducted in the Agassiz Forest Reserve in southeastern Manitoba, Canada to determine the vertical and frequency distribution of white grubs in a 929 cm^3 (1 ft^3) sample area.

In Canada, white grubs complete a three-year life cycle with the majority of this time being spent in the larval (grub) stage. The best time to sample is during June and July when populations are estimated by counting the number of second and third instar larvae, pupae and adults. For the pre-planting survey, only first through third instar larvae are counted. Both surveys have an error of misclassification of 10%.

Densities were classified as light (< 0.2), moderate (0.2-0.7) and severe (>1.1 per cubic foot). Control measures were advisable if a survey completed during the previous season estimated densities of greater than 0.7 larvae per cubic foot.

Sampling Procedure

Grub population density samples: Select a number of potential sample plots randomly throughout the area of concern. At each plot, remove all soil in a 30 by 30 cm surface area, digging into the soil to a depth of approximately 30 cm for a sample unit of 900 cm^3 (1ft^3). Remove 10 cm of soil at a time and pass it through a screen to collect grubs. Include all white grubs found in the sample due to the difficulty of identifying grubs to species. Do not try to count eggs and first instars as they are very small and thus difficult to find in the soil. Reference Table II and continue sampling until a decision is met.

Pre-planting survey samples: Sample newly harvested areas in July of the year prior to planting. The number of first through third instar larvae must be counted to predict accurately the density of grubs the following season. First instar larvae at time of sampling will become second instar larvae the following spring, which are capable of causing considerable damage. Therefore, these samples take more time to process. It is recommended that two screenings be done for pre-planting samples. Use a larger screen to catch second and third instar larvae, and to remove coarse debris. Then re-screen with a finer mesh size to capture first instar larvae. Reference Table III and continue sampling until a decision is met.

Notes

Damage classifications are subjective because of insufficient data on the relationship between density and damage. The timing of samples will likely change according to latitude and adjustments should therefore be made for sampling populations in the USA.

Reference

Shenefelt, R. D.; Liebig, H. .R.; Dosen, R. C. 1955. Protecting machine transplanted trees from white grubs. Tree Planters' Notes 20: 14-17.

Tables

Table II. Sequential sampling plan for classifying *Phyllophaga* spp. infestations. Sampling continues until the cumulative number of larvae (grubs) is ≤ or ≥ the tabulated values (refer to the original publication for sample sizes >40).

Number ft^3 soil samples examined	Cumulative number of white grubs					
	Light		Moderate	Moderate		Severe
1	---		---	---		9
2	---		---	---		10
3	---		---	---		11
4	---		---	---		12
5	---	C	---	---	C	12
6	---	O	---	---	O	13
7	---	N	---	---	N	14
8	---	T	---	---	T	15
9	---	I	---	---	I	16
10	---	N	---	---	N	17
11	---	U	---	---	U	18
12	---	E	---	---	E	19
13	---		---	---		19
14	0		---	---		20
15	0		---	---		21
16	0		---	---		22
17	1		---	---		23
18	1		---	---		24
19	1		---	---		25
20	1		10	10		26
21	2		10	10		27
22	2		11	11		27
23	2		11	12		28
24	3		11	13		29
25	3		11	14		30
26	3		12	15		31
27	4		12	16		32
28	4		12	17		33
29	4		13	17		34
30	4		13	18		34
31	5		13	19		35
32	5		13	20		36
33	5		14	21		37
34	6		14	22		38
35	6		14	23		39
36	6		15	24		40
37	6		15	25		41
38	7		15	25		41
39	7		15	26		42
40	7		16	27		43

Table III. Sequential sampling plan for use in pre-planting surveys to determine if white grub control is needed. Sampling continues until the cumulative number of grubs is ≤ or ≥ the tabulated values.

Number of ft^3 soil samples examined	Cumulative number of white grubs		
	No control needed		Control needed
1	---		4
2	---	C O N T I N U E	5
3	---		5
4	---		6
5	---		6
6	---		7
7	---		7
8	0		8
9	0		8
10	1		9
11	1		9
12	2		9
13	2		10
14	3		10
15	3		11
16	4		11
17	4		12
18	5		12
19	5		13
20	5		13
21	6		14
22	6		14
23	7		15
24	7		15
25	8		15
26	8		16
27	9		16
28	9		17
29	10		17
30	10		18

Tables reproduced with permission from the Canadian Entomologist, January 15, 2001.

Tobi, D. R.; Leonard, J. G.; Parker B. L.; Wallner, W. E. 1992. Survey methods, distribution, and seasonality of *Korshceltellus gracilis* (Lepidoptera: Hepialidae) in the Green Mountains, Vermont. Environmental Entomology 21: 447-452.

Objective

To develop methods for interpreting the basic biology and potential pest status of *K. gracilis.*

Abstract

The larvae of the conifer swift moth, *Korscheltellus gracilis* (Grote), feed on the roots of red spruce, *Picea rubens* Sarg., balsam fir, *Abies balsamea* (L.), and the leaf petiole bases of mountain wood fern, *Dryopteris campyloptera* Clarkson. Although this particular outbreak was found in red spruce-balsam fir stands near Camels Hump Mountain, Vermont, *K. gracilis* larvae could possibly be present in other mountain areas having the same host species. Feeding by *K. gracilis* can impair the trees' assimilation of water and nutrients, predispose roots to attack by root pathogens, reduce the regeneration potentials of red spruce and balsam fir, and cause decline or death.

This insect was found to have a two-year life cycle with greatest densities found above 885 m in elevation. Adult flight and mating occurred within a half hour before sunset and after sunrise, from late June through early August. Peak flight activity occurred during July, with the heaviest flights occurring on even numbered years. Greater numbers of *K. gracilis* were caught in Malaise traps than in 50-cm^2, clear plastic sticky traps placed 15 cm above the ground. However, Malaise traps were found to be too costly for widespread use.

Sampling Procedure

Interception trap study: Use sticky board traps to sample large stands and Malaise traps for smaller units.

> Sticky traps: Two types of deployment can be used: circular and transect. For circular deployment, use 50 by 50-cm clear, 2.5 mm thick Plexiglas coated with Tangle Trap (Tanglefoot, Grand Rapids, MI, USA). Suspend traps from overhanging tree limbs with nylon cord such that they are approximately 15 cm above the forest floor. Space four to eight traps 6 m from a plot center for a spacing of 14-28 m along the circumference, respectively (plot spacing in this study was at least 60 m). For transect deployment, place one or two Plexiglas sticky traps at 30 m intervals within the area to be monitored. Regardless of the deployment, traps should be in place 2-3 weeks before the initiation of flight activity (i.e., in this study early June), and maintained until 3 weeks after the end of flight activity (i.e., late August in this study). Check all traps daily during the flight period of *K. gracilis.*

Malaise traps: Place Malaise (BioQuip, Santa Monica, CA, USA) traps approximately 15 cm above the forest floor at the base of a potential host tree. Distribute traps on a 30-m spacing to obtain a representative sample of the area in question. Check all traps daily during the flight period of *K. gracilis*.

Sower, L. L.; Daterman, G. E.; Sartwell, C. 1984. Surveying populations of western pine shoot borers (Lepidoptera: Oleuthreutidae). Journal of Economic Entomology 77: 715-719.

Objective

To compare different survey methods for estimating populations of *E. sonomana* in the field.

Abstract

The western pine shoot borer, *Eucosma sonomana* Kearfott, is a pest of ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., and can infest other pines in the western USA, by mining the pith of terminal shoots. This feeding causes an average 25% growth reduction in terminal shoots. A study was carried out in south-central Oregon to determine if the population level of *E. sonomana* could be accurately estimated using visual surveys, shoot dissections, and the trapping of male moths.

The visual assessment technique was determined to be the most practical for determining population levels of *E. sonomana*, especially if the investigators had experience assessing infestations. Visual surveys were also well correlated with the number of infested shoots as determined by shoot dissections as well as trap catches of male *E. sonomana*. Current-year infestation levels, as determined by the visual survey, accurately determined infestation levels the following year. Sampling at least 4 plots per plantation (10 trees per plot) was recommended for trees less than 8 m tall. Also, to verify accuracy of the visual survey, a sub-sample of terminal and upper lateral shoots could be taken (10 shoots per tree) and dissected. Pheromone trapping for males was recommended if many plantations had to be surveyed. Pheromone traps should be placed in the mid-crown foliage of at least 5 sample trees at 20 m spacing.

Sampling Procedure

Visual survey: Pace 30 m directly into a plantation away from a road or plantation edge and select the nearest tree. Lay out a 50 by 50-m plot, marking a tree in each corner. Off each corner select a block of 24 trees (3 rows of 8 trees), and visually inspect terminal and lateral shoots for presence of short needles, which is a characteristic symptom of *E. sonomana* infestation (Stoszek 1973). The authors suggest that the leaders on as few as 10 samples of 10 trees (100 shoots per plantation) could be surveyed to provide adequate sampling accuracy.

Shoot dissection survey: Although this method is by far the most accurate means of determining infestation levels, it requires the removal and destruction of the terminal shoot. Select three adjacent trees out from each marked corner of each plot for destructive sampling of the terminal shoot. Record shoots with larval mines greater than 5 cm in length as infested. This method is also complementary to the visual inspection of terminal leaders. For intensive, small-scale applications, sample destructively 10 vigorous lateral shoots on each of 10 trees per plantation to estimate infestation levels.

Pheromone traps: Use Pherocon II pheromone traps baited with a 0.005% pheromone in a 70 mg polyvinyl chloride (PVC) pellet (Daterman 1974). Place traps in the mid-crown of 5 trees on a 100-m loop (20 m spacing between traps) within the area to be treated. Set traps one week prior to the predicted flight period (i.e., April in south-central Oregon) and leave in place until a week after the predicted flight period (i.e., June). This trapping method is effective at detecting populations of *E. sonomana* over large scale areas. For intensive, small-scale applications, the use of many pheromone traps may actually reduce moth density when populations exist at low to moderate levels.

References

Daterman, G. E. 1974. Synthetic sex pheromone for detection survey of European pine shoot moth. Res. Pap. PNW-180. Corvallis, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 12 p.

Stoszek, K. J. 1973. Damage to ponderosa pine plantations by the western pine shoot borer. Journal of Forestry 71: 701-705.

Miller, W. E. 1960. The European pine shoot moth: relationship between proportion of trees infested and number of insects per tree. Journal of Forestry 58: 647-648.

Objective

To determine if the number of *R. buoliana* per tree was related positively to the proportion of trees infested by *R. buoliana.*

Abstract

The European pine shoot moth, *Rhyacionia buoliana* (Denis & Schiff.), has become an important pest of two- and three-needle pines, *Pinus* spp., in the northern USA following its introduction into Long Island, NY in 1914. This insect primarily infests terminal shoots causing severe deformation, and reduced growth. This study was conducted in red pine, *Pinus resinosa* Ait., plantations in Michigan.The number of *R. buoliana* per tree (*Y*) was related positively to the proportion of trees infested by *R. buoliana* (*X*) ($Y = -1.09 + 0.02X$). The sampling of at least 15 trees per stand to determine the proportion of infested trees was recommended.

Sampling Procedure

Use this method in pine plantations at 1.8 by 1.8-m spacing and from approximately 1 m in height to crown closure. Sample at least 15 trees in the area of concern by selecting every fifth tree in every fifth row. Inspect the terminal bud cluster of each sample tree for pitch globules and distorted or dying shoots (i.e., shepherd's crooking). Damage from *R. buoliana* persists throughout the winter so this method can be carried out when populations are in diapause. Enter the proportion of infested trees (*X*) into the equation $Y = -1.09 + 0.02X$ to determine the number of *R. buoliana* per tree (*Y*).

During April and June in lower Michigan, the late larval and pupal stages could be collected and sent for identification to confirm the presence of *R. buoliana* to distinguish from other closely related species in the genus *Rhyacionia*.

Note

The inter-tree distribution of *R. buoliana* was random within all plantations.

Nantucket Pine Tip Moth

Rhyacionia frustrana (Comstock)
Lepidoptera: Tortricidae

Fettig, C. J.; Berisford, C. W. 1999. A comparison of three common indices for estimating Nantucket pine tip moth damage in the field. Journal of Entomological Science 34: 203-209.

Objectives

To determine if terminal damage was correlated positively to top whorl and whole tree damage; and if top whorl damage was correlated positively to whole tree damage.

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. Four loblolly pine plantations were sampled in the Georgia Piedmont and four in the Georgia and South Carolina Coastal Plain. Sampling was conducted three times annually in the Piedmont and four times annually in the Coastal Plain, and coincided with the pupal stage of each generation.

Terminal damage (Y) was correlated positively with top whorl ($Y = 0.04 + 1.29X$, $R = 0.87$, $P < 0.0001$), and with whole tree damage ($Y = 0.17 + 1.23X$, $R = 0.71$, $P < 0.0001$). Top whorl damage (Y) was correlated positively with whole tree damage ($Y = 0.09 + 0.99X$, $R = 0.86$, $P < 0.0001$). Top whorl damage indices were the most sensitive indicator of damage levels in all tree strata examined.

Sampling Procedure

Select sample trees randomly, and count the number of damaged and undamaged shoots in the terminal and first cluster of lateral shoots (usually 3-6) beneath the terminal (e.g., top whorl). A shoot is defined as greater than 10 cm of apical stem containing foliage. The terminal is the new leader occurring at the top of the main stem. If the leader is damaged severely or aborted by causes other than *R. frustrana*, consider the tallest lateral shoot of the top whorl growing in a vertical orientation to be the terminal. Calculate the proportion of infested shoots, (# infested/total number) x 100, in the top whorl. Top whorl damage indices may be the best compromise for estimating *R. frustrana* damage when considering the time constraints of obtaining more detailed estimates versus allocating that time toward another sample.

Note

The associations between top whorl damage and terminal and whole-tree damage may be limited to trees less than three years old.

Gargiullo, P. M.; Berisford, C. W. 1981. Sampling for pine tip moths-a procedural guide. Res. Bull. 272. Athens: The University of Georgia; 25 p.

Objective

To determine the mean number of immature *R. frustrana* per shoot, per tree, and per unit area for developing life tables and absolute population estimates.

Abstract

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is an important pest of Christmas tree and pine plantations in the eastern USA. Larval feeding can cause shoot mortality and tree deformity, height and volume reductions, formation of compression wood, and occasional tree mortality. Damage is most severe on seedlings and saplings less than 5-years-old. This paper discusses field sampling procedures and the use of a FORTRAN program to provide estimates of the mean number of immatures per shoot, per tree, and per area (e.g., per ha), with respective variances.

Sampling Procedure

The sampling procedure is described clearly in Gargiullo and others (1983). Once the data is collected, a FORTRAN program can be used to compute estimates of population size. Refer to Appendix B for the FORTRAN coding.

Note

Do not confuse the larvae of *R. frustrana* with those of *R. rigidana*. The relative position of the three prespiracular setae are used to differentiate these two insects (Miller and Wilson 1964).

References

* Gargiullo, P. M.; Berisford, C. W.; Pienarr, L. V. 1983. Two-stage cluster sampling for pine tip moths. Environmental Entomology 12: 81-90.

Miller, W. E.; Wilson, L. F. 1964. Composition and diagnosis of pine tip moth infestations in the southeast. Journal of Economic Entomology 57: 722-726.

Nantucket Pine Tip Moth

Rhyacionia frustrana (Comstock)
Lepidoptera: Tortricidae

Gargiullo, P. M.; Berisford, C. W.; Pienaar, L. V. 1983. Two-stage cluster sampling for pine tip moths. Environmental Entomology 12: 81-90.

Objective

To develop a sampling scheme for *R. frustrana* for a known SE.

Abstract

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a serious pine regeneration pest. Larvae feed within newly developing shoots causing flagging, tree deformity and reductions in growth. In the Georgia Piedmont, there are three generations per year with the pupa of the third generation overwintering inside the shoots. A sampling scheme was described for the immature stages of *R. frustrana*, on 3-year-old loblolly pine, *Pinus taeda* L., in the Georgia Piedmont.

Sampling involved a two-stage process whereby trees were selected randomly (stage 1) and then the crown stratified into two levels, with shoots being sampled in each level (stage 2). Depending on the desired standard error (SE), from 2 (50% SE) to 454 (5% SE) trees are sampled. On these trees, as few as 2 or as many as 5 shoots were sampled per level. The time required to complete a sample was inversely related to desired SE.

Sampling Procedure

Select the desired SE (Table 1). Sample the number of trees indicated in Table 1 randomly throughout the area of concern. On all sample trees less than 0.5 m tall, treat the entire live crown as level 1 and sample according to desired SE (i.e., if SE was 10%, then 2 shoots would be sampled) (Table 1). On trees greater than 0.5 m tall, divide the live crown into two strata. Sample each level according to the desired SE. All samples, regardless of location within the crown, should be chosen to include nearly equal amounts of foliage. Thus, shoots should be non-overlapping and account for all foliage within a level. Shoots are numbered, clipped, placed into bags, and then put in a cooler.

In the lab, examine shoots for the life stages of *R. frustrana*. Counts are recorded according to shoot, level, and tree. A FORTRAN program along with documentation has been written to compute the necessary statistics presented in this article as well as procedures used to handle trees up to 2.5 m tall (Gargiullo and Berisford 1981).

Note

Do not confuse the larvae of *R. rigidana* with those of *R. frustrana*. The relative positions of the three prespiracular setae are used to distinguish between the two species (Miller and Wilson 1964).

References

*Gargiullo, P. M.; Berisford, C. W. 1981. Sampling for pine tip moths-a procedural guide. Res. Bull. 272. Athens: The University of Georgia. 25 p.

Miller, W. E.; Wilson, L. F. 1964. Composition and diagnosis of pine tip moth infestations in the southeast. Journal of Economic Entomology 57: 722-726.

Table

Table 1. Optimum numbers of trees and shoots to sample to obtain various desired precisions for minimized costs.

Desired SE (%)[b]	No. of trees	No. of shoots in stratum 1	No. of shoots in stratum 2	Total cost of sample (human-h)
5	454	2	2	781.1
10	114	2	2	197.0
15	51	2	2	88.5
20	29	2	2	50.5
25	18	2	2	31.5
30	8	3	4	22.4
35	9	2	2	15.9
40	6	2	3	12.4
45	3	3	5	9.4
50	2	4	5	7.2

Computed for the overall density of *R. frustrana* immature stages, based on pilot sample number 19097.
[b] SE (%) = (variance of the unbiased mean per tree estimate)$_{1/2}$ ÷ unbiased mean per tree estimate.

Table 1 reprinted with permission from Environmental Entomology, January 15, 2001.

Nantucket Pine Tip Moth

Rhyacionia frustrana (Comstock)
Lepidoptera: Tortricidae

Waters, W. E. 1974. Sequential sampling applied to forest insect surveys. In: Proceedings of IUFRO/SAF/SUNY symposium on monitoring forest environments through successive sampling. June 24-26; Syracuse, NY; 290-311.

Objective

To develop a sequential sampling plan for the integrated pest management of *R. frustrana*.

Abstract

A sequential sampling plan was developed from data on the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), infesting loblolly pine, *Pinus taeda* L., in eastern Maryland. Larval feeding can cause substantial terminal and subterminal shoot deformation and reduced growth. In Maryland, *R. frustrana* has 2-3 generations a year with pupae of the final generation overwintering inside shoots. This sampling plan was intended for the first generation of *R. frustrana* as a basis for deciding if control measures were needed for the next generation.

A maximum of 50 trees, selected randomly, was recommended at each survey point. If $\leq$10% of trees had infested terminals, then control was not recommended. If $\geq$20% of trees had infested terminals, then control was recommended. If the percentage of infested terminals was between 10-20% after all 50 trees had been sampled, then control was warranted with an estimate >15%, and not warranted with an estimate <15%.

Sampling Procedure

Select sample trees randomly in the area of concern. Examine the terminal bud cluster for the presence of *R. frustrana*. If *R. frustrana* is present, then record the terminal as infested. Reference the sequential sampling plan, and continue sampling until a decision is met (Fig. 1). A maximum of 50 trees is sampled at each survey point. If after sampling 50 trees the cumulative count of infested trees lies in the continue sampling zone (i.e., no decision zone), then select the category closest to this count. Changing either the class limits or the risk levels will alter the size of the no decision zone as well as changing the number of terminals to be examined (Figs. 2, 4).

Note

The distribution of *R. frustrana* follows a binomial distribution.

Figures

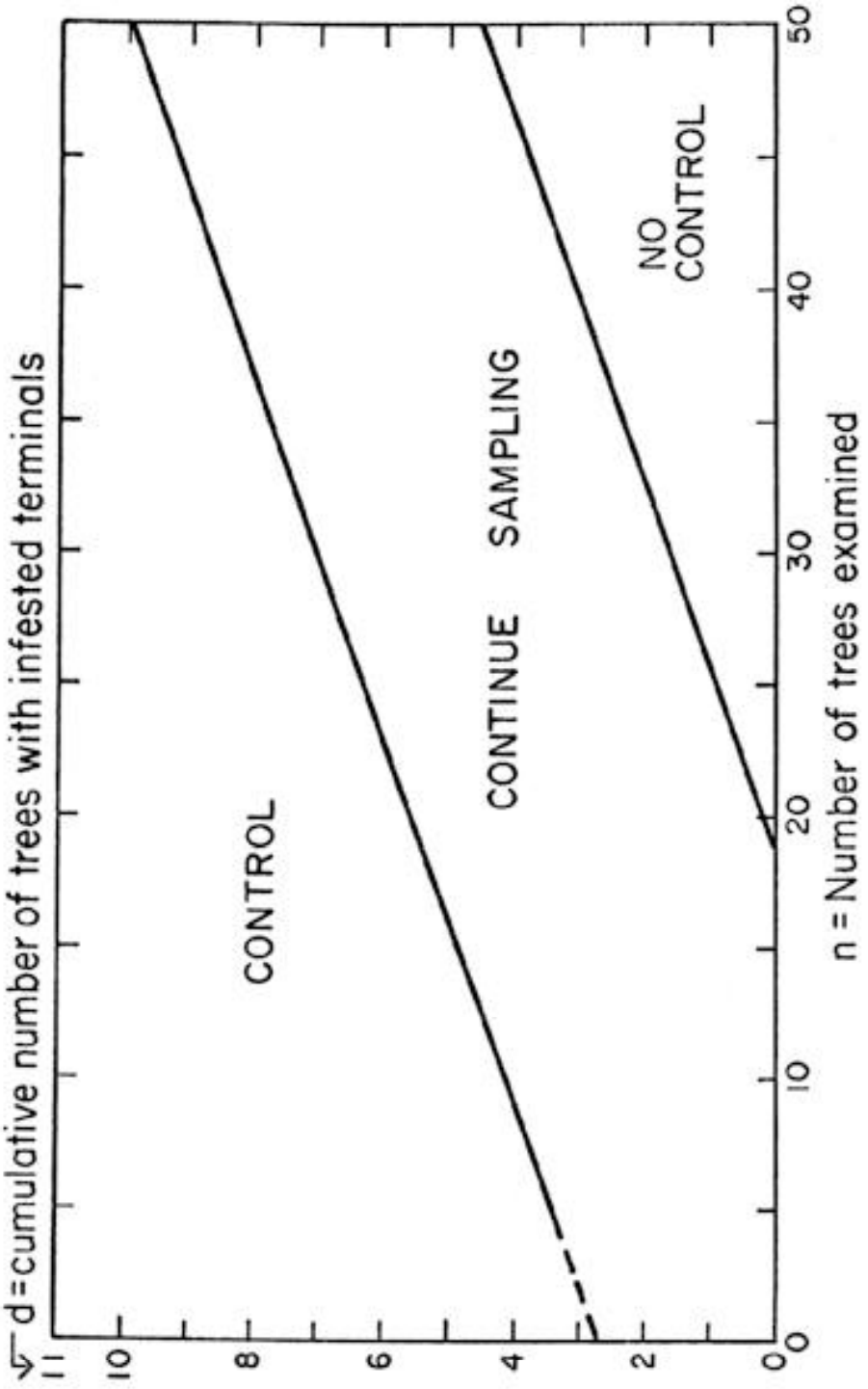

Figure 1. Sequential graph for sampling Nantucket pine tip moth in loblolly pine.

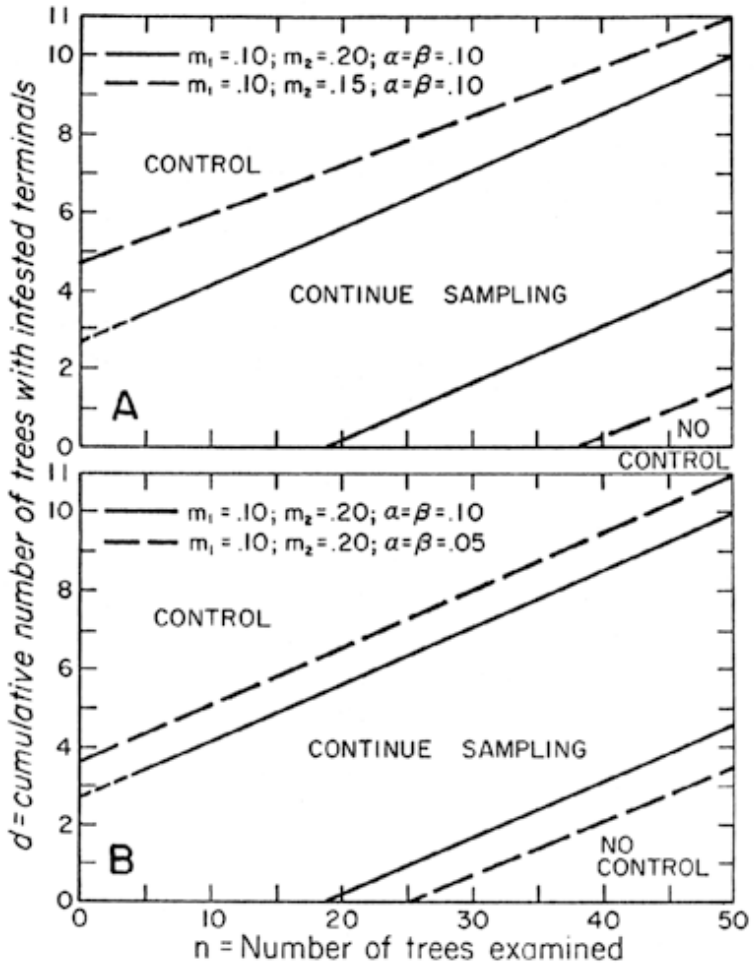

Fig. 2. Comparison of decision boundaries of sequential sampling plan for Nantucket pine tip moth in loblolly pine: A with gap between m_1 and m_2 reduced, and B with risk levels reduced.

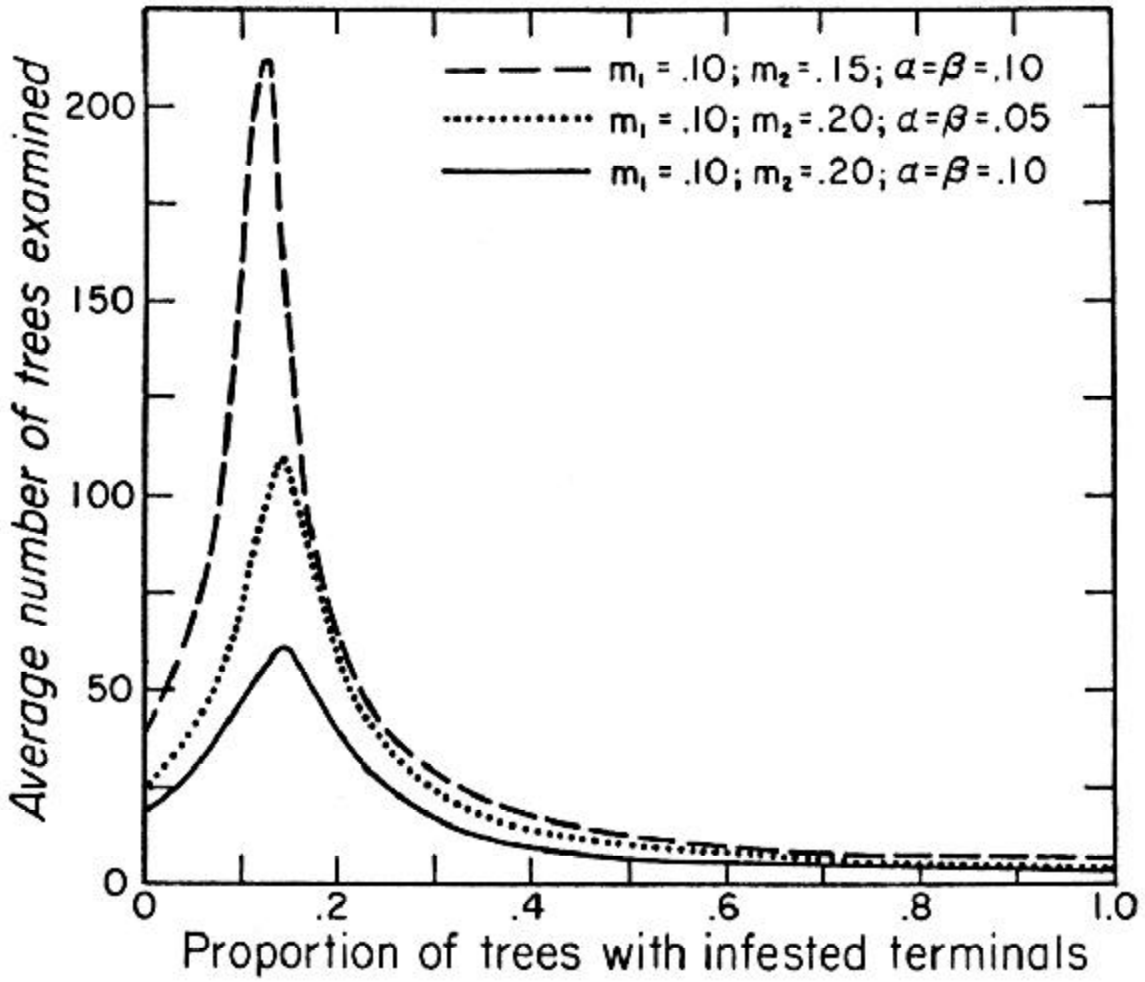

Fig. 4. Average Sample Number curve(s) for the Nantucket pine tip moth sequential sampling plan(s).

Figures reprinted with permission from the IUFRO/SUNY symposium, January 15, 2001.

Pitch Pine Tip Moth

Rhyacionia rigidana (Fernald)
Lepidoptera: Tortricidae

Gargiullo, P. M.; Berisford, C. W. 1981. Sampling for pine tip moths-a procedural guide. Res. Bull. 272. Athens: The University of Georgia; 25 p.

Objective

To determine the density of immature *R. rigidana* in order to develop life tables and absolute population estimates.

Abstract

The pitch pine tip moth, *Rhyacionia rigidana* (Fernald), is a common associate of the more abundant Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), and often shares the same host. Both species are important regeneration pests of pine plantations in the eastern USA. This paper discusses field sampling procedures and the use of a FORTRAN program to provide estimates of the mean number of immatures per shoot, tree, and unit area (e.g., per ha) with known levels of precision.

Sampling Procedure

The basic sampling procedure is described clearly in our review of Gargiullo and others 1983. Once the data has been collected appropriately, a FORTRAN program can be used to compute estimates of population size. Refer to Appendix B in the original publication for the FORTRAN coding.

Note

Do not confuse the larvae of *R. rigidana* with those of *R. frustrana*. The relative positions of the three prespiracular setae are used to distinguish between the two species (Miller and Wilson 1964).

References

*Gargiullo, P. M.; Berisford, C. W.; Pienarr, L. V. 1983. Two-stage cluster sampling for pine tip moths. Environmental Entomology 12:81-90.

Miller, W. E.; Wilson, L. F. 1964. Composition and diagnosis of pine tip moth infestations in the southeast. Journal of Economic Entomology 57:722-726.

Pitch Pine Tip Moth

Rhyacionia rigidana (Fernald)
Lepidoptera: Tortricidae

Gargiullo, P. M.; Berisford, C. W.; Pienaar, L. V. 1983. Two-stage cluster sampling for pine tip moths. Environmental Entomology 12: 81-90.

Objective

To develop a sampling scheme for *R. rigidana* for a known SE.

Abstract

The pitch pine tip moth, *Rhyacionia rigidana* (Fernald), is a common associate of the more abundant Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), and often shares the same host. Larvae feed within newly developing shoots causing flagging, tree deformity and reductions in growth. In the Georgia Piedmont, there are two generations per year with the pupa of the second generation overwintering inside the shoots.

A sampling scheme was described for the immature stages of *R. rigidana*, on 3-year-old loblolly pine, *Pinus taeda* L., in the Georgia Piedmont. Sampling involved a two-stage process whereby trees were selected randomly (stage 1) and then the crown stratified into two levels, with shoots being sampled in each level (stage 2). Depending on the desired standard error (SE), from 2 (50% SE) to 454 (5% SE) trees are sampled. On these trees, as few as 2 or as many as 5 shoots were sampled per level. The time required to complete a sample was related negatively to desired SE.

Sampling Procedure

Select the desired SE (Table 1; see p. 31). Sample the number of trees indicated in Table 1 randomly throughout the area of concern. On all sample trees less than 0.5 m tall, treat the entire live crown as level 1 and sample according to desired SE (i.e., if SE was 10%, then 2 shoots would be sampled) (Table 1). On trees greater than 0.5 m tall, divide the live crown into two levels. Sample each level according to the desired SE. All samples, regardless of location within the crown, should be chosen to include nearly equal amounts of foliage. Thus shoots should be non-overlapping and account for all foliage within a level. Shoots are numbered, clipped, placed into bags and then put in a cooler. In the lab, examine shoots for the life stages of *R. rigidana*. Counts are recorded according to shoot, level, and tree. A FORTRAN program along with documentation has been written to compute the necessary statistics presented in this article as well as procedures used to handle trees up to 2.5 m tall (Gargiullo and Berisford 1981).

Note

Do not confuse larvae of *R. rigidana* with those of *R. frustrana*. The relative positions of the three prespiracular setae are used to distinguish between the two species (Miller and Wilson 1964).

References

*Gargiullo, P. M.; Berisford, C. W. 1981. Sampling for pine tip moths-a procedural guide. Res. Bull. 272. Athens: The University of Georgia. 25 p.

Miller, W. E.; Wilson, L. F. 1964. Composition and diagnosis of pine tip moth infestations in the southeast. Journal of Economic Entomology 57: 722-726.

Turgeon, J. J.; Régnière, J. 1987. Development of sampling techniques for the spruce budmoth, *Zeiraphera canadensis* Mut. and Free. (Lepidoptera:Tortricidae). Canadian Entomologist 119: 239-249.

Objectives

To develop a practical and meaningful sample unit for assessing *Z. canadensis* populations; to determine the required sample size for density estimates with a given level of precision; and to develop a sequential sampling plan for *Z. canadensis*.

Abstract

The spruce budmoth, *Zeiraphera canadensis* Mut. and Free., is a serious pest of young white spruce, *Picea glauca* (Moench) Voss, plantations. Larvae feed on newly developing terminal shoots causing multiple leaders, crown deformation, and growth loss.

A 15-cm branch segment, measured distally from the scales of the branch's apical growth and taken from the upper one-third of the crown, was considered an adequate sample unit for density estimates of *Z. canadensis* eggs and larvae. A minimum of 5 and maximum of 100 branch samples was recommended (Fig. 7). Populations of *Z. canadensis* were considered high and thus potentially damaging if more than 5 larvae were found per upper crown branch segment. Control measures were deemed necessary for populations exceeding this threshold level. Populations were considered low, and thus not potentially damaging, if less than 5 larvae were found per upper crown branch segment. The authors stated that to obtain accurate estimates of *Z. canadensis* population levels one need only sample trees less than 4 m in height.

Sampling Procedure

Select at least 5 trees randomly within the area of concern. Cut a 15-cm branch segment from the upper third of the crown of each tree (Fig. 1). Sample until the cumulative number of larvae rises above or drops below the decision thresholds (Fig. 7).

Z. canadensis eggs: If the population of *Z. canadensis* is still in the egg stage, then cut out the previous years' bud scales (Fig. 1) and place them in a Mason jar. Place a lid on the Mason jar, replacing the metal center with an equal size piece of filter paper. Store at room temperature with at least 16 h of light daily. Each day, check all jars, count and remove all *Z. canadensis* larvae. Maintain colony a week after the last larva has been removed (note: larvae may need to be reared on budmoth diet until they can be correctly identified as *Z. canadensis*). This method can be carried out well before *Z. canadensis* becomes active in the field, providing enough preparation time if control measures are determined to be necessary.

Z. canadensis larvae: If the population of *Z. canadensis* is in the larval stage, and the majority of shoots have not elongated and still have bud scales on their tips, then sample as described at the beginning of this section. Each shoot will need to be dissected by removal of the bud scale covering the tip of each shoot. Feeding *Z. canadensis* or their damage should be readily visible beneath the bud scale. If the majority of shoots have elongated and most of the bud scales have fallen from the tips of the shoots, then sample as described at the beginning of this section. Shoots with bud scales still attached to the shoot tip will usually contain a larva. However, examine carefully all shoots for presence of this forest pest.

Figures

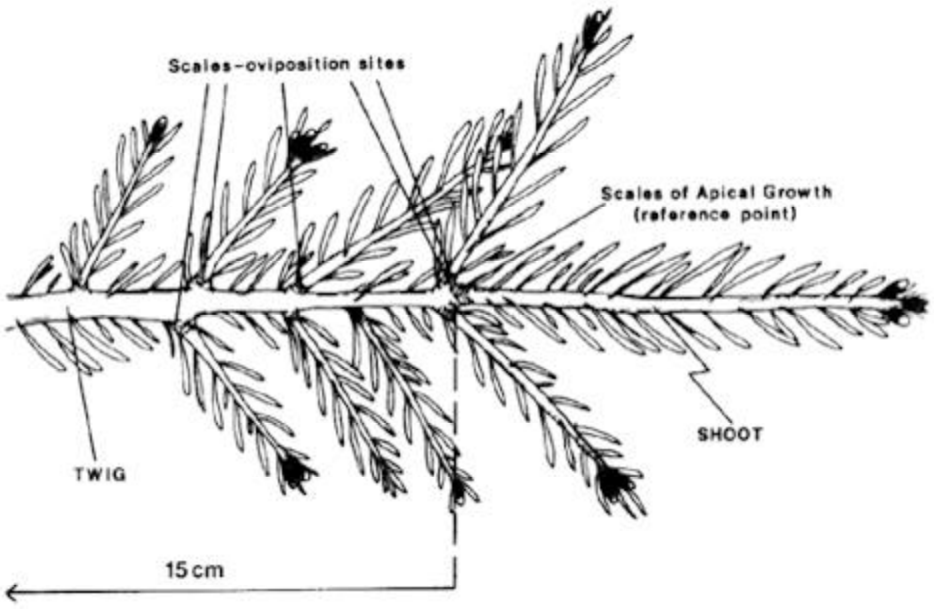

Fig. 1. Illustration of a white spruce branch (late July), showing the terms defined and the measurement methods described in the text.

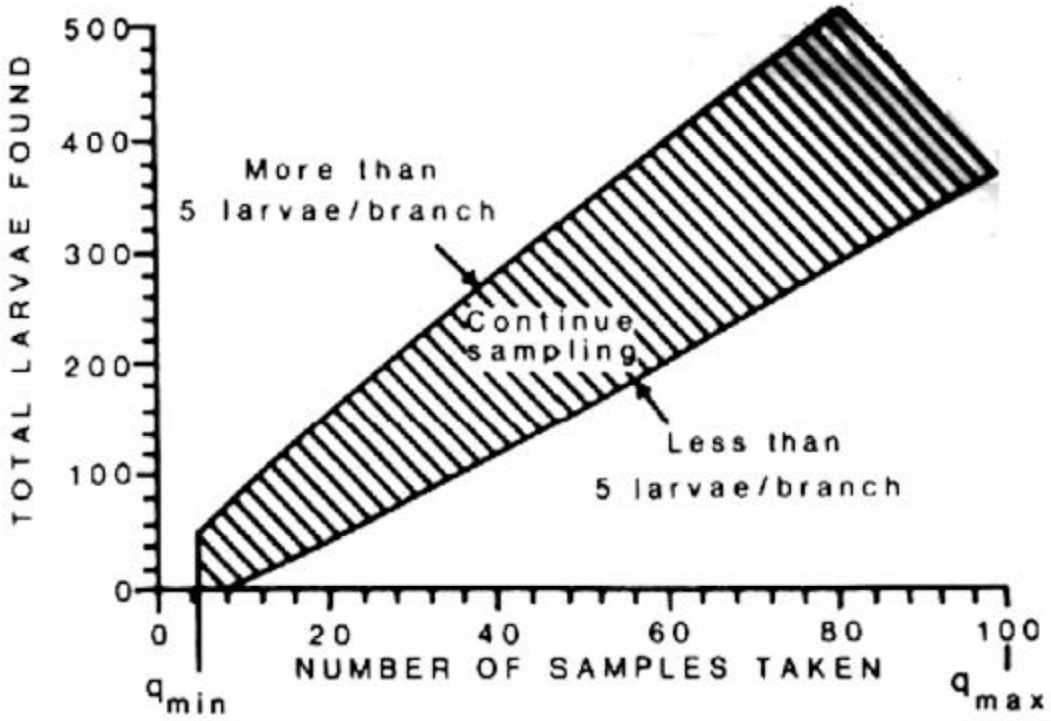

Fig. 7. Sequential sampling plan for larvae of *Z. canadensis* in the upper third of crown of white spruce based on a critical level of five larvae per 15-cm branch segment. Minimum sample size: 5; maximum: 100; equation [7]).

Figures 1 and 7 reprinted with permission from the Canadian Entomologist, January 15, 2001.

DEFOLIATING INSECTS

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

Objective

To develop a monitoring system for *P. luteola* for control decision-making.

Abstract

The elm leaf beetle, *Pyrrhalta luteola* (Müller), is one of the most important urban elm, *Ulmus* spp., pests in the USA and Canada. Most damage is caused by larval feeding, which skeletonizes the leaves. Recently, monitoring methods have become an integral part of the Integrated Pest Management (IPM) program for *P. luteola*. A monitoring program was developed from 1984-1993 in California, which predicts damage levels based on the occurrence of egg clusters on eight elm branch terminals in the lower crown of each tree sampled.

Sampling Procedure

Refer to Table 1 to determine the number of trees to be sampled depending on surrounding elm densities. Sample trees should be selected randomly for the first sample, and then resampled again on each sample date. Collect one 30-cm branch tip from both the inner and outer crown in four cardinal directions (n = 8). Remove samples during peak egg deposition (233 and 903 degree-days °C) for generations 1 and 2.

Record damage ratings by visual estimation of adult and larval defoliation on each branch terminal sampled from a scale of 0-10, where 0 equals 0% defoliation and 10 equals 100% defoliation. In locations having one generation per season, damage is assessed at the end of the season in the fall. For locations having greater than one generation per season, damage is rated for each generation. A damage threshold of 4 (40% defoliation) was established for the first generation. If 45% or less of samples have viable egg clusters present, then damage at the end of that generation will be tolerable and control is not warranted (probability of error = 10%). In the second generation, a maximum of 30% defoliation is acceptable. Weekly monitoring, beginning at approximately 50 degree-days (°C) before the predicted peak egg deposition for each generation and continuing for an additional week, was recommended.

Notes

Degree-day predictions for peak egg deposition are based on a lower developmental threshold of 11°C with accumulations beginning March 1. The corresponding predictions for each generation may vary with location. This method can also be used to estimate egg parasitism rates for evaluating the effectiveness of a biocontrol program.

Table

Table 1. Suggested sample size for elm leaf beetle egg cluster monitoring on English elm in stands of different sizes. Eight locations per tree are sampled: north, east, south and west; inner and outer crown.

Total trees	Sample trees	Samples/tree	Samples/ segment	Total samples	Trees (%)
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

Criteria: (1) Minimum of 128 branches should be sampled. (2) Minimum of 25% of the trees should be sampled.

Table reprinted from Dahlsten and others 1998, California Agriculture 52: 17-23, copyrighted by University of California Regents.

Redheaded Pine Sawfly

Neodiprion lecontei (Fitch)
Hymenoptera: Diprionidae

Wilson, L. F.; Wilkinson, R. C., Jr.; Averill, R. C. 1992. Redheaded pine sawfly—its ecology and management. Agric. Handbook 694. East Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 54 p.

Objectives

To evaluate the risk of potential injury from *N. lecontei*; to detect if *N. lecontei* or its damage is present at any particular time or place; and to evaluate population density or its potential to cause injury.

Abstract

The redheaded pine sawfly, *Neodiprion lecontei* (Fitch), is a major regeneration pest of pines, *Pinus* spp., in the eastern USA. The larvae feed gregariously on new and old needles of most eastern pines and also on the tender bark of young seedlings. The degree of damage is highly variable, depending on stress levels of infested trees. Young pines in plantations and nurseries are particularly susceptible to damage, and therefore need to be monitored regularly.

Several kinds of surveys are available for rating the risk of potential damage from *N. lecontei* and for detecting, evaluating, and suppressing populations. Risk of injury is a concern even before trees are planted because the condition of the site can affect the fecundity and survival of *N. lecontei*. Should the risk of injury be detected from the survey, management guidelines can be applied that maintain healthy, productive plantations.

Sampling Procedure

Risk survey: Prospective pine sites should be rated for risk of potential *N. lecontei* injury before planting. Risk ratings on established sites are not necessary if pines are taller than 4.5 m in the North, and taller than 8 m in the South. To evaluate risk, consider proximity to brood sources (do not plant within 1.6 km), soil type and moisture holding capacity, associated vegetation, and previous land use. Please refer to original publication for more details.

Detection survey**:** Detection surveys are usually evaluated on the ground either casually or systematically, but can also be done via low flying aircraft when infestation levels are heavy. Once presence of the insect is detected by any one method, cease surveying. Sample high risk areas until one of the following symptoms or signs is found:

> Damage: Look for clusters of needles that have been skeletonized and resemble bottle brushes. This type of injury indicates that feeding has begun recently. In most instances, new and old needles will be missing on portions of the branches.

Eggs: Eggs are laid in the needles and appear as a row of cream yellow spots on the edge of needles growing in a cluster (Fig 1). In the North, eggs are deposited on the old growth needles only. In the South, eggs may also be deposited on newly formed needles. Egg-bearing new growth needles can often be identified at a distance because they curl in response to infestation.

Larvae: Larvae are observed easily as they tend to feed gregariously. Colonies of *N. lecontei* larvae from a few up to 100 individuals will be found on the edges of defoliated branches feeding on the remaining green foliage (Fig. 2).

Frass: Small piles of frass may be noticeable on the ground below the defoliated branches. Each pellet is cylindrical in shape with oblique ends, and is less than 2 mm in length and 1 mm wide.

Cocoons: To find cocoons, search the upper 5 cm of soil beneath the crowns of defoliated trees.

Adults: Male *N. lecontei* can be monitored by using pheromone-baited sticky traps. Place the trap at 1-2 m intervals within trees before the predicted male flight period and monitor regularly.

Evaluation survey: In order to obtain accurate information, timing is a critical component to evaluation surveys. Since *N. lecontei* phenology follows closely that of its host, the use of indicator plants along with particular events in their life cycle can aid in predicting emergence.

Surveys for eggs and larvae: Samples should be taken systematically along transects every 25 m. Examine each tree carefully for the presence of eggs and larvae, and record each tree as either infested or uninfested (1 = infested and 0 = uninfested). Sampling should continue until all the high risk areas are surveyed. When sampling is complete, calculate the percentage of trees that are infested. Depending upon location and tree size, different decision levels apply:

Damage surveys: This survey helps to determine tree mortality and growth loss of northern pines. Unlike most southern pines, northern pine species usually succumb to defoliation levels greater than 90% in a single year (Benjamin 1955). Conduct the survey systematically, recording

Location	**Tree Height**	**If the infestation level is . . .**	**Then . . .**
North	<2 m	≥10%	CONTROL IS JUSTIFIED
	>2 m	≥20%	
South	<3 m	≥10%	
	>3 m	≥20%	

NOTE: In Christmas tree plantations, control measures should be taken as soon as the insect is detected.

the nearest tree every 10 paces as either <90% defoliated, or >90% defoliated. At the end of the survey, determine the proportion of trees having >90% defoliation, and consider this figure to represent the expected mortality rate. Trees suffering <90% defoliation eventually recover well enough to avoid significant growth losses at harvest.

Note

The reader must have a significant understanding of the phenology of *N. lecontei* in their region in order to time the sampling of specific life stages properly in the field.

Reference

Benjamin, D. M. 1955. The biology and ecology of the red-headed pine sawfly. Tech. Bull. 1118. Washington, DC: U.S Department of Agriculture, Forest Service; 57 p.

Figures

Fig. 1 - Eggs appear as rows of yellow-white spots along the edges of individual needles growing in a cluster.

Fig. 2 - Colonies of up to 100 larvae are usually found on the needles at the juncture of the foliage and the defoliated branch.

Connola, D. P.; Waters, W. E.; Nason, E. R. 1959. A sequential sampling plan for red-pine sawfly *Neodiprion nanulus* Schedl. Journal of Economic Entomology 52: 600-602.

Objective

To develop a sequential sampling plan for *N. nanulus nanulus* defoliation.

Abstract

The red pine sawfly, *Neodiprion nanulus nanulus* Schedl., can cause considerable damage to red pine, *Pinus resinosa* Ait., plantations in the northeastern USA and Canada. The larvae are gregarious and usually consume all of the mature needles from one branch before migrating to another branch. Little or no tree mortality results from complete defoliation in a single year, but can occur with repeated defoliation in multiple years. Eggs are laid in the needles in early fall, and do not hatch until the following spring, which offers ample opportunity to determine if control is warranted. A sequential sampling plan, based on the number of egg-infested needles on a 15-cm twig, is presented to predict damage levels. Damage is classified as either zero to light or moderate to heavy defoliation.

One twig is sampled from each of five trees, the cumulative number of egg infested needles is recorded, and then compared to the sequential sampling table (Table 1). If further sampling is required to reach a decision, the sixth sample should be taken from the first tree sampled. This method continues until each of the five trees have been sampled up to five times in order to reach a decision. If after 25 twig samples are obtained no classification decision is reached, then decisions are made on the basis of whether or not the count is closer to 21 (zero to light infestation) or 49 (moderate to heavy infestation) and classified accordingly. A field validation test showed that predictions failed only once in 25 attempts (i.e., 96% precision).

Sampling Procedure

Follow the sequential plan in Table 1. Sampling sites should be distributed evenly within a plantation. In large plantations, sampling should be done every 1.6-2 ha. Sample in fall and winter when eggs are present.

Sample one 15-cm long twig from each of five trees. Count and record the cumulative number of egg infested needles and then refer to Table 1. If further sampling is necessary to reach a decision, then take a sixth sample from the first tree sampled. This method continues until each of the five trees have been sampled up to five times. If after 25 twig samples are obtained no decision is reached, then base your decision on whether or not the count is closer to 21 (zero to light infestation) or 49 (moderate to heavy infestation). The confidence level for this plan was set at 90%.

Table

Table 1. Sequential sampling plan for red-pine sawfly egg populations on 15-cm red pine tips.

No. twig samples	Cumulative total number of egg-infested needles		
	No. expected to produce zero to light defoliation	Range within which the amount of defoliation expected is doubtful[a]	No. expected to produce moderate to heavy defoliation
1	—	0-14	≥15
2	—	0-16	≥17
3	—	0-17	≥18
4	—	0-19	≥20
5	—	0-20	≥21
6	—	0-21	≥22
7	—	0-23	≥24
8	—	0-24	≥25
9	—	0-26	≥27
10	0	1-27	≥28
11	≤1	2-28	≥29
12	≤3	4-30	≥31
13	≤4	5-31	≥32
14	≤5	6-33	≥34
15	≤7	8-34	≥35
16	≤8	9-35	≥36
17	≤9	10-37	≥38
18	≤11	12-38	≥39
19	≤12	13-40	≥41
20	≤14	15-41	≥42
21	≤15	16-42	≥43
22	≤17	18-44	≥45
23	≤18	19-45	≥46
24	≤19	20-47	≥48
25	≤21	22-48	≥49

[a] Continue sampling if count falls in this column.

Note: Chances are 1 in 10 that defoliation will be predicted incorrectly.

Table 1 reprinted with permission of the Journal of Economic Entomology, January 15, 2001.

Talerico, R. L.; Wilson, R. W., Jr. 1978. A sampling device for counting insect egg clusters and measuring vertical distribution of vegetation. Research Note NE-250. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 4 p.

Objective

To develop an efficient, accurate sampling method to estimate *N. sertifer* density in the field.

Abstract

The European pine sawfly, *Neodiprion sertife*r (Geoffroy), was introduced into North America in 1925 and now occurs throughout the north-central and northeastern USA and Canada. The pest feeds on two- and three-needle pines, but often causes little damage as feeding occurs almost exclusively on old foliage. Eggs are laid in the fall in loose clusters, and are often used as a means to estimate population density. Lyons (1964) recommended the use of whole trees as sample units, which are rather costly to sample unless the trees are quite small. The use of a vertical sampling pole that delineates known foliage volumes was used to count *N. sertifer* eggs and egg clusters.

The sampling pole was a 2.5 cm diameter and 183 cm long hardwood pole intersected with wooden dowels at 30 cm intervals. This tool can be used to quantify the amount of foliage, estimate coverage, and to determine the distribution of damage. The number of eggs per cluster was found to range from 60-170, with a mean of 59.3 ± 6.28 eggs per cluster, using this method.

Sampling Procedure

The authors describe the sampling pole as a hardwood pole, 2.54 cm in diameter and 183 cm in length, intersected by 0.95 cm diameter wooden dowels at 30 cm intervals. Each dowel is at a right angle to the one below. Drill a 0.5 cm vertical hole near the end of each dowel (i.e., holes are 21 cm apart), and string a sighting wire from top to bottom of the pole through each hole (refer to Fig. 2 in the original publication). The dowels and sighting wires delineate a 7000 cm^3 volume.

Place the sampling pole as close as possible to the sample tree. Record the amount of current year's foliage, and number of eggs and egg clusters within each vertical sample unit. Divide the total number of eggs or egg clusters by the amount of current year's foliage to determine egg density per unit foliage.

Note

Variable sampling volumes can be created by simply changing the distance between dowels and sighting wires.

Reference

Lyons, L. A. 1964. The spatial distribution of two pine sawflies and methods of sampling for the study of population dynamics. Canadian Entomologist 96: 1373-1407.

European Pine Sawfly

Neodiprion sertifer (Geoffroy)
Hymenoptera: Diprionidae

Wilson, L. F.; Gerrard, G. J. 1971. A new procedure for rapidly estimating European pine sawfly (Hymenoptera: Diprionidae) population levels in young pine plantations. Canadian Entomologist 103: 1315-1322.

Objective

To estimate the population density of *N. sertifer* based on the proportion of infested trees in a random sample.

Abstract

The 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. The pest feeds on two- and three-needle pines, but often causes little damage as feeding occurs almost exclusively on old foliage. A method was proposed for rapidly estimating the population levels of *N. sertifer* in young red, *Pinus resinosa* Aiton, and Scots pine, *P. sylvestris* L., plantations.

Sampling Procedure

An estimate of the mean number of *N. sertifer* larvae per tree (Y) may be predicted from the proportion (p) of trees infested by the equation

$$Y = k\,[(1/1\text{-}p)^{1/k} - 1]$$

where k is an estimate of a distribution parameter, and is derived beforehand by Maximum Likelihood from a series of insect populations representative of those where predictions are contemplated. Data from sampled sites derived a k-value of 1.37, yielding a curve that accounted for 91% of the variation among the means. To prevent loss of growth and vigor, control should be considered on trees 1.5-2.5 m tall when the mean number of colonies (Y) is ≥5 colonies per tree (Wilson 1966).

Notes

While the population means may vary from plantation to plantation, the aggregation index (k) is constant. The proportion of samples greater than 0.9 does not make adequate estimates and needs additional points for improvement. Due to the detailed nature of this particular study, we refer you to the origin publication for more information concerning the sampling procedures and associated statistical equations.

Reference

Wilson, L. F. 1966. Effects of different population levels of the European pine sawfly on young Scotch pine trees. Journal of Economic Entomology 59: 1043-1049.

Tostowaryk, W.; McLeod, J. M. 1972. Sequential sampling for egg clusters of the Swaine jack pine sawfly, *Neodiprion swainei* (Hymenoptera: Diprionidae). Canadian Entomologist 104: 1343-1347.

Objective

To develop a sequential sampling plan that determines the intensity of *N. swainei* infestations.

Abstract

The Swaine jack pine sawfly, *Neodiprion swainei* Middleton, is one of the most important defoliators of pine, *Pinus* spp., throughout Canada and the Lake States. The larvae are gregarious and feed primarily on older foliage. Numerous outbreaks occur on regular eight year cycles in jack pine, *P. banksiana* Lamb., stands in Ontario and Quebec. Heavy tree mortality often occurs in stressed, senescing stands. A sequential sampling method for egg clusters of *N. swainei* is described that classifies infestations as either light (≤ 3.3 egg clusters per tree), moderate (8.3-14 egg cluster per tree) or severe (≥26 egg clusters per tree). The maximum number of trees to be sampled is 10.

Sampling Procedures

Select a codominant or dominant jack pine randomly within the area of concern and fell the tree. Remove, count, and record the number of shoots bearing egg clusters. Sampling follows the sequential table until the cumulative number of egg clusters exceeds a decision level (Table 2). The maximum number of trees to be sampled is 10. If after sampling 10 trees no decision is met, the following rule is applied

Light-moderate band:	if d <51 classify as light or ≥51 classify as moderate
Moderate-severe band:	if d <188 classify as moderate or ≥188 classify as severe, where d represents the cumulative number of egg clusters.

Sampling should be conducted any time after oviposition is complete. To do this a dominant or co-dominant tree is chosen and d.b.h. is measured. The nearest dominant or co-dominant trees are then chosen and their diameter recorded until 20 trees are tallied. The tree with the smallest diameter is then used as a base line for sampling successive trees.

Table

Table 2. Sequential plan for sampling Swaine jack pine sawfly, *Neodiprion swainei* Middl., populations based on the number of egg clusters per tree.

No. of trees		Cumulative number of egg clusters							
		≤		≥		≤		≥	
1		—		—		—		83	
2		—		—		—		102	
3		2		—		—		120	
4		7		—		—		139	
5	*Light*	12	*Continue Sampling*	—	*Moderate*	—	*Continue Sampling*	158	*Severe*
6		17		44		49		177	
7		22		49		68		196	
8		27		54		86		214	
9		33		59		105		233	
10		38		64		124		252	

Table 2 reprinted with permission from the Canadian Entomologist, January 15, 2001.

Hard, J. S. 1971. Sequential sampling of hemlock sawfly eggs in southeast Alaska. Res. Note PNW-142. Portland, OR: U.S. Department of Agriculture, Forest Service; 9 p.

Objectives

To classify population densities of *N. tsugae* quickly and with known confidence, and to enable intergeneration comparisons of density.

Abstract

The hemlock sawfly, *Neodiprion tsugae* Middleton, is an important defoliator of western hemlock, *Tsuga heterophylla* (Raf.), in southeast Alaska. Females insert eggs singly into the edges of hemlock needles in the fall. Following a lengthy overwintering period, larvae emerge the following June. The period from October through June provides an opportunity for estimating population levels of *N. tsugae* based on egg density.

Neodiprion tsugae egg densities are classified rapidly through examination of branch samples from the upper crowns of intermediate-sized western hemlock trees. Branch samples are examined until a single egg is found, which reduces greatly the amount of time spent sampling. A tree is classified as infested if the sample yields one or more eggs, and uninfested if it yields none. The percentage of infested trees is used to classify populations as light (≤33.3% infested) or moderate to heavy (≥50% infested).

Sampling Procedure

Select trees and plots randomly within the area of concern. Climb or fell the nearest intermediate crown class western hemlock and remove four 46-cm branch tips from the midpoint of the upper crown. Examine each sample for eggs. If a single egg is found, record as infested, discontinue sampling, and disregard the rest of the sample from that tree. If after examining all four branches, no eggs are found, the tree is classified as uninfested. Using the sequential sampling form (Fig. 3), and beginning at the origin of the graph, draw a line up one square for an infested tree or a line right one square for a uninfested tree. Discontinue sampling once a decision threshold is crossed (Fig. 3). If a decision is not met, sampling should be discontinued at 15 trees and the plot considered a borderline case. Stands are classified as light populations if ≤33.3% of sample trees have eggs and moderate to heavy if ≥50% of sample trees have eggs.

Notes

Only eggs deposited during the current generation are counted. Eggs from the previous generation, which appear brown, may still be found but should not be considered. If the infested area is relatively large, a single plot may not be adequate to provide a useful population index.

Figure

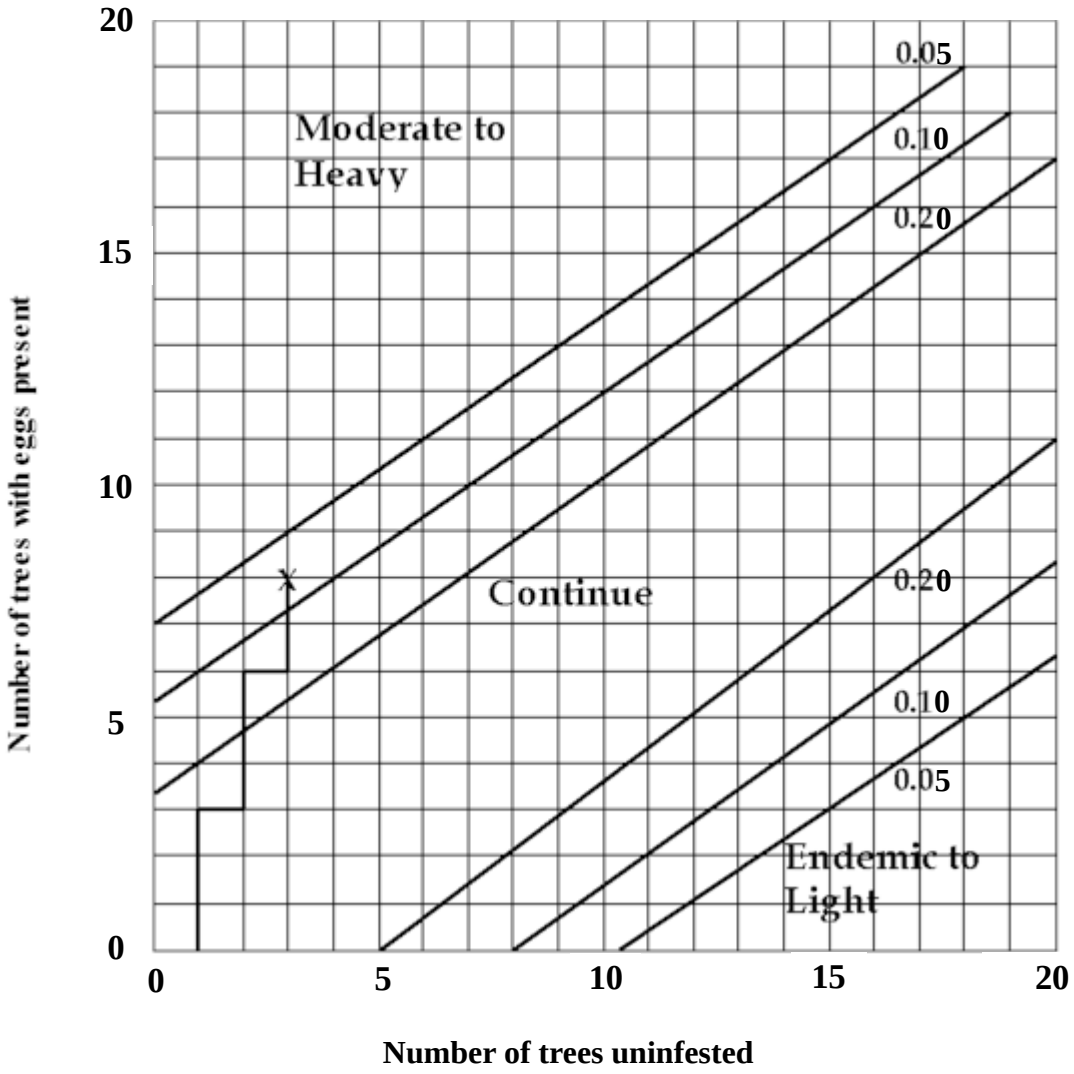

Figure 3. Hemlock sawfly egg sequential sampling.

Ciesla, W. M.; Bousfield, W. E. 1974. Forecasting potential defoliation by larch casebearer in the northern Rocky Mountains. Journal of Economic Entomology 67: 47-51.

Objective

To predict defoliation by *C. laricella* using counts of overwintering larvae.

Abstract

The larch casebearer, *Coleophora laricella* (Hübner), is an introduced species first recorded in Massachusetts in 1886. It now occurs throughout most of the range of larch, *Larix* spp. *Coleophora laricella* overwinters as third instar larvae within a larval case attached to the base of needle fascicles (i.e., spur shoots) after the trees have shed their foliage. Heavy losses result from reduced growth and twig mortality. Trees defoliated completely for two or more consecutive years are usually killed.

The quadratic regression model, $Y = 4.015 + 0.4419X - 0.001036X^2$, for forecasting defoliation potential by *C. laricella*, was developed on western larch (Fig. 4). The model uses counts of overwintering third instar *C. laricella* on 40 branch samples per sample point (X) to forecast feeding injury, which is expressed as a numerical rating (Y), and can be translated into negligible, light, moderate, and heavy defoliation. The procedure classified defoliation levels correctly on 83% of the sample plots for the first year's data, and 64% for the second year's data. Predictions were within one defoliation class 98% of the time during both generations.

Sampling Procedure

Collect four branch samples of at least 100 spur shoots (25 per branch) from the mid-crown of 10 dominant or codominant western larch with pole pruners (n = 1000). In the laboratory, count the number of overwintering third instar larvae on the terminal 100 spur shoots per sample (X). Compare this value to the threshold limits in Table 3 to determine the predicted defoliation class as negligible (no visible defoliation or discoloration), light (<26% foliage discolored), moderate (26-50% foliage discolored) or heavy (>50% foliage discolored).

Notes

Other variables such as elevation, natural enemy abundance, foliage volume, infestation age and climatic factors can alter the relationships observed in this study. This study was conducted in natural stands of western larch, 9-15 m in height, adjacent to logging roads. The applicability of these results may be limited to similar stands.

Figure and Table

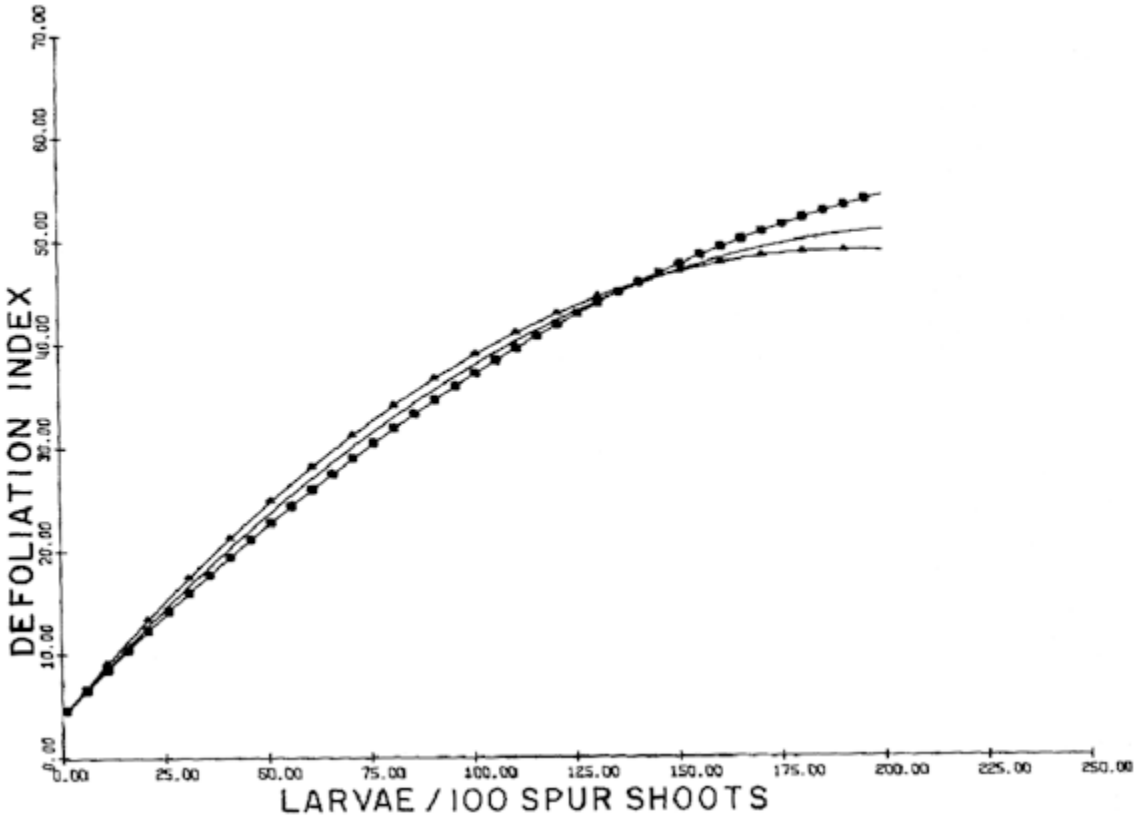

Fig. 4. Curve of larch casebearer defoliation; prediction equation $Y = 4.015+0.4419x-0.001036X^2$, based on 2-year data, data vs. curves for the 1970-71 generation (circles) and 1971-72 generation (triangles).

Table 3. Overwintering larch case bearer population density and predicted defoliation based on the equation $Y=4.015+0.4419X-0.00104X^2$.

No. overwintering larvae/100 spur shoots (x)	Defoliation index (y)	Predicted defoliation
0 - 11.5	0 - 8.9	Negligible
11.6 - 60.4	9.0 - 26.9	Light
60.5 - 136.5	27.0 - 44.9	Moderate
136.6 - 236.75[a]	45.0	Heavy

[a]Highest population density observed.

Figure 4 and Table 3 reprinted with permission from the Journal of Economic Entomology, January 15, 2001.

Stark, R. W. 1952. Sequential sampling of the lodgepole needle miner. Forest Chronicle 28: 57-60.

Objective

To develop a sequential sampling plan for classifying populations of *C. milleri.*

Abstract

The lodgepole needle miner, *Coleotechnites milleri* (Busck), is an important defoliator of lodgepole pine, *Pinus contorta* Dougl., in the western USA. Infestations cause severe growth loss and extensive tree mortality as is evidenced in the Ghost Forest of Yosemite National Park. A sequential sampling program for estimating *C. milleri* populations was developed. Four to eight branch tips were sampled from the lower and upper crown in each tree until a classification was reached. Populations were classified as either light (≤5), medium (15-25), or heavy (≥35 larvae per branch tip).

Sampling Procedure

Collect an equal number of branch tips from the upper and lower crown of lodgepole pines. Although there is no fixed sample size, it is recommended that four to eight branch tips be sampled per tree, taking four from the upper crown and four from the lower crown. Cut back branch tips to include 5-year old needles and record the number of viable larvae. Continue sampling trees until the cumulative number of larvae, when plotted, crosses one of the four lines on the sequential graph (Fig. 1). Error estimates are 5% for medium and heavy infestations, and 10% for light infestations.

Figure

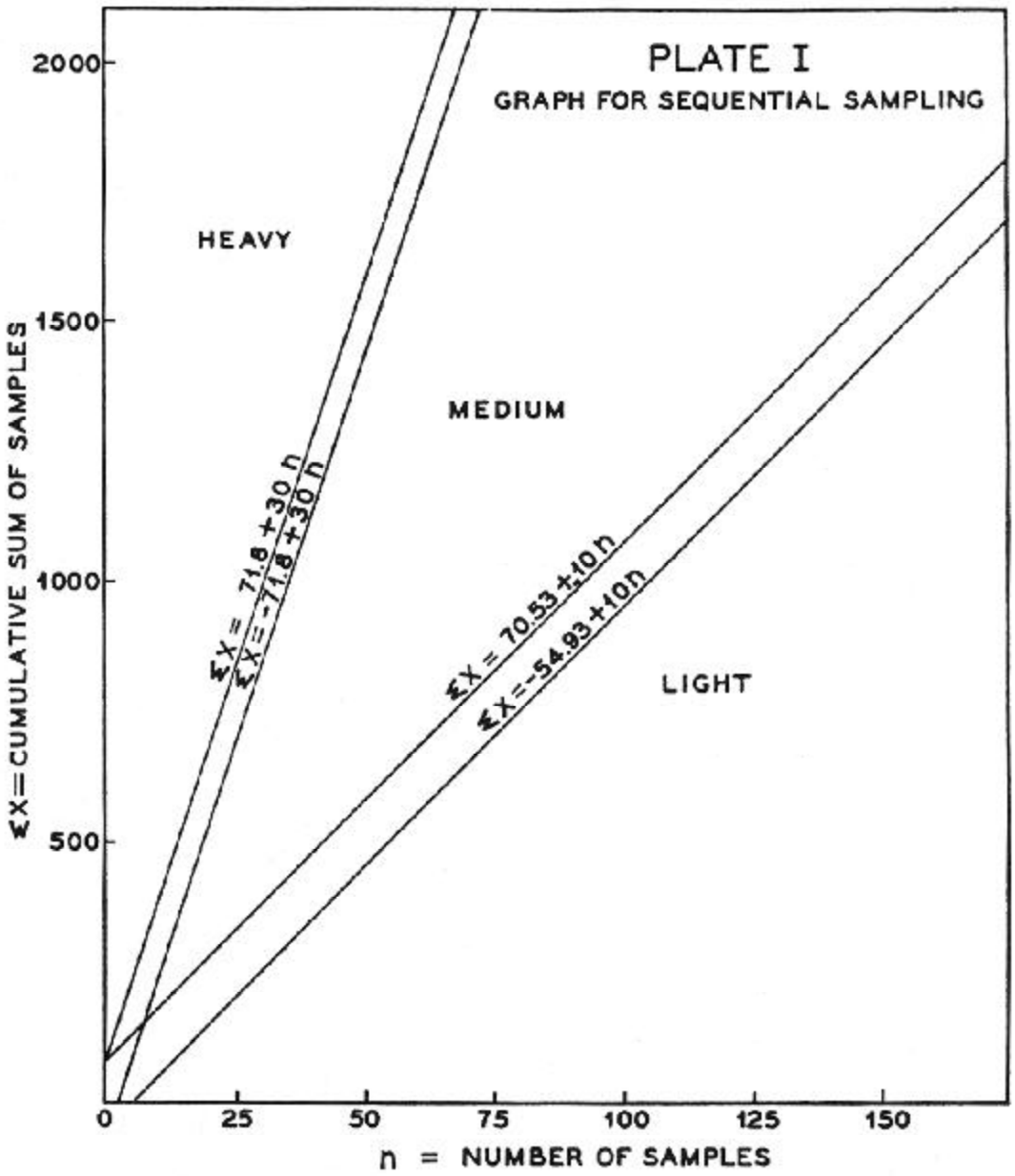

Figure 1. Sequential sampling plan for classifying populations of *Coleotechnites milleri* as light (error = 10%), medium or heavy (error = 5%) based on the cumulative number of larvae sampled.

Figure reprinted with permission from The Forest Chronicle, January 15, 2001.

Stevens, R. E.; Stark, R. W. 1962. Sequential sampling for the lodgepole needle miner, *Evagora milleri.* Journal of Economic Entomology 55: 491-494.

Objective

To develop a sequential sampling plan for classifying population densities of *C. milleri.*

Abstract

The lodgepole needle miner, *Coleotechnites milleri* (Busck), is an important defoliator of lodgepole pine, *Pinus contorta* Dougl., in the western USA. Infestations cause severe growth loss and extensive tree mortality as is evidenced in the Ghost Forest of Yosemite National Park. A sequential sampling program is presented, which is based on Stark (1952). This modified plan is designed primarily for use in extensive surveys and control operations. It was developed for the sampling of late instar larvae, but may also be used for earlier ones. Population were classified as either light (<8), medium (12-22), heavy (26-36) or very heavy (>40 larvae per branch tip).

Sampling Procedure

The sampling unit is a branch tip cut back to include only 2-year old needles. Sample 12-15 trees (approximately 0.1 ha) randomly and a minimum of 20 branch tips per plot in the area of concern. Remove samples with pole pruners from the mid-crown. Once branches are felled, trim the latest two years' infested growth. Count all insects in the field, recording all newly-hatched larvae as alive. As larvae develop, differentiating between live and dead larvae is possible by simply tapping the needle. When the total number of live larvae falls into one of the decision classes, discontinue sampling (Table 1).

Notes

All pupae are considered alive due to the difficulty in differentiating between live and dead pupae. Sampling the last two whorls of foliage gave meaningful estimates of the population in this study, but may not hold true elsewhere. The authors suggest preliminary sampling to determine if the population is distributed uniformly along the branch. If it appears that the average annual needle production per tip deviates heavily from 60, another sequential graph should be made to reflect those differences.

Reference

* Stark, R. W. 1952. Sequential sampling of the lodgepole needle miner. Forest Chronicle 28:57-60.

Table

Table 1. Abbreviated sequential table for field use in sampling lodgepole needle miner larval populations.

No. of samples	Cumulative number of larvae											
		Light		Medium		Medium		Heavy		Heavy		Very heavy	
11	Light	1	Continue sampling	—	Medium	—	Continue sampling	—	Heavy	—	Continue sampling	528	Very heavy
15		40		—		—		—		—		680	
20		90		310		370		590		650		870	
25		140		360		490		710		840		1060	
30		190		410		610		830		1030		1250	
35		240		460		730		950		1220		1440	

Table 1 reprinted with permission of the Journal of Economic Entomology, January 15, 2001.

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

Objectives

To develop a sequential sampling plan to aid in monitoring population density; and to crudely forecast the amount of defoliation caused by *L. fiscellaria fiscellaria*.

Abstract

The eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenée), causes severe defoliation, growth loss, and subsequent mortality in balsam fir, *Abies balsamea* (L.) Mill., stands. The young larvae feed on a variety of hosts, but survive best on newly developing balsam fir needles. Older larvae feed indiscriminately, and defoliation is usually evident by late July to early August. A sequential sampling plan that classifies defoliation levels as light or severe was derived for *L. fiscellaria fiscellaria* egg populations in Newfoundland, Canada.

More eggs were found on mid-crown balsam fir branches than on other sampling substrates, including ground mosses, loose bark from white birch, *Betula papyrifera* Marsh., and crown lichens. An average of less than 6 mid-crown branches is required to reach a decision. Infestations were classified as light (<25% defoliation; ≤4 eggs per branch) or severe (75% defoliation; ≥10 eggs per branch).

Sampling Procedure

Remove one mid-crown branch randomly from balsam fir with pole pruners. Soak branches in 2% solution of sodium hypochlorite (NaOCl) for 45 min. Agitate the solution vigorously for 5 min then filter through a nest of sieves to extract eggs, which were classified as fertile (brown), infertile (green), or parasitized (black). The relationship between defoliation and egg density suggests a damage boundary of ≤4 eggs per branch for light infestations (<25% defoliation), and ≥10 eggs per branch for severe infestations (>75% defoliation). Consult Table 3 for the number of samples required to reach a decision (error = 10%). Continue sampling until the cumulative number of eggs reaches or exceeds a decision threshold. Defoliation below the lower limit is predicted to be light, while those that exceed the upper limit will be severe. No more than six branches should be required to reach a decision.

Note

These data are specific to spruce-fir forests of Newfoundland and may not yield statistically sound decisions in other regions.

Table

Table 3. Sequential sampling table for hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenée), egg populations on whole branch samples of balsam fir, *Abies balsamea* (L.) Mill., in Newfoundland.

No. of whole branch samples	No. of eggs[a]		
	Cumulative total eggs	Lower limit	Upper limit
1	---	0	19
2	---	0	25
3	---	5	32
4	---	11	38
5	---	17	44

[a] Sampling should be continued until cumulative total eggs exceeds or equals upper limit or is less than or equals lower limit. For lower limit, light defoliation is recommended, whereas for upper limit, severe defoliation is recommended.

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.

Objective

To describe an efficient method of processing moss and bark for sampling *L. fiscellaria fiscellaria* eggs.

Abstract

The eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenée), causes severe defoliation, growth loss and subsequent mortality in balsam fir, *Abies balsamea* (L.) Mill., stands. The young larvae feed on a variety of hosts, but survive best on newly developing balsam fir needles. Older larvae feed indiscriminately, and defoliation is usually evident by late July to early August. Traditional sampling procedures for newly-hatched larvae provide only 2 weeks advance notice for control scheduling. Eggs are present from September to June, and could be sampled in fall, thereby providing ample time for planning control actions the following spring. Bleach solutions (2, 5, 10, 15, and 20%) were examined for their potential to loosen eggs from shredded moss and bark samples.

The stronger solutions (5, 10, 15, and 20%) released eggs quicker than the weakest one, but the eggs disintegrated following soaking. A 2% bleach solution bath for 45 minutes will release *L. fiscellaria fiscellaria* eggs without deleterious effects. This sampling technique is more efficient and permits egg sampling over more extensive areas than the use of direct observations.

Sampling Procedure

Collect moss and bark samples containing *L. fiscellaria fiscellaria* eggs within the area of concern. Soak samples in a 2% bleach solution for 45 min in a mechanical shaker to separate eggs from their substrate. Remove large debris and filter the remainder through Number 10 and 40 sieves to collect eggs. Rinse screens under running water for 10 min to halt the corrosive action of the bleach. Wash eggs onto filter paper, and place under a dissecting microscope to tally. Hand shredding of moss and bark samples into smaller pieces increased significantly the number of eggs obtained. Eggs collected by this method can be used subsequently to determine egg viability.

Western Hemlock Looper

Lambdina fiscellaria lugubrosa (Hulst)
Lepidoptera: Geometridae

Carolin, V. M.; Johnson, N. E.; Buffam, P. E.; McComb, D. 1964. Sampling egg populations of western hemlock looper in coastal forests. Res. Pap. PNW-14. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 15 p.

Objectives

To determine the best sampling unit for detecting infestations; to determine preferred locations of egg deposition on codominant western hemlock, *Tsuga heterophylla* (Raf.) Sarg. trees, and on ground sites below these trees; and to determine which ground-site samples produce estimates representative of egg deposition on the tree.

Abstract

The western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is a destructive defoliator that causes damage periodically to western hemlock stands and other coniferous hosts. Outbreaks occur every 11-17 years in coastal areas of the Pacific Northwest. The infestations arise suddenly, persist for 3 years, and cause growth reduction, top kill, and tree mortality. Most outbreaks occur in mature and senescing stands of western hemlock intermixed with Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franc., sitka spruce, *Picea sitchensis* (Bong.) Carr., Pacific silver fir, *Abies amabilis* (Dougl.) Forbes, and western red cedar, *Thuja plicata* Donn.

Potential outbreaks must be detected at an early stage and evaluated so that direct control can be applied promptly. Sampling of egg populations has been directed at mossy surfaces accessible from the ground or overstory trees, but never both. Studies to determine the distribution of *L. fiscellaria lugubrosa* eggs on both overstory trees and ground sites were conducted to improve sampling techniques for detecting and evaluating infestations over large areas.

Sampling Procedure

An in-depth study of possible sampling locations for correlating egg density with defoliation levels is discussed. Due to the high costs of tree felling to obtain samples and the high error associated with all sampling locations, no procedure is recommended for estimating egg density. However, detection of looper infestations may be accomplished by visual examination of mossy log surfaces and bole sections at breast height, which were found superior to tree crown units.

Liang, Q.; Otvos, I. S.; Bradfield, G. E. 1996. Distribution pattern and sampling of eggs of the western hemlock looper (Lepidoptera: Geometridae) in mature western hemlock stands. Journal of Economic Entomology 89: 1531-1536.

Objectives

To determine the vertical distribution of eggs within tree crowns; to determine the optimum sample sizes for different error levels; to investigate tree variation related to oviposition; and to develop a sampling plan based on egg frequency.

Abstract

The western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is a destructive defoliator that causes damage periodically to western hemlock, *Tsuga heterophylla* (Raf.) Sarg., stands and other coniferous hosts. Damage occurs in mature and senescing stands where severe defoliation causes growth reduction, top kill, and tree mortality. An egg sampling study was conducted in mature western hemlock stands from 1992-1994 in British Columbia, Canada.

Egg distribution within crowns was homogenous, suggesting that the lower crown was acceptable for egg density estimation. The optimal sample size for estimating eggs was presented for error margins of 10, 20, 40, 60 and 80% (Table 3). Tree height, d. b. h., crown width, crown length, and presence of heartrot did not affect egg lay. Lichen samples (40 g, air dried) were taken from the lower crown. Eggs are separated using the method of Otvos and Bryant (1972) for eastern hemlock looper, *Lambdina fiscellaria fiscellaria* (Guenée).

Sampling Procedure

Because random sampling is difficult to conduct in mature hemlock stands, choose dominant or codominant trees subjectively. Sample the lower crown for lichen using a pole pruner, and collect enough from each tree to fill a polyethylene bag (20 by 10 by 46 cm) loosely. Remove debris from the lichen and determine a sample size to use, which is measured in grams of air dried lichen. In this study, 40 g was chosen as a sample size because it was the smallest common to all samples collected. Separate eggs from the lichen using the method outlined in Otvos and Bryant (1972). Count only eggs of the current year as either healthy (brown), infertile (green), or parasitized (black). Refer to Table 3 to determine optimal sample sizes based on five levels of error. An error of 20% is generally considered appropriate, and would require the sampling of 16 trees if an average of 25 eggs per sample were collected (Table 3).

Note

Restrict sampling to mature western hemlock stands that have an abundance of lichen.

Reference

* 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.

Table

Table 3. Optimum sample size (number of 40 g air-dried lichen samples per plot) for sampling *L. fiscellaria lugubrosa* eggs in mature western hemlock stands in interior of British Columbia, based on data of 1992-1994.

Mean	D (95% error margin/mean)				
	0.1	0.2	0.4	0.6	0.8
1	1316	329	82	36	21
25	63	16	4	2	1
50	37	9	2	1	1
75	28	7	2	1	1
100	24	6	1	1	1
125	21	5	1	1	1
150	19	5	1	1	1

Shore, T. L. 1989. Sampling western hemlock looper pupae (Lepidoptera: Geometridae) using burlap traps. Journal of Entomological Science 24: 348-354.

Objective

To develop procedures for using pupae caught in burlap traps as an index of *L. fiscellaria lugobrosa* density.

Abstract

The western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), is a destructive defoliator that periodically causes damage to western hemlock, *Tsuga heterophylla* (Raf.) Sarg., stands. Damage generally occurs in mature stands where severe defoliation causes growth reduction, top kill, and tree mortality. Burlap bands wrapped around western hemlock trees at breast height were used to sample *L. fiscellaria lugubrosa* pupae. The number of pupae was highly variable, and not related to tree diameter or trap surface area. There was a significant positive linear relationship between the number of viable pupae per trap (X) and the number of healthy eggs (Y) subsequently deposited on lichen in the trees ($Y = 0.368X$; $R^2 = 0.88$, $P = 0.017$, $n = 4$). A figure demonstrating the relationship between the mean number of pupae per trap and the sample size required with a 20% sampling error was presented.

Sampling Procedure

The number of sample trees required to obtain estimates within 20% of the population mean at low densities is large (Fig. 1). Alternatively, sampling to a fixed level of precision, such as ± 10 pupae, is acceptable (Fig. 1).

Wrap a 25 cm wide piece of burlap around the bole of each tree at breast height. Secure the band loosely to allow larvae to crawl beneath the burlap. Visit trees frequently during the pupation period and remove all pupae from beneath each band. Count and record the number of pupae attached to the burlap. A positive linear relationship exists between the number of healthy eggs per 100 grams lichen, and the number of pupae per burlap trap:

$$Y = 0.368\,X$$

where, Y is the number of healthy eggs per 100 grams lichen, and X is the number of viable pupae per burlap band ($R^2 = 0.88$, $P = 0.017$, $n = 4$).

This predictive index appears to overestimate defoliation levels. The author suggests it can be used as a predictive index for population density and defoliation estimates the following year, but may require modifications as more data become available.

Notes

The number of pupae attached to the burlap was selected as the best estimator since it is less variable with respect to the mean, and is the most sensitive indicator at low populations levels. Since there were no significant differences among trap surface areas, d.b.h., and the number of pupae caught, it is not necessary to standardize pupal counts to represent the trap surface area.

Figure

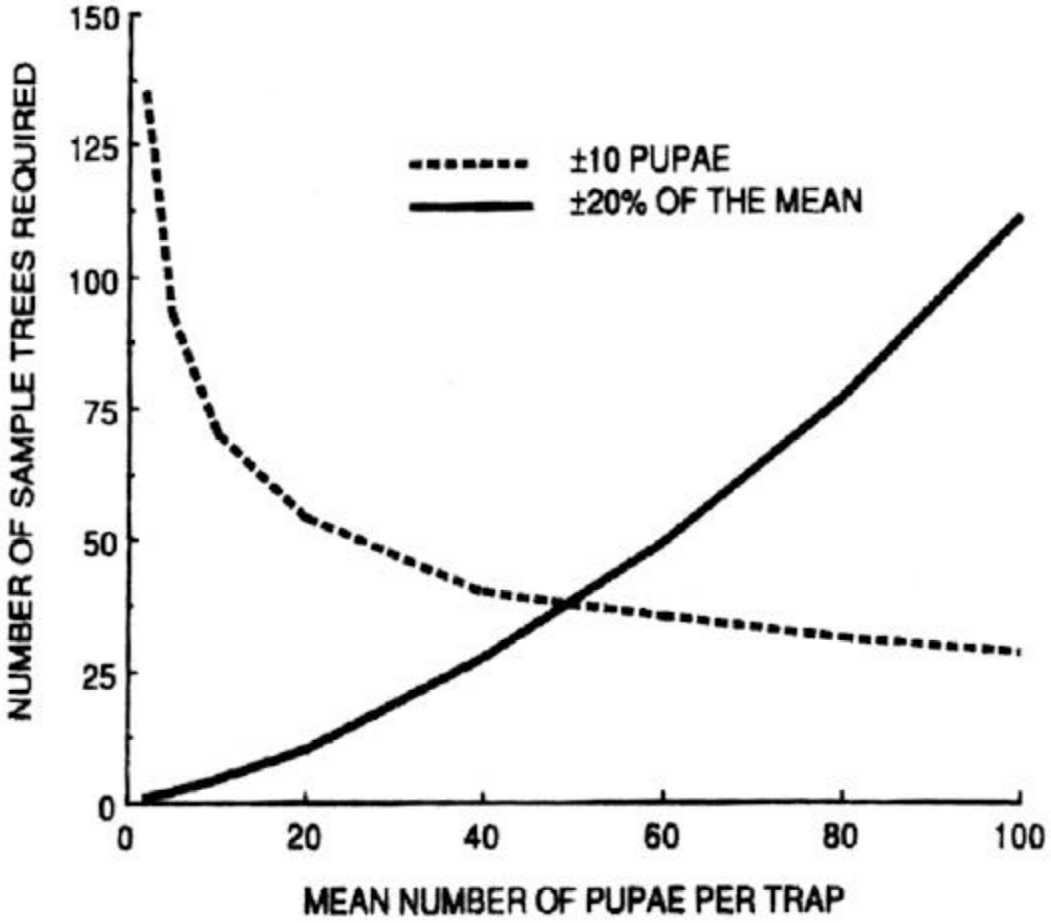

Fig. 1. The relationship between mean number of pupae per trap and the sample size required to obtain precision of ±20% of the mean of ±10 pupae.

Figure 1 reprinted with permission from the Journal of Entomological Science, January 15, 2001.

Herbert, 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.

Objective

To develop a useful and efficient sampling method for *O. bruceata*.

Abstract

The bruce spanworm, *Operophtera bruceata* (Hulst), is a major defoliator of maple, *Acer* spp., and aspen, *Populus* spp., stands throughout Canada. Previous sampling methods included the use of sticky bands to sample the wingless female, but they were costly and laborious to maintain. A new egg sampling method that uses an oviposition trap has been developed. The trap, constructed from a piece of black ABS pipe, is placed in the ground and a styrofoam band and lid are attached to facilitate egg laying by *O. bruceata*. The styrofoam band is later removed and then returned to the laboratory for egg counts.

Sampling Procedure

Cut a piece of black ABS pipe, 10 cm in diameter and 1.2 m long, and draw a line 30 cm from one end. This line will later indicate the depth the pipe should be driven into the ground. Obtain a 6 mm-thick band of styrofoam 10 by 36 cm, and connect the ends to make an opened cylinder using 5-cm wide masking tape. Obtain a black cover with a hole drilled in the center for the pipe and a Multi-Pher® trap lid (Jobin and Coulombe 1988) or similar lid (26.5 cm in diameter). The two lids are attached together with a bolt and butterfly nut. The Multi-Pher® lid provides a shelter for female insects and protects the styrofoam from weathering. Use a wooden mallet and drive the pipe into the ground. Install the styrofoam band onto the mounted ABS pipe cover. Install the entire assembly on the post making sure that the styrofoam band is supported along the entire periphery of the lid. The masking tape seam should face a northern aspect.

Eggs are recovered by removing the styrofoam band and returning them to the laboratory for tally.

Note

For more information contact Dr. Christian Herbert, Canadian Forest Service, Laurentian Forestry Centre, 1055 du PEPS, PO Box 3800, Sainte-Foy, Quebec G1V 4C7.

Reference

Jobin, L. J.; Coulombe, C. 1988. The Multi-Pher® insect trap. Inf. Leafl. LFC-24E. Saint-Foy, PQ Canadian Forest Service, Quebec Region; 8 p.

Forest Tent Caterpillar

Malacosoma disstria (Hübner)
Lepidoptera: Lasiocampidae

Batzer, H. O.; Martin, M. P.; Mattson, W. J.; Miller, W. E. 1995. The forest tent caterpillar in aspen stands: distribution and density estimation for four life stages in four vegetation strata. Forest Science 41: 99-121.

Objective

To develop a procedure for estimating density of *M. disstria*.

Abstract

The 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.

The forest tent caterpillar exemplifies the mobile class of defoliators by expanding its vertical distribution during development from the tree canopy to the ground. This study investigated the distribution of eggs, small larvae, large larvae, and cocoons in overstory-tree, high-shrub, low-shrub, and ground strata in stands of *P. tremuloides*. All parts of *P. tremuloides* as well as ground vegetation underneath aspen stands were sampled for *M. disstria* life stages.

Egg mass sampling was the most reliable estimator of population density as larval and pupal counts proved to be rather laborious and imprecise. The number of egg masses per tree was estimated from samples in the upper and mid-crown, and d.b.h. using a branch model.

Sampling Procedure

Collect the three longest mid-crown branches and the single longest upper crown branch. Record the number of egg masses, and diameter at 1.3 m height. Whole tree egg mass numbers can be calculated using the equation

$$EMT = 1.83\ UC_1 + [1.48\ MC_1 + 0.91\ (MC_2 + MC_3) + 0.48]\ (diam.)^{0.311}$$

where,

EMT	= numbers of egg masses in the tree
UC_1	= numbers of egg masses on the longest upper-crown branch
MC_1	= numbers of egg masses on the longest mid-crown branch
MC_2, MC_3	= numbers of egg masses on the second and third longest mid-crown branches

Note

Edge trees should not be sampled since the number of egg masses is usually less than the population mean.

Connola, D. P.; Waters, W. E.; Smith, W. E. 1959. The development and application of a sequential sampling plan for forest tent caterpillar in New York. Bull. No. 366, Albany: New York State Museum; 22 p.

Objective

To develop a sequential plan for *M. disstria* based on egg counts to predict defoliation levels.

Abstract

The forest tent caterpillar, *Malacosoma disstria* (Hübner), is a major defoliator of hardwood forests in the eastern USA and Canada. Young larvae feed on developing buds, while later instars feed gregariously on leaves often defoliating the tree completely. Defoliation causes reduced leaf area, growth loss, twig dieback and tree mortality in cases of prolonged infestation.

Three methods of obtaining egg mass counts were tested, including direct observation with binoculars, a cut-twig method, and whole-tree method where the sample tree was cut down and all branches examined for egg masses. The direct observation and whole-tree methods were shown to be ineffective. A sequential sampling plan was then developed in response to an outbreak of *M. disstria* in northern New York based on egg counts using the cut-twig method. The purpose of the plan was to predict, from year to year, the amount of defoliation simply classified as either noticeable or unnoticeable.

Sampling Procedure

Select 10 (76-cm) twig samples randomly from 25 trees in the area of concern. Sampling preference is given to cherry, *Prunus* spp., and poplar, *Populus* spp., trees wherever possible, and other susceptible species are used only to fill the 25 tree quota, if necessary. Begin by cutting and then examining 10 twigs from the first sample tree. The number of egg masses obtained will determine whether or not it is necessary to cut and examine an additional 10 twigs from another tree by referring to the classification thresholds in Table 2. If a decision is not met, take another 10 twig sample, record the cumulative total, and continue referencing Table 2 until a decision is made. Defoliation will be classified as unnoticeable or noticeable.

Table

TABLE 2

Sequential plan for sampling forest tent caterpillar egg mass populations in New York

Sampling guide showing minimum numbers of 10-twig samples that must be taken in an egg mass survey to permit site classification with respect to expected forest tent caterpillar defoliation.

No. of 10-Twig Sample Units	Cumulative Total Number of Egg Masses		
	Number expected to produce no noticeable defoliation	Range within which the amount of defoliation expected is doubtful (Continue sampling if count falls in this column	Number expected to produce noticeable defoliation
1	--	0 - 5	6 or more
2	0	1 - 7	8 " "
3	2 or less	3 - 9	10 " "
4	4 " "	5 - 11	12 " "
5	6 " "	7 - 14	15 " "
6	8 " "	9 - 16	17 " "
7	11 " "	12 - 18	19 " "
8	13 " "	14 - 20	21 " "
9	15 " "	16 - 22	23 " "
10	17 " "	18 - 24	25 " "
11	20 " "	21 - 27	28 " "
12	22 " "	23 - 29	30 " "
13	24 " "	25 - 31	32 " "
14	26 " "	27 - 33	34 " "
15	28 " "	29 - 35	36 " "
16	30 " "	31 - 38	39 " "
17	33 " "	34 - 40	41 " "
18	35 " "	36 - 42	43 " "
19	37 " "	38 - 44	45 " "
20	39 " "	40 - 46	47 " "
21	41 " "	42 - 48	49 " "
22	43 " "	44 - 51	52 " "
23	46 " "	47 - 53	54 " "
24	48 " "	49 - 55	56 " "
25	50 " "	51 - 57	58 " "

This plan is set up with specified confidence levels. The chances are only 1 in 10 that a "not noticeable" area will be called "noticeable" and only 1 in 20 that a "noticeable" area will be called "not noticeable." This means that 1 out of every 10 areas labeled "noticeable" may show "no noticeable" defoliation and 1 out of every 20 areas labeled "not noticeable" defoliation may show "noticeable" defoliation.

Printed with permission from the New York State Museum, Albany, New York.

Shepherd, R. F.; Brown, C. E. 1971. Sequential egg-band sampling and probability methods of predicting defoliation by *Malacosoma disstria* (Lepidoptera: Lasiocampidae). Canadian Entomologist 103: 1371-1379.

Objective

To describe methods for sequential sampling of *M. disstria* egg masses and predicting defoliation levels the following spring.

Abstract

The forest tent caterpillar, *Malacosoma disstria* (Hübner), is a major defoliator of hardwood forests. Young larvae feed on developing buds, while later instars feed gregariously often defoliating the tree completely. Defoliation causes reduced leaf area, growth loss, twig dieback and tree mortality in cases of prolonged infestation. A sequential sampling plan for predicting defoliation of trembling aspen, *Populus tremuloides* Michx., based on *M. disstria* egg mass density, is described and its accuracy assessed.

The cumulative egg mass totals from 46-cm branch samples were compared to decision thresholds that classify the amount of defoliation expected the following year as light, moderate, or heavy (Table IV). The plan achieved an accuracy rate of 65% when comparing predicted with actual defoliation levels the following spring. A second method, sequential sampling with sliding boundaries, is a combination of the sequential sampling plan but adjusts for the age of the outbreak (Table VIII). This plan improved the accuracy rate to 73%.

Sampling Procedure

Sequential sampling plan: Select only dominant and codominant trees, and sample two branches per tree from among the top four branches exclusive of the terminal. Record the number of egg masses on the first 46 cm of the main branch from the tip. Any lateral shoots initiating within this distance should also be examined. Compare the cumulative egg mass totals to the decision thresholds presented in Table IV and continue sampling until a decision is met. The amount of defoliation will be classified in one of three categories:

Light:	No trees exhibit complete defoliation. Feeding damage nonexistent or confined to the top of aspen crowns. Little or no feeding evident on other tree species or underbrush.
Moderate:	The occasional aspen may be completely defoliated, however most have tops partially defoliated (thinned). Little feeding on underbrush.
Heavy:	Aspen trees completely defoliated with conspicuous feeding damage present to other species including underbrush.

This plan achieved a predictive level of 65%, indicating that the number of egg masses found per branch in the fall is probably not a consistent predictor of defoliation levels the following spring. This discrepancy between expected and actual defoliation increases with age of the outbreak. Forest tent caterpillar populations typically suffer lower egg viability and higher larval mortality in late outbreak stages than in early ones, which results in less tree defoliation.

Sequential sampling with sliding class boundaries: Sequential sampling with sliding class boundaries involves estimating the number of egg masses on a two branch sample rather than simply estimating defoliation class. A table of defoliation levels, which is adjusted depending upon the stage of the outbreak (i.e., age), is used to classify defoliation as either light-moderate or moderate-heavy (Table VIII). Using the new defoliation estimates the predictive level was increased to 73%, and was particularly useful during the later stages of the outbreak. It may be advantageous to consult the original publication prior to conducting this sampling technique.

Notes

Defoliation levels during the first year of a *M. disstria* outbreak can be assessed most accurately with the sequential sampling plan, which is critical in preparation of control programs. As the outbreak ages, the sequential sampling plan with sliding class boundaries should be used to predict subsequent defoliation levels. For the sequential sampling plan with sliding class boundaries, it is assumed that the same sequence of yearly defoliation within any local situation will be repeated throughout each outbreak.

Tables

Table IV. Sequential table of decision lines for three defoliation levels of aspen associated with forest tent caterpillar egg-mass densities.

No. of trees	Accumulated no. of egg masses per 2-branch sample							
		≤		≥		≤		≥	
1	Light	-	Continue Sampling	-	Moderate	-	Continue Sampling	11	Heavy
2		-		-		-		13	
3		-		-		-		15	
4		2		-		-		17	
5		3		-		-		19	
6		4		-		-		22	
7		5		-		-		25	
8		6		-		-		27	
9		7		13		13		30	
10		8		14		16		32	
11		9		15		18		34	
12		10		16		20		37	
13		11		17		23		39	
14		13		18		25		42	
15		14		19		28		44	
16		15		21		30		46	
17		16		22		32		49	
18		17		23		35		51	
19		18		24		37		53	
20		19		25		39		56	
21		20		26		42		58	
22		21		27		44		61	
23		22		28		47		63	
24		24		29		49		65	
25		25		30		51		68	

Table VIII. Relation between defoliation class boundaries for aspen stands as denoted by number of egg bands of the forest tent caterpillar per two upper branches per tree, and age of outbreak.

	Defoliation - class boundary	
	Light - moderate	Moderate - heavy
Age of outbreak (yr)	Egg bands per two-branch sample	
1	1.20	2.40
2	1.55	2.75
3	1.90	3.10
4	2.25	3.45
5	2.60	3.80
6	2.95	4.15
7	3.30	4.50
8	3.65	4.85

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Buss, L. J.; McCullough, D. G.; Ramm, C. W. 1999. Comparison of three egg mass survey methods in relation to gypsy moth (Lepidoptera: Lymantriidae) defoliation in Michigan. Environmental Entomology 28: 485-495.

Objectives

To compare and contrast three egg mass survey methods (fixed-radius plots, timed walks, and 100-tree plots); and to correlate each of these methods with defoliation levels.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors, can cause excessive tree mortality. Fixed-radius plots, timed walks, and a 100-tree plot were used to assess egg mass density and predict defoliation levels in oak, *Quercus* spp., stands. Egg mass counts from the fixed-radius plot and 100-tree plot methods were correlated positively with subsequent defoliation, but timed walks were not. Treatment decisions based on fixed-radius plots and timed walks were similar. However, the 100-tree plot method yielded fewer erroneous classifications. All stands that sustained greater than 30% defoliation had greater than 84% new egg masses and a density of at least 6,583 egg masses per hectare.

Sampling Procedure

Fixed-radius plots: Examine all trees within a circular 100-m^2 plot for egg masses, scanning the entire tree with binoculars. Logs and large branches should be overturned in search of egg masses. The average time needed to conduct the sample is 18.1 min.

Timed walks: Choose a random direction and starting point to establish a transect, and tally the number of egg masses along that transect for 5 min. Repeat the count along the transect back to the starting point and calculate the mean. The average time needed to conduct the sample is 10 min.

100-tree plots: Begin at plot center and walk in a circular path of increasing diameter until 100 trees (>4 cm d.b.h.) have been examined. Count the number of new egg masses on the lower 2 m of each tree bole, measuring the length along the longest axis of the first 10-15 egg masses encountered and computing the mean. To determine the ground area of each 100-tree plot, add the N-S and E-W radii, and then multiply to determine the area of each 100-tree plot. Allow 30 minutes to collect the sample. This method is most accurate at predicting defoliation levels and is, therefore, recommended for use.

A two-step protocol has been developed for decision-making based on the 100-tree plot. Control is recommended if the mean number of new egg masses per tree is greater than 2.0, and not recommended if this value is less than 0.2. When the mean is between the two values, use the following equation:

$$\text{Defoliation class} = 0.458 * \%\text{Oak} + 0.744 * EML + 0.432 * ratio$$

where, *EML* is the mean length of new egg masses (inches) and *ratio* is the ratio of new to old egg masses ((new egg masses + 10)/ (old egg masses + 10)). A defoliation class of 2 represents 37.5% defoliation and is used as the decision cutoff for recommending control.

Note

Defoliation classes and subsequent control recommendations are based on the number of new egg masses.

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Carter, J. L.; Ravlin, F. W.; Gray, D. R.; Carter, M. R.; Coakley, C. W. 1994. Foliage presence and absence effect on gypsy moth (Lepidoptera: Lymantriidae) egg mass sample counts and the probability of exceeding action thresholds with foliage present. Journal of Economic Entomology 87: 1004-1007.

Objective

To determine if there is a significant difference between egg mass estimates taken when foliage is present (summer) or absent (winter), and to determine the probability of exceeding action thresholds for summer counts based on winter data.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality. Egg mass sampling is the primary method of estimating populations in order to make control decisions. Fixed-and-variable-radius plot samples were taken when foliage was present (summer) and absent (winter) at 136 sites, and their relationship analyzed with nonparametric statistics.

Winter counts were 14–36% higher than summer egg counts. The probability of summer egg mass counts exceeding action thresholds was determined by fitting a logistic curve to empirical data for thresholds of 618 and 1,236 egg masses per hectare. If egg mass samples are taken when foliage is present, then the data needs to be adjusted for differences between summer and winter counts.

Sampling Procedure

Ninety-seven fixed and variable-radius plots (BAF 20) were established on a 50-m grid in two 9-ha study areas in Shenandoah National Park, Virginia. The sampling method is described in detail in Wilson and Fontaine (1978). Summer egg mass sampling began after male moth flight had ceased and continued through September. Winter egg mass samples were taken after leaf abscission through February.

The number of egg masses per hectare was calculated for summer and winter counts for each plot. Summer egg mass counts were grouped into intervals of 200 (excluding zero), and the frequency distribution of winter counts was determined. For each interval, the cumulative frequency in which winter counts were above each of the action thresholds of 618 and 1,236 egg masses per hectare was used to construct a probability curve (Fig. 1).

Winter counts (W) were significantly higher than summer counts (S) on a per tree basis ($W = 1.18 * S$; $X^2 = 129.03$, df = 79, $P = 0.0003$) and plot basis ($W = 2.28 + 1.23 * S$; $X^2 = 635.48$, df = 136, $P = 0.0001$). Use Fig. 1 to determine the probability that summer counts will exceed an action threshold based on winter counts. For example, given an action threshold of 618 egg masses per hectare and a

summer count of 200 egg masses per hectare, there is only a 31% chance that a winter count would exceed the action threshold (Fig. 1). If 600 egg masses were counted per hectare, there is a 93% chance that a winter count would exceed the action threshold.

Note

The authors suggest there is error in sampling and predation of egg masses, which can result in lower winter counts even though greater visibility of egg masses occurs when foliage is absent.

Reference:

* 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.

Figure

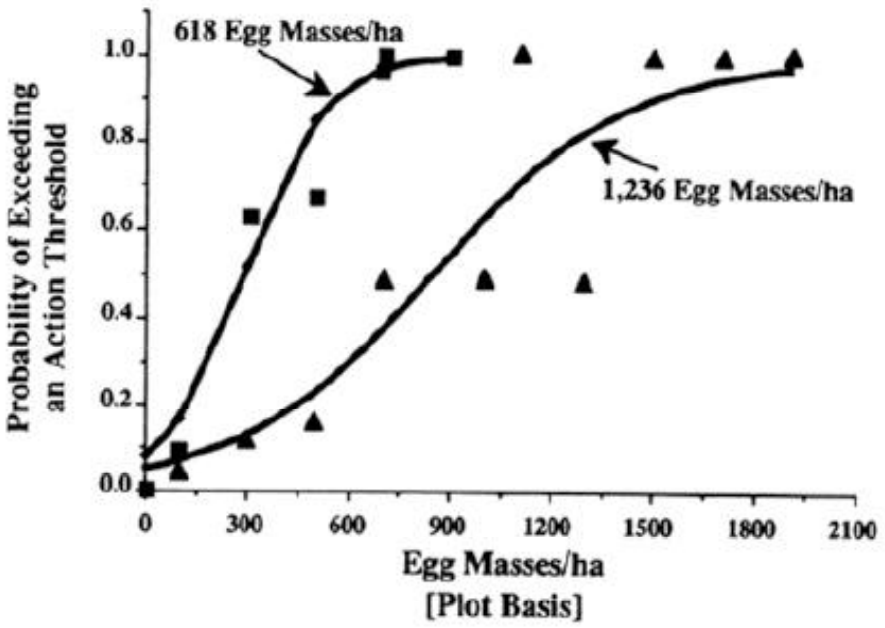

Fig. 1. Probability of a summer egg mass per hectare count for a plot exceeding the action thresholds of 618 egg masses per hectare (■) or 1,236 egg masses per hectare (▲). Observed probabilities of a summer egg mass count exceeding an action threshold are included for both action thresholds. Logistic curve equation for action threshold of 618 egg masses per hectare is $\{1 + \exp[-0.00846*(X - 296.21)]\}^{-1/1.02}$ and 1,236 egg masses per ha is $\{1 + \exp[-0.00344*(X - 843.44)]\}^{-1/0.992}$ where X is a summer egg mass count.

Figure 1 reprinted with permission from the Journal of Economic Entomology, January 15, 2001.

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Carter, J. L.; Ravlin, F. W. 1995. Evaluation of binomial egg mass sampling plans for low density gypsy moth populations in continuously forested habitats. Journal of Economic Entomology 88: 890-896.

Objective

To develop a useful binomial sampling method for estimating low density populations of *L. dispar*.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality. The use of binomial sampling for low-density (<618 egg masses per hectare) populations was examined. Fixed- and variable-radius plot egg mass samples were also collected at 28 locations (Wilson and Fontaine 1978). A model was fit to the egg mass density and the proportion of trees with zero egg masses. Binomial sampling plans were developed for sample sizes of 9, 16, 49, and 98 and compared with fixed- and variable-radius plot samples.

The binomial method was more efficient than the fixed- and variable-radius plot methods; however, the precision of sample sizes was unacceptable. Binomial sampling was not an effective sampling method for low density populations of *L. dispar*.

Sampling Procedure

The fixed- and variable-radius sampling unit consists of variable-radius plot (BAF 20) for sampling overstory trees and a fixed-radius plot of 20 m^2 for sampling understory plants. The technique is described in detail by Wilson and Fontaine (1978).

Binomial sampling is an efficient sampling technique whereby the presence or absence of an insect is used to estimate population density. The plan is based on the relationship between the proportion of trees (P_T) with zero egg masses and the population mean. Once the relationship is established, a population mean can be estimated efficiently for any observed value of $P_T = 0$. Binomial sampling significantly reduced the amount of time required for sampling *L. dispar* egg masses. However, the high variability associated with this technique outweighs any savings in time. The continued use of the fixed- and variable-radius plot method (Wilson and Fontaine 1978) for sampling low-density populations is recommended.

Reference

* 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.

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

Objective

To develop a sequential sampling plan for rapid classification of *L. dispar* populations.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality. Sample units (timed walks and fixed-radius plots) used for determining egg mass density were evaluated for use in area-wide integrated pest management (IPM) programs. Sequential sampling plans based on fixed-radius plots (Table 3) were validated within 131 1-km cells. The sequential plans gave the same pest management decisions as fixed-sample size plans in 79-84% of the cells, recommended additional samples in 7-19% of the cells, and gave incorrect decisions in 2-3% of cells.

Sampling Procedure

Due to the instability of the regression coefficients relating timed walks to fixed-plot data, 100-m^2 plots were used. Take a minimum of 4 and maximum of 10 plots in which you locate and record the number of egg masses found on all trees, rocks, and in the understory. Use binoculars to examine taller objects, if necessary. Continue sampling until a decision is met for one of the three management thresholds (Table 3).

The sequential plans used fewer samples and yielded correct decisions in 74-96% of the 1-km cells tested. Incorrect decisions did not occur in any cells below a treatment threshold using plan 3 or in any cells above treatment threshold using plan 5 (Table 3).

Notes

Area-wide IPM programs have a wide range of thresholds, acceptable errors, and resources allocated for sampling efforts. No single plan can be expected to be useful throughout a large project. The plans presented in Table 3 are a conservative pest management decision-making tool based on meetings with managers of southern Appalachian hardwood forests.

Table

Table 3. Sequential sample plan parameters using a negative binomial distribution with $k_c = 1.1$ for 0.01 ha fixed-radius plot sample units developed interactively with field managers using a computer spreadsheet for use in a large area IPM project.

Plan no.	α	β	Density threshold (egg masses/0.01 ha)	Lower limit (egg masses/ 0.01 ha)	Upper limit (egg masses/ 0.01 ha)	*n* range	Stop line[a]	
							Intercept	Slope
1[b]	0.25	0.25	49	0.3	0.7	4-10	1.843	0.464
2	0.25	0.25	49-124	0.3	1.5	4-10	1.109	0.688
3	0.25	0.25	618	5.0	7.5	4-10	17.722	6.095
4	0.25	0.25	1236	10.0	15.0	4-10	32.706	12.178
5	0.25	0.25	2471	21.0	29.0	4-10	79.461	24.580
6	0.05	0.05	25	0.2	0.3	21-50	1.279	0.246

[a] The positive value of the intercept gives the upper stop line and the negative value gives the lower stop line.

[b] Plan 1 was not used alone but in combination with plans 3, 4, or 5 to make plans that classify populations into three categories.

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.

Objective

To develop a sequential sampling plan for classifying egg mass density into three categories for two land classifications.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor and in combination with other stress factors can cause excessive tree mortality. A sequential sampling plan was developed for estimating *L. dispar* egg mass density in forested and urban-suburban habitats. Sequential sampling decision plans for three egg density thresholds (250, 500, and 1000 eggs per acre) are presented and are based on a 100-m^2 sample plot.

Sampling Procedure

Forested habitats: Take a minimum of 4 and maximum of 10 plots, in which you locate and record the number of egg masses found on all plants and rocks in the understory. Use binoculars to examine taller objects, if necessary. The sum of samples is compared to a range of values for the corresponding sample number in the table for each management threshold selected. Continue sampling until a decision is met for one of the three management thresholds (Table 2).

The plan gives the same pest management decision in 79-84% of the areas that were surveyed using current operational techniques. This rate of success is achieved with a labor savings of 40%. Only 2-3% of the areas were classified improperly.

Urban and suburban habitats: A suburban habitat is defined as an area with a minimum of one house per 4 hectares. In these environments, the influence of man-made objects causes egg mass distributions to be aggregated. The sequential sampling plan is presented in Table 3. Take a minimum of six 100-m^2 (1/40 acre) plots where you locate and record the number of egg masses found on all trees, rocks, and man-made objects. Use binoculars to examine taller objects, if necessary. The sum of samples is compared to a range of values for the corresponding sample number in the table for each management threshold selected. Continue sampling until a decision is met for one of the three management thresholds. Appendix 1 provides the equations used to generate the sequential plan tables.

The plan gives the same pest management decision in 90-100% of the areas that were surveyed by using current operational techniques. This rate of success was achieved with a labor savings of 49%. Only 6% of the areas were classified improperly.

Note

The frequency distribution and damage thresholds must be known as the frequency distribution is used to estimate the probability of being above or below the threshold.

Tables

Table 2. Sequential sampling decision charts for three management thresholds in continuously forested eastern hardwoods.

Threshold (Egg masses/acre)	Sample Number (1/40 acre)	Stop Sampling (below threshold)	Continue Sampling	Stop Sampling (above threshold)
		..... *Cumulative Egg Mass Count*		
250	4	0-6	7-42	>42
	5	0-12	13-48	>48
	6	0-18	19-54	>54
	7	0-24	25-60	>60
	8	0-30	31-66	>66
	9	0-36	37-73	>73
500	4	0-15	16-81	>81
	5	0-27	28-94	>94
	6	0-39	40-106	>106
	7	0-52	53-118	>118
	8	0-64	65-130	>130
	9	0-76	77-143	>143
1000	4	0-18	19-178	>178
	5	0-43	44-202	>202
	6	0-67	68-227	>227
	7	0-92	93-252	>252
	8	0-116	117-276	>276
	9	0-141	142-301	>301

Table 3. Sequential sampling decision charts for three management thresholds in urban/suburban habitats.

Threshold (Egg masses/acre)	Sample Number (1/40 acre)	Stop Sampling (below threshold)	Continue Sampling	Stop Sampling (above threshold)
		….. *Cumulative Egg Mass Count* …..		
250	6	0-3	4-71	>71
	7	0-9	10-77	>77
	8	0-15	16-83	>83
	9	0-21	22-89	>89
	10	0-27	28-95	>95
	11	0-33	34-101	>101
	12	0-39	40-107	>107
	13	0-45	46-113	>113
	14	0-51	52-119	>119
	15	0-57	58-125	>125
500	7	0-6	7-159	>159
	8	0-18	19-171	>171
	9	0-30	31-182	>182
	10	0-42	43-194	>194
	11	0-53	54-206	>206
	12	0-65	66-218	>218
	13	0-77	78-229	>229
	14	0-89	90-241	>241
	15	0-100	101-253	>253
	16	0-112	113-265	>265
	17	0-124	125-277	>277
	18	0-136	137-288	>288
	19	0-148	149-300	>300
	20	0-159	160-312	>312
	21	0-171	172-324	>324
	22	0-183	184-335	>335
1000	7	0-10	11-334	>334
	8	0-34	35-359	>359
	9	0-59	60-383	>383
	10	0-84	85-408	>408
	11	0-104	109-432	>432
	12	0-133	134-457	>457
	13	0-158	159-482	>482
	14	0-182	183-506	>506
	15	0-207	208-531	>531
	16	0-231	232-555	>555
	17	0-256	257-580	>580
	18	0-280	281-604	>604
	19	0-305	306-629	>629
	20	0-329	330-654	>654
	21	0-354	355-678	>678
	22	0-379	380-703	>703
	23	0-403	404-727	>727
	24	0-428	429-752	>752

Appendix 1. Equations to generate sequential sampling plans for 1/40[tn] acre fixed plot samples in various habitats.

Threshold (EM/Acre)	Decision Stop Line[a]	
	Continuously Forested Habitat	Urban/Suburban Habitat[b]
250	$y = 6.095 \pm 17.722$	$y = 6.089x \pm 34.013$
500	$y = 12.178x \pm 32.706$	$y = 11.781x \pm 76.258$
1000	$y = 24.580x \pm 79.461$	$y = 24.576x \pm 162.128$

[a]Decision stop line in the form $y = mx \pm b$, where y = cumulative sum required to stop sampling, m is the shape, x is the sample number, and b is the intercept. The positive value of the intercept gives the upper stop line and the negative value gives the lower stop line.
[b]Defined as $\geq$ 1 house per 10 acres.

Gansner, D. A.; Herrick, O. W.; Ticehurst, M. 1985. A method for predicting gypsy moth defoliation from egg mass counts. Northern Journal of Applied Forestry 2: 78-79.

Objective

To develop a method of predicting defoliation from egg mass counts.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation causes reduced growth, decreased vigor and extensive tree mortality. A model is provided which correctly predicted defoliation levels as greater or less than 60% for 92% of the 300 plots analyzed.

Sampling Procedure

Establish two 100-m^2 plots throughout the stand. No recommendations as to the spacing of plots is provided. Within each plot, locate and record the number of newly deposited egg masses on trees, rocks, stumps, etc. Multiply the median of the two plots by 40 to estimate the number of egg masses per acre. The equation for predicting defoliation based on egg mass counts is:

$$\text{Percent defoliation} = 100[1.0 + 7.24\ (0.368)^{0.00173X}]^{-1}$$

where X represents the number of egg masses per acre (Table 1).

Table 1. Defoliation predictions based on the mean number of egg mass per acre (derived from Gansner and others 1995).

Number of egg masses/acre	Predicted defoliation (%)
0	12.1
500	24.6
1000	43.8
1500	64.9
2000	81.4
2500	91.2
3000	96.1

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

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.

Objectives

To evaluate the precision and costs of several sampling procedures; and to develop sampling plans for estimating *L. dispar* egg mass (GMEM) density with constant-precision levels.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation results in reduced growth, decreased vigor, and extensive tree mortality. Plots of 100-m^2, 400-m^2, 10-prism BAF, and 20-prism BAF were evaluated in relation to their efficiency for sampling gypsy moth egg masses in 14 oak, *Quercus* spp., woodlots in Maryland. The reliability of each sampling method varied with egg mass density. There was no significant difference in precision between 10 and 20 BAF plots. However, the 20 BAF plot required 40% less time to survey than the 10 BAF. An analysis of cost and precision showed that 100-m^2 plots were superior to the other sampling methods throughout the range of egg mass densities evaluated. The total number of new egg masses per plot was determined and compared to three sequential sampling plans. Sampling was continued until a decision was met, and populations were classified relative to three critical densities as either 50, 617, or 2469 egg masses per hectare.

Sampling Procedure

Sampling 100-m^2 plots was found to yield greater precision per unit sample time than the 400-m^2 or BAF plots. Therefore, sequential sampling plans were developed based on this sample unit.

Establish 100-m^2 plot centers randomly within the woodlot to be sampled. Count and record all new egg masses, and consult one of the three sequential sampling plans based on three different critical values for classifying densities as either less or greater than 50, 617, 2,469 egg masses per hectare (Table 4). Continue sampling a minimum of three times or until a decision is met. If the observed total falls outside the critical values, a decision to treat or not to treat is made.

Note

Site and stand characteristics associated with other geographic locations may alter the relationships observed in this study.

Table 4. Sequential sampling table for classifying GMEM infestations relative to three critical densities.

No. of samples	Cumulative GMEM											
	<50		>50		<617		>617		<2469		>2469	
5	---		13		---		71		39		211	
10	---	CONTINUE	20	CONTINUE	8	CONTINUE	118	CONTINUE	135	CONTINUE	365	
15	---		26		27		161		237		513	
20	---		32		48		202		342		658	
25	---		37		70		242		449		801	
30	---		42		93		282		558		942	
35	---	SAMPLING	46	SAMPLING	117	SAMPLING	320	SAMPLING	669	SAMPLING	1081	
40	---		51		141		359		780		1220	
45	---		55		166		396		892		1358	
50	---		59		191		434		1005		1495	
55	---		63		216		471		1118		1632	
60	---		67		242		508		1232		1768	

Table 4 reprinted with permission from Environmental Entomology, January 15, 2001.

Liebhold, A. M.; Elkinton, J. S. 1988. Techniques for estimating the density of late-instar gypsy moth, *Lymantria dispar* (Lepidoptera: Lymantriidae), populations using frass drop and frass production measurements. Environmental Entomology 17: 381-384.

Objective

To develop procedures for estimating *L. dispar* larval densities based on frass drop.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation results in reduced growth, decreased vigor and extensive tree mortality. A technique was developed for estimating larval densities using measurements of the amount of frass produced per larva (frass yield), and the amount of frass falling in the forest per unit area (frass drop). The technique was tested in a post-season experiment in which 6,000 larvae were released in a stand. Frass yield was measured by caging larvae individually in the field on cut host foliage. The most reliable and efficient method of measuring frass drop was the deployment of several large funnel-shaped frass traps (16 cm diameter) on wooden stakes. Number of pellets was found to be superior to frass weight as a unit for quantifying frass yield and drop, because it was not influenced strongly by instar distribution. The distribution of frass widths suggest frass size can be used as a tool to differentiate among instars.

Sampling Procedure

Several traps were evaluated for their effectiveness at collecting *L. dispar* frass: (1) an 82 by 82-cm canvas tarp stretched across a wooden frame and placed on the forest floor; (2) a 63 by 63-cm cheesecloth stretched across a wooden frame and placed on the forest floor; (3) a 16-cm diameter plastic disk with an acrylic sticker attached to a wooden stake; (4) the disk in (3) with cylindrical sheet metal sides to prevent frass bouncing; and (5) a funnel. The funnel trap consists of a polyethylene funnel (16 cm diameter) inserted into a section of tygon tubing (1.0 cm diameter by 5 cm long) with mosquito netting glued over the bottom. Place the trap on top of a 1 m wooden stake positioned vertically in the ground. Count and remove the number of frass pellets every 5 d. The pellets are characteristically star shaped in cross section, and distinguished easily from other forest insects. The equation for calculating larval density for each day is:

$$\text{Larvae/ha} = C \cdot \text{frass/trap} \cdot \text{larvae/frass}$$

where, C = 1/area (ha) of one trap, and C is determined from measuring the horizontal area of the trap. The mean amount of frass per trap is determined by the frass/trap (frass drop) term. Density estimates based on the number of frass pellets provide more reliable estimates than frass weight.

Frass size is a useful tool to determine the abundance of each instar at any given stage after the third instar. The diameter ranges of frass pellets for the different instars are as follows:

Instar	Frass Diameter (mm)
Fourth	1.0-1.5
Fifth	1.5-2.1
Sixth	2.1-3.0

Note

Because frass diameters may vary with host quality or population density (Lance and others 1986), determination of instars by this method should be done with caution.

Reference

Lance, D. R.; Elkinton, J. S.; Schwalbe, C. P. 1986. Components of density-related stress as potential determinants of population quality in the gypsy moth (Lepidoptera: Lymantriidae). Environmental Entomology 15: 914-918.

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Liebhold, A.; Thorpe, K.; Ghent, J.; Lyons, D. B. 1994. Gypsy moth egg mass sampling for decision-making: a user's guide. NA-TP-04-94. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area; 12 p.

Objectives

To provide detailed procedures for estimating *L. dispar* egg mass density and to predict defoliation levels using a density-defoliation relationship.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality.

This guide provides detailed information on procedures used for estimating egg density, which is traditionally used in decision-making. A 100-m^2 plot was recommended for determining egg mass densities, which were used to predict the severity of defoliation levels the following year. The relationship between egg mass density and subsequent defoliation for three damage criteria are presented (Fig. 8). The control thresholds for noticeable defoliation, growth loss and tree mortality were 500-750, 700-900, and 1,000-1,400 egg masses per acre, respectively.

Sampling Procedure

There are three methods widely used for estimating egg mass density: fixed and variable radius plots (Wilson and Fontaine 1978), and timed walks (Buss and others 1999). However, fixed radius plots are recommended for use because they provide similar levels of precision as variable radius plots and timed walks, while having reduced sampling costs.

Identify the boundaries of the potential treatment block where egg mass density is to be estimated. Determine the number of samples for the desired level of precision (Fig. 1), and delineate sample points on the map. Establish a 100-m^2 circular plot, and locate and record all of the egg masses present within its boundaries. Use binoculars to sample the taller trees if necessary, and make sure to look for egg masses under rocks, logs, etc. Determine the proportion of new egg masses in the understory. Multiply the number of new egg masses in the plot by 40 to obtain an estimate of egg mass density per acre. The mean density of the entire block is estimated from the mean of the plots within it.

There is a positive relationship between defoliation (Y) and egg mass density (X) (Fig. 7). Locate the estimated egg mass density on the horizontal axis and read the corresponding predicted defoliation levels off the vertical axis. There was much variability in this relationship particularly between 100-1000 egg masses per acre where defoliation levels ranged between 0 and 100%. In these situations, it is helpful to determine if the population is increasing using such factors as proximity to the leading edge, egg mass length (>30 mm), and proportion of new egg masses (>75%).

Figure 8 shows the relationship between egg mass density and subsequent defoliation for three damage criteria. The following control thresholds are provided:

Defoliation and Damage	Egg Density Per Acre
Noticeable (>30%)	500 - 750
Growth loss (>40%)	700 - 900
Tree mortality	1,000 - 1,400

Note

The procedures described here represent a scientifically based approach to decision-making. However, it is impossible to predict defoliation levels without a certain amount of error.

References

* Buss, L. J.; McCullough, D. G.; Ramm, C. W. 1999. Comparison of three egg mass survey methods in relation to gypsy moth (Lepidoptera: Lymantriidae) defoliation in Michigan. Environmental Entomology 28: 485-495.

* 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

Figures

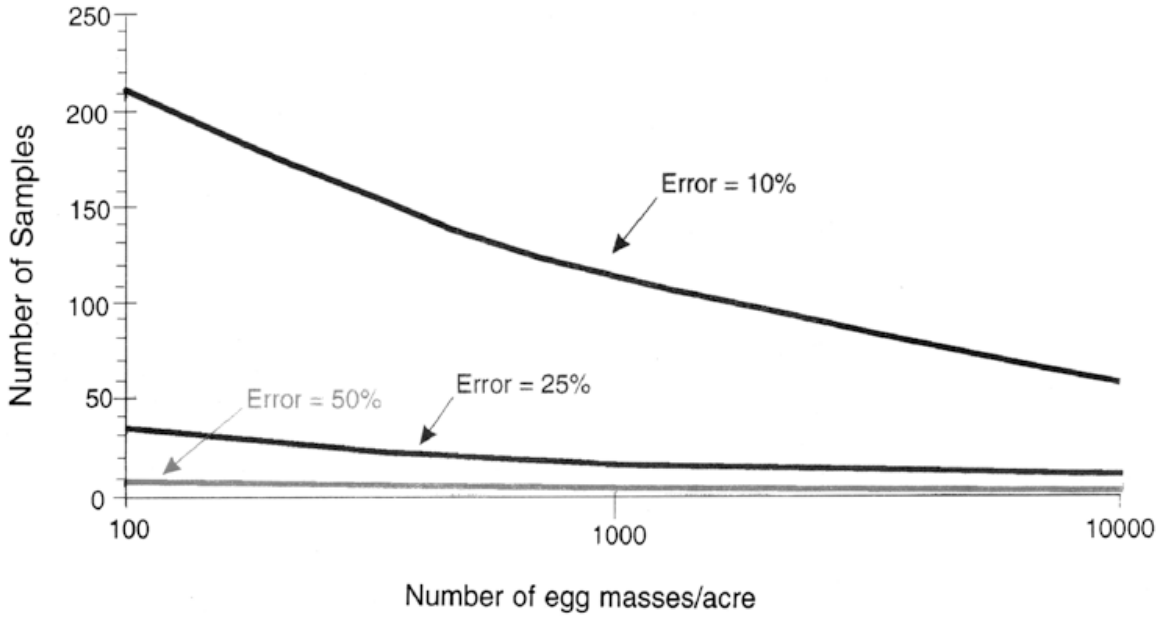

Figure 1. Minimum number of fixed radius samples (plots) necessary to achieve various levels of precision at different densities. Error is expressed as a percentage of estimated density.

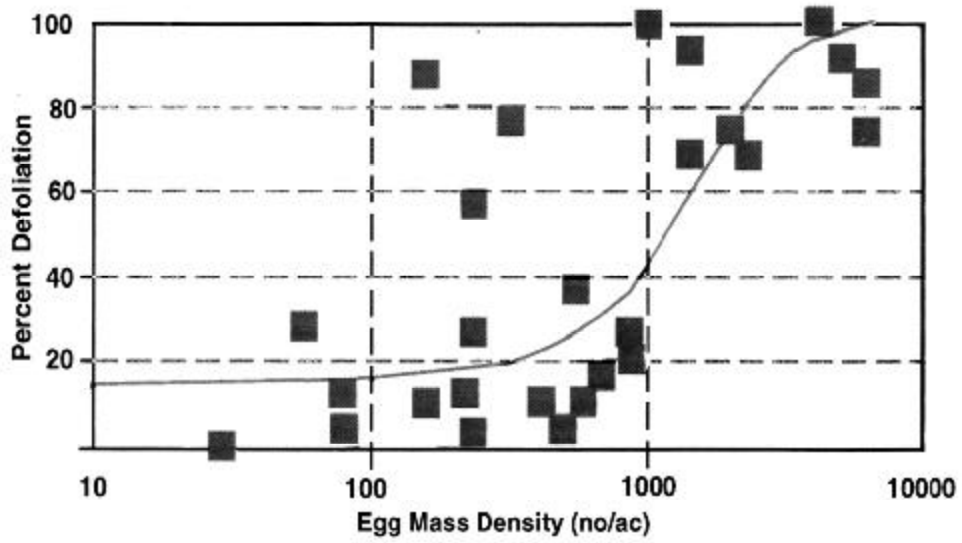

Figure 7. Relationship between egg mass density and defoliation at several locations.

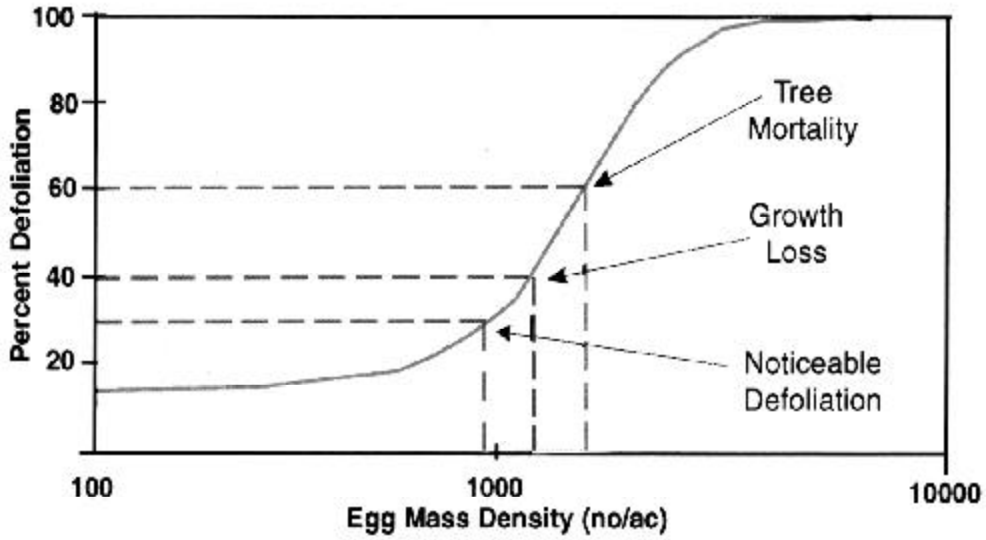

Figure 8. Relationship between defoliation and egg mass density thresholds for three damage criteria.

Liebhold, A. M.; Elkinton, J. S.; Zhou, G.; Hohn, M. E.; Rossi, R. E.; Boettner, G. H.; Boettner, C. W.; Burnham C.; McManus, M. L. 1995. Regional correlation of gypsy moth (Lepidoptera: Lymantriidae) defoliation with counts of egg masses, pupae, and male moths. Environmental Entomology 24: 193-203.

Objective

To compare three *L. dispar* census methods, and determine their ability to predict regional defoliation levels.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation results in reduced growth, decreased vigor and extensive tree mortality.

Three different *L. dispar* sampling techniques were compared for their spatial correlation with regional defoliation maps. Counts of pupae and egg masses under burlap bands, and counts of male moths in pheromone-baited traps, were taken in a network of 150 plots distributed irregularly throughout Massachusetts. These counts were compared with aerial sketch maps of *L. dispar* defoliation collected during the same period. Egg mass and pupal counts were correlated positively with subsequent defoliation. These results indicate that counts of egg masses (or pupae) under burlap bands may be the most suitable measure for predicting *L. dispar* defoliation on a regional scale.

Sampling Procedure

Place a standard milk carton pheromone (50 +:- disparlure) trap surrounded by 20 oak, *Quercus* spp., trees >13 cm d.b.h., where burlap bands are placed. Establish traps in early summer and revisit in late summer and early fall. Count all egg masses and pupal remains under the burlap bands, and the number of male moths per pheromone trap.

If egg mass counts are greater than 1.8 per tree, or pupal counts are greater than 4 per tree then defoliation is likely to occur. The authors suggest that defoliation predictions can be extrapolated, with some caution, out to 10 km from where counts are made. For operational use, establish permanent plots on a grid network with less than 10 km between plots.

Notes

Egg mass counts under burlap bands may be more useful than pupal counts because they usually remain intact providing a census over several months.

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Liebhold, A.; Luzader, E.; Reardon, R.; Roberts, A.; Ravlin, F. W.; Sharov, A.; Zhou, G. 1998. Forecasting gypsy moth (Lepidoptera: Lymantriidae) defoliation with a geographical information system. Journal of Economic Entomology 91: 464-472.

Objective

To describe quantitatively the spatial relationship of *L. dispar* infestations in order to improve the quality of defoliation forecasts.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality. A maximum likelihood estimation procedure was used to fit 15 regression models that predict noticeable defoliation in 1 ha grids from egg mass density, male moth catch, presence of defoliation in the previous year, distance to the population boundary, and their interaction.

Models that included egg mass density and distance to the population boundary provided the most reliable predictions of defoliation. Decision errors were greatest for models that incorporated a single independent variable. Models 1, 5 and 11 yielded the lowest decision errors and included egg mass density as an independent variable. The results indicated that the use of traditional egg mass density thresholds may perform as well or better than the logistic models with the exception of models 5 and 11. However, the associated errors for all models are rather high and improved techniques for predicting defoliation were therefore recommended.

Sampling Procedure

Data on defoliation levels, egg mass densities, pheromone trap catches, and proximity to the population boundary were obtained from infestations in Virginia and West Virginia, and were used to construct and validate model accuracy.

Gypsy moth traps were deployed annually on 2 by 2-km grids and baited with disparlure (Schwalbe 1981). At the end of the season, the number of moths was recorded in each trap. If greater than 200 moths were caught, egg mass densities were sampled using three to ten 100-m^2 plots (Liebhold and others 1994). Values were estimated for unsampled locations as weighted means of values in nearby locations. Distance to the population boundary was determined using the best classification method (Sharov and others 1995).

Fifteen logistic regression equations were used to predict the probability of defoliation as >30%. All possible combinations of the four variables were evaluated. All coefficients were found significant and made biological sense (refer to original publication). Decision errors were greatest for models that incorporated only one independent variable. Models 1, 5, and 11 yielded the lowest decision

errors, and include egg mass density as an independent variable. Results indicate that the use of traditional egg mass density thresholds may perform as well or better than the logistic models with the exception of models 5 and 11. Both models include egg mass density and distance to population boundary variables. The capture of male moths was a poor indicator of subsequent defoliation.

Notes

The authors provide a detailed example of two scenarios to illustrate the choice of an egg mass density threshold for use in decision-making, and then discuss clearly the effect of each error. The data used in these models were collected by the Appalachian Integrated Pest Management program (AIPM) at the leading edge of *L. dispar* advancement. Therefore, these models may not be applicable in other locations (i.e., New England) where populations have been established, and variables such as proximity to population boundary are unlikely to be useful indicators of defoliation levels.

References

* Liebhold, A.; Thorpe, K.; Ghent, J.; Lyons, D. B. 1994. Gypsy moth egg mass sampling for decision-making: a user's guide. NA-TP-04-94. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area; 12 p.

Schwalbe, C. P. 1981. Disparlure-baited traps for survey and detection. In: Doane, C. C.; McManus, M. L. editors. The gypsy moth: research toward integrated pest management. Tech. Bull. 1584. Washington, DC: U.S. Department of Agriculture, Forest Service; 542-548.

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

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Thorpe, K. W.; Ridgway, R. L. 1992. Gypsy moth (Lepidoptera: Lymantriidae) egg mass distribution and sampling in a residential setting. Environmental Entomology 21: 722-730.

Objective

To determine the distribution of *L. dispar* egg masses in residential settings; and to compare the cost effectiveness of several sampling techniques for determining their density.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation results in reduced growth, decreased vigor and extensive tree mortality.

The spatial distribution of *L. dispar* egg masses was determined in 60 developed lots in a residential community of Maryland. The community was divided into low (393 egg masses per hectare) and high (2,656 egg masses per hectare) densities. In the high-density lots, the proportion of egg masses found on trees, man-made objects, and houses was 73.9, 21.6, and 4.5%, respectively. Distributions were similar in the low density lots. Oaks, *Quercus* spp., had the highest proportion of egg masses at both low and high population densities. The cost effectiveness of a number of potential sampling units (entire lots, back yards, fixed area plots, and individual trees) for determining egg mass density was also evaluated. The entire lot sampling units was most precise. However, 100-m^2 samples were most cost effective, and are therefore recommended for determining egg mass density.

Sampling Procedure

Fixed-area plots (Kolodny-Hirsch 1986) were compared with binomial sampling procedures (Binns and Bostanian 1990). Residential lots were surveyed by recording the number of egg masses found on all objects. These data were then used in a computer simulation to compare the reliability and cost effectiveness of sampling the lots for egg masses using 100-m^2 fixed-area plots, entire backyard plots, or individual trees (all species and oaks only).

Mark and delineate boundaries for each fixed-area plot sample. Locate and record the number of egg masses found on all trees, man-made objects, and houses. Disassemble stacked objects (such as firewood) to locate hidden egg masses. Use binoculars to examine taller objects, if necessary. Examine all egg masses in reach to determine if they are from the current (new) or previous (old) generation. The number of egg masses (*EM*) per ha for each lot can be determined by:

$$EM/\text{ha} = EM\ x\ [\text{new}/(\text{new} + \text{old})]/\text{area}$$

Note:

The authors recommend further investigations of binomial sampling techniques because of their effectiveness and the ease of which residents can aid in monitoring programs. Methods for using the fixed-area plots are further discussed in Kolodny-Hirsch (1986). In low density lots, sampling time ranged from 97 min for a fixed area plot to 219 min for entire lot samples.

References

Binns, M. R.; Bostanian, N. J. 1990. Robustness in empirically based binomial decision rules for integrated pest management. Journal of Economic Entomology 83: 420-427.

* 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: 122-27.

Gypsy Moth

Lymantria dispar (L.)
Lepidoptera: Lymantriidae

Wallner, W. E.; Jones, C. G.; Elkinton, J. S.; Parker, B. L. 1991. Sampling low density gypsy moth populations. In: Gottschalk, K. W.; Twery, M. J.; Fields, S. I., editors. Proceedings of the U.S. Department of Agriculture Interagency Gypsy Moth Research Review—1990. Gen. Tech. Rep. NE-146. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 40-44.

Objective

To review the sensitivity, reliability and cost of methods for sampling low density *L. dispar* infestations.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality. The techniques for sampling gypsy moth populations at low densities (less than 100 egg masses per hectare) were compared. The use of pheromone traps has demonstrated the highest level of male moth detection, but cannot be related to subsequent egg mass and/or larval density or defoliation, levels. Therefore, its use for population monitoring is limited to detection and delineation of new infestations.

A series of burlap banded trees can be used to monitor fluctuations in egg mass densities. Egg masses beneath bands on sample trees reflected densities on unbanded trees, and are much easier to deploy than other conventional sampling techniques such as fixed-radius, prism, stem, and timed walk samples. Populations were considered in outbreak mode when densities were greater than 100 egg masses per hectare, and were triggered at densities between 10-25 egg masses per hectare.

Sampling Procedure

Place a burlap band around the bole of each oak, *Quercus* spp., tree >7 cm diameter and 1.3 m high in clusters of 10 trees. Separate each cluster by 100 m to reflect an estimate that is based on 1 ha. Return annually to the same locations, record the number of egg masses within each band, and compute the mean of the 10-tree sample per plot. Populations are in outbreak mode when densities are greater than 100 egg masses per hectare. Expect populations to reach outbreak status if densities are between 10-25 egg masses per hectare.

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.

Objective

To provide detailed procedures for sampling *L. dispar* egg masses.

Abstract

The gypsy moth, *Lymantria dispar* (L.), was introduced into Medford, Massachusetts in 1869, and is now a major defoliator of hardwoods throughout the northeastern USA and Canada. Defoliation reduces tree growth and vigor, and in combination with other stress factors can cause excessive tree mortality. Two methods: sampling with fixed- and variable-radius plots (FVP) are intended for forested areas greater than 5 hectares in area with egg mass densities greater than 250 per hectare. Fixed-radius plots of 20 m^2 are first sampled to determine the mean number of egg masses per hectare on all objects in the understory (EM_x). The variable-radius plot is taken from the center of the fixed-radius plot to estimate the mean number of egg masses per hectare on overstory trees (EM_y). The mean number of total egg masses per hectare (EM) is then determined by the formula $EM = EM_x + EM_y$. Topics discussed in this handbook include the description, organization, and execution of this survey technique, and compilation of the associated data.

Sampling Procedure

The sampling unit consists of variable-radius plots (BAF 20) for sampling overstory trees, and a fixed-radius plot (20 m^2) for sampling the understory. Lay out 30 sample points systematically, with a 30-m spacing between plots. The authors provide considerable detail on sample size derivations, sample point locations, and crew organization for which we refer you to the original publication.

Fixed-radius plots: Sample fixed-radius plots first before the understory is disturbed. Locate and record the number of egg masses per plot. Examine all objects for egg masses except overstory trees (dominant, codominant, and intermediate). To determine the mean number of egg masses per acre, multiply the number of egg masses found by 200.

Variable-radius (prism) plots: The prism point is the center of the fixed-radius plot. If the tree is not alive or is receiving direct sunlight on its crown, then do not include it in the sample. Record the tree species, d.b.h., and proceed with the egg mass census. To determine the egg mass count corrected for tree size, divide it by the d.b.h.^{2} (inches) and then sum for each tree sampled. Then to determine the number of egg masses per acre, divide the sum of the weighted egg counts by the total number of trees sampled and multiply by 3,667.

To estimate the mean total number of egg masses per acre, add the average counts for the overstory and understory samples.

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

Daterman, G. E. 1978. Monitoring and detection. In Brooks, M. H.; Stark, R. W.; Campbell, R. W., editors. The Douglas-fir tussock moth: a synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture, Forest Service; 99-102.

Objective

To review methods of monitoring *O. pseudotsugata* populations.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly so that a large number of trees are often defoliated before direct control measures can be applied. Growth loss, top-kill, and tree mortality are common during outbreaks. The traditional method of monitoring populations requires that early instar larvae be counted on individual sample trees. Such data are useful for establishing population trends, but greater resolution is required at low population densities to predict outbreaks. In the early 1970's improved monitoring and sampling techniques for *O. pseudotsugata* were developed in response to devastating infestations in the Pacific Northwest. A review of these sampling methods is presented here.

Sampling Procedure

Most of the information contained in this chapter is presented in other reviews of *O. pseudotsugata*. Sections describe larval density estimation by beat and lower crown samples, adult monitoring by pheromone trapping methods and their utility for predicting population trends, and postdetection larval and egg surveys. This chapter on monitoring and detection is a useful supplement to other reviews if difficulty is encountered in understanding sampling principles and methodologies.

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.

Objective

To develop sequential sampling plans for classification of *O. pseudotsugata* populations.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), periodically causes severe damage to Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur every 7-10 years and usually persist for 3-4 years. Growth loss, top-kill and tree mortality are common when *O. pseudotsugata* populations are high.

Sequential sampling plans for making quick classifications of incipient populations were developed for *O. pseudotsugata* eggs and larvae. After each tree is sampled, a sequential sampling plan is referenced, and sampling is discontinued when a decision threshold is reached. Populations are classified as either light or heavy. These plans are designed to be applied independently in a suspected infestation for distinguishing between low density populations and high density populations capable of reaching outbreak levels within one generation.

Sampling Procedure

Egg: Sample one, two, and one whole branches from the upper, middle and lower crown, respectively. Count the number of egg masses on all four branches, and express their density per 0.645 m^2. After each tree is sampled, reference the sequential sampling plan (Fig. 2), and continue sampling until a decision threshold is reached, and infestations are classified as either light or heavy.

The number of eggs in the field plan (Fig. 2) is converted to the number of egg masses by dividing the number of eggs by 260. These factors can be adjusted accordingly if there is reason to believe that the average number of eggs per mass deviates significantly from 260.

Larvae: Cut one 43-cm foliated twig sample from the outer mid-crown, and two similar sized samples from the inner mid-crown. The outside crown is defined as the outer 43 cm from the tip of the main branch. Special care should be taken when using pole pruners so that larvae are not dislodged from the samples. Count the number of larvae from all three twigs, and express their density per 0.645 m^2. After each tree is sampled, reference the sequential sampling plan (Fig. 1), and continue sampling until a decision threshold is reached, and infestations are classified as either light or heavy.

A tally sheet, which can be found in the original publication, would greatly facilitate the use of this sampling plan in the field. The upper left number indicates the upper limit for classification as a light population, and the lower right number represents the lower limit for classification as a heavy

population. As trees are sampled, the cumulative number of larvae is recorded in the square across from the sample point and beneath the appropriate tree taken in sequence.

Time larval samples to coincide with the presence of small larvae. If late instar larvae are sampled, classification may become less accurate. In endemic populations, it is much easier to locate young larvae dispersed in the foliage than egg masses. For this reason, extensive surveys for detection of low level populations will be obtained most efficiently by sampling larvae.

Note

The data used in developing these sequential sampling methods were gathered from infestations on white fir, *A. concolor* (Good. and Glend.) Lindl., and may not be applicable to infestations on other species.

Figures

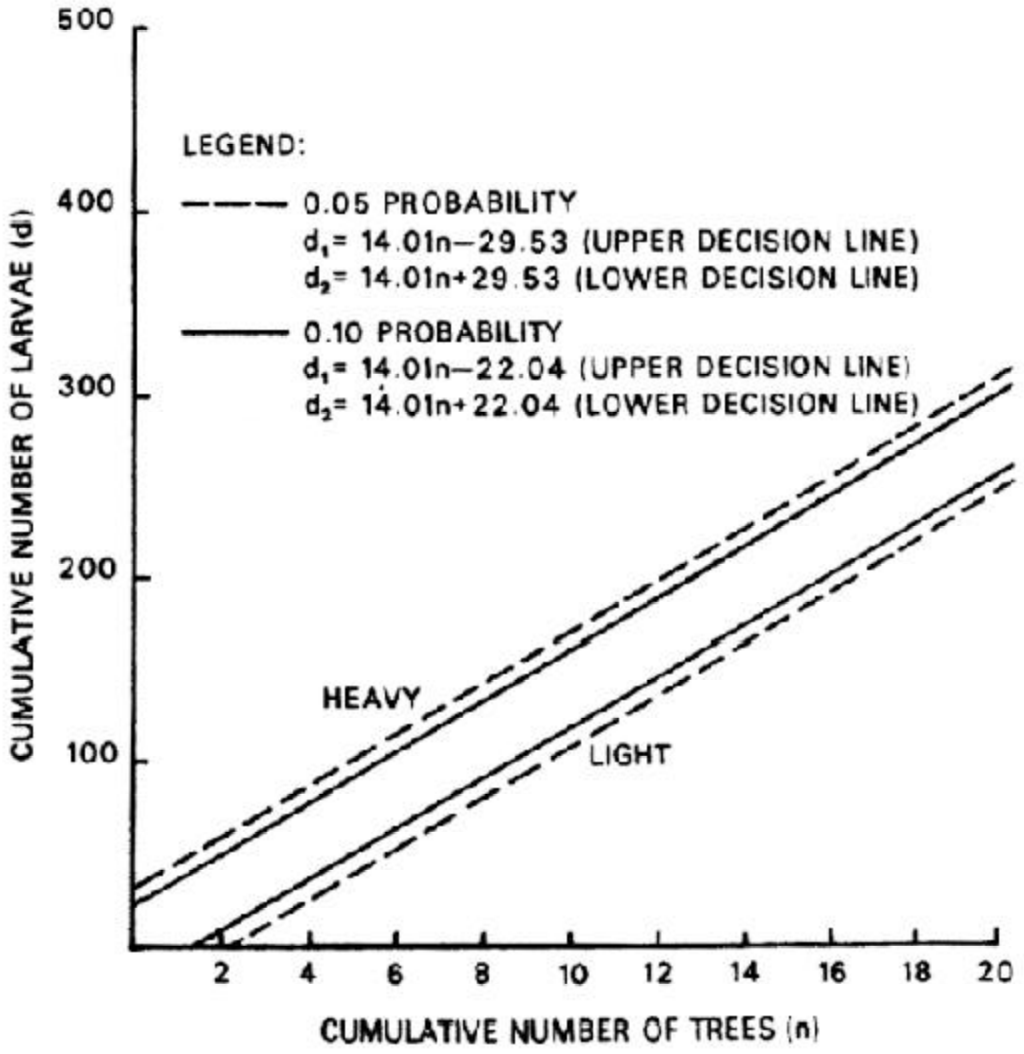

Figure 1. Sequential graph for classifying Douglas-fir tussock moth larvae into two population levels.

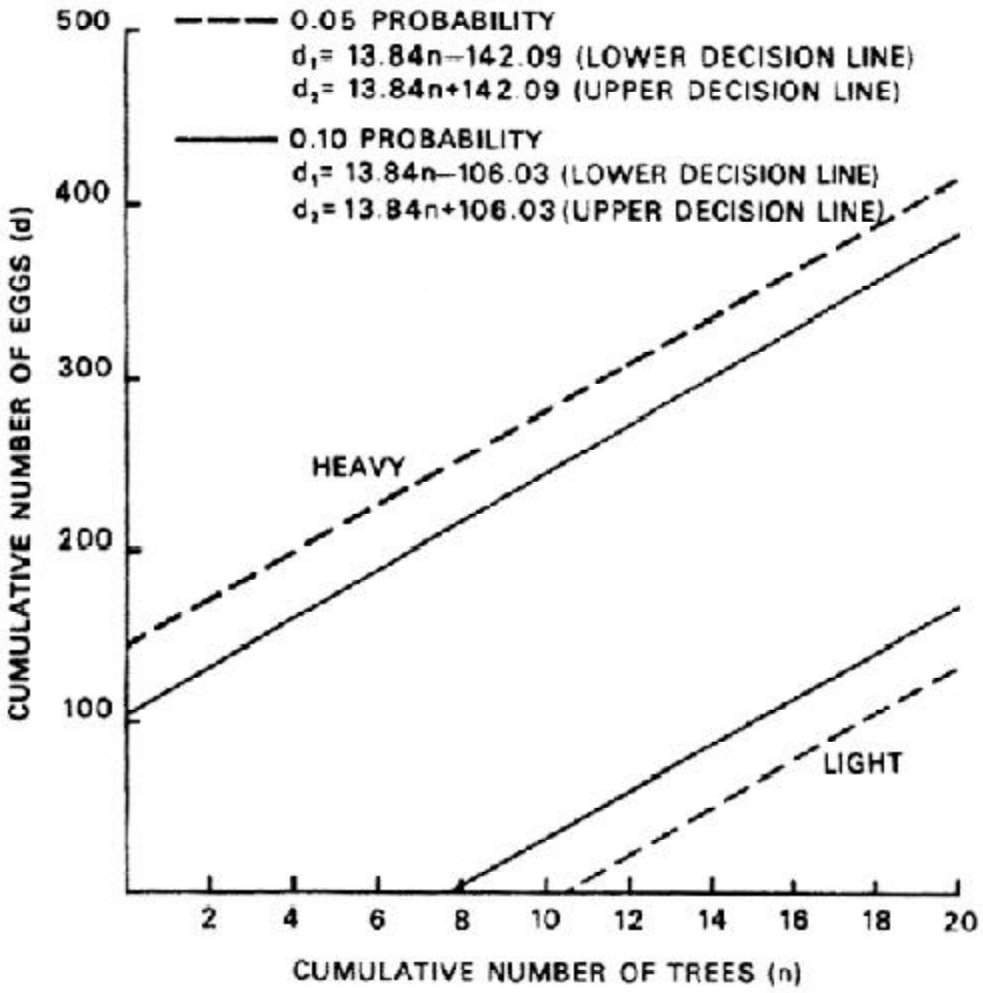

Figure 2. Sequential graph for classfying Douglas-fir tussock moth eggs into two population levels.

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

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

Objective

To develop and compare methods of sampling *O. pseudotsugata* populations.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly so that a large number of trees are often defoliated before direct control measures can be applied. Growth loss, top-kill and tree mortality are common during outbreaks. Procedures that estimate the density of eggs and larvae of *O. pseudotsugata* were developed and compared with respect to their standard error relative to the mean.

Population density was estimated in terms of the number of eggs or larvae per 0.645 m^2 of branch area. A significant proportion of the variation in the density of eggs and larvae was attributed to crown level and outbreak status. In an outbreak, egg masses are concentrated on inside branches near the bottom of the crown. However, in light infestations they are often on outside branches in the upper crown. The mean density of larvae in the mid-crown was representative of the whole tree. Egg density was estimated from whole branch samples collected from three crown levels. Larval density was estimated from 43-cm twig samples collected from the mid-crown. Since eggs are clumped in masses and larvae are dispersed over the foliage, larval density was estimated with less effort. Tables are provided that list required sample sizes to estimate egg and larval populations with known precision.

Sampling Procedure

Eggs: Sample one branch from the upper crown, two from the mid-crown, and one from the lower crown. The number of eggs in each sample unit is expressed as a function of the foliated area of each branch. Estimate the foliated area per branch by dividing the product of length and width by two ((W*L)/2). All insect counts are adjusted to a 0.645 m^2 of branch area. The number of eggs in the sample is simply calculated by multiplying the average number of eggs per mass by the number of egg masses. Table 1 lists the number of sample trees required for four levels of precision.

Larvae: Cut one 43-cm foliated twig sample from the outer mid-crown, and two samples from the inner mid-crown. Special care should be taken when using pole pruners so that larvae are not dislodged from the samples. The number of larvae on each sample unit is expressed as a function of the foliated area of each twig. Calculate twig area as in the egg sample. Table 2 lists the number of sample trees required for four levels of precision.

The authors suggest that a standard error within 20% of the mean is adequate for estimating population densities of *O. pseudotsugata*. This level of error can be attained by sampling 11 trees for larval populations in heavy infestations. In light larval or egg populations more samples would be required.

Notes

In practice, surveys of light populations are better handled through different sampling techniques involving sequential analysis. The authors suggest that this data should not be extrapolated to include trees greater than 12 m in height. Because larvae are better dispersed through the foliage than eggs, the variance is significantly smaller for larvae than for eggs. Sampling the larval population will yield more accurate results, with much less sampling effort, than sampling eggs.

Tables

Table 1. Number of sample trees required at different levels of error for estimating egg populations at a sample point.

Mean no. of eggs per 0.645 m^2 (1,000 in^2)	Standard error as per cent of mean			
	5	10	20	40
2	1,141	285	71	18
5	1,064	266	66	16
10	981	245	61	15
20	961	240	60	15
30	955	239	60	15
40	951	238	60	15
50	949	237	59	15
60+	948	237	59	15

Table 2. Number of sample trees required at different levels of error for estimating larval populations at a sample point.

Mean no. of larvae per 0.645 m^2 (1,000 in^2)	Standard error as per cent of mean			
	5	10	20	40
2	370	92	23	6
5	260	65	16	4
10	210	52	13	3
20	190	48	12	3
30	183	46	12	3
40	180	45	11	3
50	178	44	11	3
60+	176	44	11	3

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Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

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.

Objective

To develop a practical sampling plan for estimating very low densities of *O. pseudotsugata*.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly so that a large number of trees are often defoliated before direct control measures can be applied. Growth loss, top-kill and tree mortality are common during outbreaks. Conventional control methods of sampling larvae include examining and measuring branches removed from the mid-crown with a pole pruner (Mason 1969, 1970).

A new method is described for estimating larval density rapidly when populations are very low. This procedure is a large improvement over existing methods because observations are quickly and efficiently made in the lower crown without destructive sampling. Three branches are sampled using a beat cloth, and the presence or absence of larvae is recorded for each tree. Data are collected on the proportion of trees that contain larvae, which can be used to estimate the density in the lower and mid-crown.

Sampling Procedure

Select three branches randomly from the lower crown of Douglas-fir and beat over a portable drop cloth (61 by 123 cm), recording the presence or absence of larvae in each sample. The beat cloth should be placed within 56 cm of the branches. If a larva is found on the first branch, it is unnecessary to sample the remaining branches. The density of larvae in the lower crown can be estimated by substituting 2.0 for *R* in the equation:

$$L = -2R\ln(1 - P_x)$$

where, P_x is the estimated proportion of sample units in the lower crown containing larvae. Older larvae migrate toward the lower crown prior to pupation, and therefore *R* decreases through the season and affects the estimate of larval density. An *R* of 2.0 is recommended for sampling first and second instars, 1.5 for third and fourth instars, and 1.0 for fifth and sixth instars and pupae. Table 1 provides mid-crown larval density estimates for these three *R* values.

Notes

The sampling plan presented is for low density, sub-outbreak populations and should be applied to first and second instar larvae. The density equation assumes that the same frequency distribution of larvae in

the lower crown applies to that of the mid-crown where data were collected originally. The distribution of larvae within each crown level, regardless of density, follows the same distribution.

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.

Table

Table 1. Conversion of the proportion of infested lower crown samples (P_x) to density of larvae in the mid-crown ($\hat{M}$). Densities are calculated from ($\hat{M}$) = -2R ln(1 - p_x) for three values of R[1] and expressed as number of larvae per 0.645 m^2.

	$\hat{M}$				$\hat{M}$		
P_x	R = 1.0	R = 1.5	R = 2.0	P_x	R = 1.0	R = 1.0	R = 1.0
.001	.002	.003	.004	.31	.74	1.11	1.48
.002	.004	.006	.008	.32	.77	1.16	1.54
.003	.006	.009	.012	.33	.80	1.20	1.60
.004	.008	.012	.016	.34	.83	1.25	1.66
.005	.010	.015	.020	.35	.86	1.29	1.72
.006	.012	.018	.024	.36	.89	1.34	1.78
.007	.014	.021	.028	.37	.92	1.39	1.85
.008	.016	.024	.032	.38	.96	1.43	1.91
.009	.018	.027	.036	.39	.99	1.48	1.98
.01	.02	.03	.04	.40	1.02	1.53	2.04
.02	.04	.06	.08	.41	1.06	1.58	2.11
.03	.06	.09	.12	.42	1.09	1.63	2.18
.04	.08	.12	.16	.43	1.12	1.68	2.25
.05	.10	.15	.20	.44	1.16	1.74	2.32
.06	.12	.19	.25	.45	1.20	1.79	2.39
.07	.15	.22	.29	.46	1.23	1.85	2.46
.08	.17	.25	.33	.47	1.27	1.90	2.54
.09	.19	.28	.38	.48	1.31	1.96	2.62
.10	.21	.32	.42	.49	1.35	2.02	2.69
.11	.23	.35	.47	.50	1.39	2.08	2.77
.12	.26	.38	.51	.51	1.43	2.14	2.85
.13	.28	.42	.56	.52	1.47	2.20	2.94
.14	.30	.45	.60	.53	1.51	2.27	3.02
.15	.32	.49	.65	.54	1.55	2.33	3.11
.16	.35	.52	.70	.55	1.60	2.40	3.19
.17	.37	.56	.74	.56	1.64	2.46	3.28
.18	.40	.60	.79	.57	1.69	2.53	3.38
.19	.42	.63	.84	.58	1.74	2.60	3.47
.20	.45	.67	.89	.59	1.78	2.67	3.57
.21	.47	.71	.94	.60	1.83	2.75	3.67
.22	.50	.75	.99	.61	1.88	2.82	3.77
.23	.52	.78	1.04	.62	1.94	2.90	3.87
.24	.55	.82	1.10	.63	1.99	2.98	3.98
.25	.58	.86	1.15	.64	2.04	3.06	4.09
.26	.60	.90	1.20	.65	2.10	3.15	4.20
.27	.63	.94	1.26	.66	2.16	3.24	4.32
.28	.66	.99	1.31	.67	2.22	3.33	4.43
.29	.68	.102	1.37	.68	2.28	3.42	4.56
.30	.71	.107	1.43	.69	2.34	3.51	4.68
				.70	2.41	3.61	4.82

[1] R = 2.0 is recommended for sampling first and second instars (small larvae), R = 1.5 for third and fourth instars (medium larvae), and R = 1.0 for fifth and sixth instars (large larvae).

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.

Objective

To develop a sequential sampling plan for classifying *O. pseudotsugata* infestations based on the occurrence of first instar larvae in the lower crown.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly so that large numbers of trees are often defoliated before direct control measures can be applied. Growth loss, top-kill and tree mortality are common during outbreaks. The early recognition of impending outbreak conditions is essential for managing this insect.

A sequential sampling plan was described for identifying the outbreak potential of *O. pseudotsugata* populations. The plan uses a technique for sampling early instar larvae by non-destructive examination of lower crown foliage (Mason 1977). After each tree is sampled, the sequential sampling plan is referenced (Figs. 2), and sampling is continued until a decision is reached. Infestations are classified as either low level or suboutbreak, which indicates a population capable of reaching outbreak levels within one generation. The sampling plan is applied independently on individual plots to classify the density of each plot. It is an appropriate method for screening populations quickly in evaluation surveys, but is not intended as a single evaluation of large forested areas.

Sampling Procedure

Trees are sampled randomly within each 2 ha plot. Sampling techniques are described in detail by Mason (1977). Beat three branches selected randomly from the lower crown of Douglas-fir against a portable drop cloth, and record the presence or absence of larvae in each sample. If a larva is found on the first branch, it is unnecessary to sample the remaining branches. After each tree is sampled, reference the sequential sampling plan (Fig. 2), and continue sampling until a decision threshold is met (i.e., infestations are classified as either low level or capable of outbreak levels within one year).

A field tally sheet (see Fig. 4 in original document) has been designed to increase the efficiency of this sampling system. The class limits for decision-making are printed in the squares across the top of the columns for the number of trees sampled. The top left corner gives the upper limit for low level classification, and the bottom right corner gives the lower limit for populations capable of

outbreak potential. The number of primary sample units that are infested is accumulated across the page as trees are sampled at each plot (Fig. 4). If no decision is reached after sampling 20 trees, the infestation is classified as intermediate.

Note

Sampling must be conducted after egg hatch when the majority of larvae are first instar, and new shoot growth is at least 2.5-5 cm in length.

Reference

* 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.

Figure

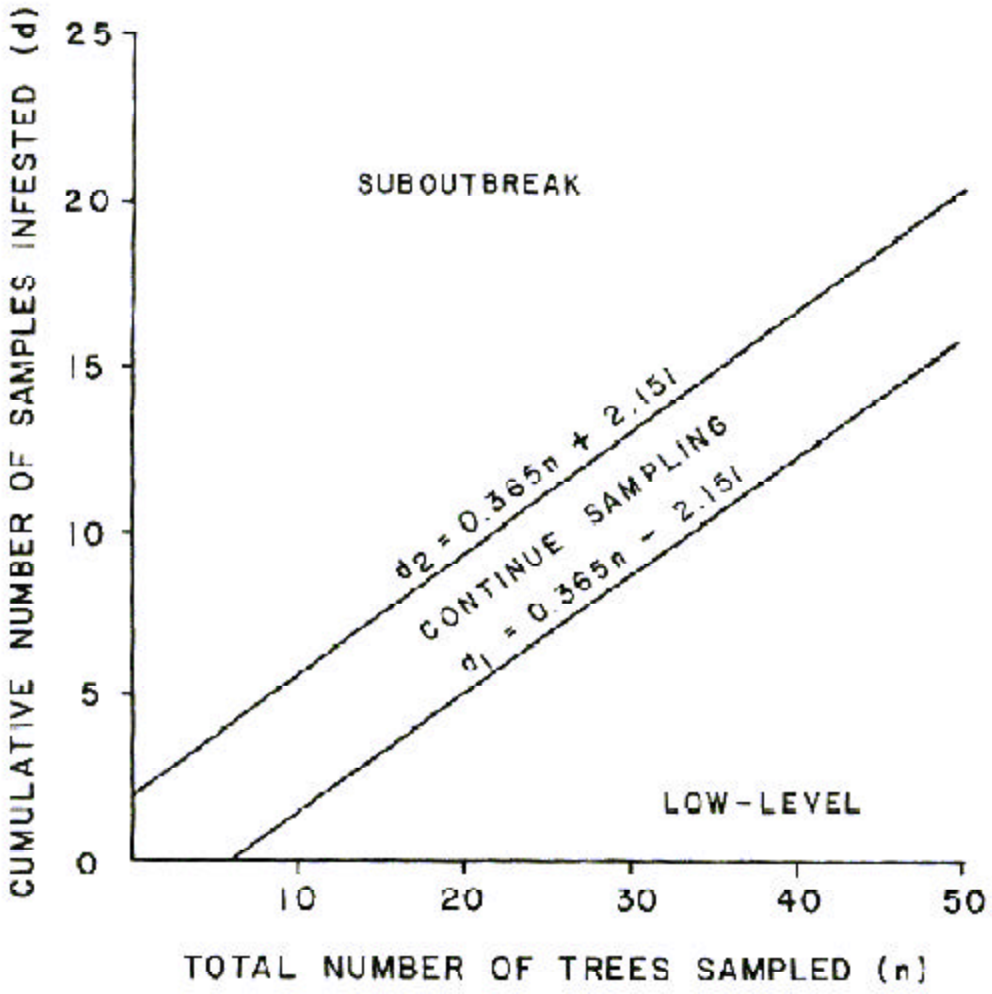

Figure 2. Sequential graph for sampling early larvae of the Douglas-fir tussock moth in the lower tree crown.

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

Objective

To provide a system that classifies *O. pseudotsugata* populations into general density categories that are meaningful for evaluating outbreak potential.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly so that a large number of trees are often defoliated before direct control measures can be applied. Growth loss, top-kill and tree mortality are common during outbreaks. The early detection of impending outbreak conditions is essential for managing this insect, and is measured by the number of larvae present when populations are low. This review contains detailed information on how to properly sample *O. pseudotsugata* populations.

Sampling Procedure

Most of the information contained in this handbook is presented elsewhere. However, the author provides clear and concise instructions explaining how to estimate larval densities by sampling the mid-crown (Mason 1969, 1970) and lower crown (Mason 1977) of host trees. Sequential sampling plans are also reviewed (Mason 1969, 1978). This manual is a useful supplement to previous publications, particularly if difficulty is encountered in understanding sampling methods.

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; 11p.

* 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.

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

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

Objectives

To derive and compare two models for estimating density from ***p***; and to determine which is most versatile over a wide range of larval ages and densities.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Outbreaks occur quite unexpectedly so that a large number of trees are often defoliated before direct control measures can be applied. Growth loss, top-kill and tree mortality are common during outbreaks. The density of insects in the mid-crown is the standard expression of abundance for analysis and management of *O. pseudotsugata* populations.

Procedures (Mason 1977, 1978, 1979) have been developed for predicting mid-crown densities of first and second instar larvae by sampling the lower crown where foliage is examined easily without destructive sampling methods. In that scheme, a value p (proportion of samples containing at least one insect) was estimated from examination of lower crown branches, and translated into mid-crown density by a correction factor for the vertical distribution of larvae within crowns (Mason 1977). Mid-crown densities calculated from mean proportions from the lower crown ($M = -17.754d^{-0.598} \ln (1 - p)$) and densities from direct mid-crown sampling compared favorably. A chi-square goodness-of-fit test between calculated and observed values indicated density estimates from the two sampling methods did not differ significantly ($P < 0.005$). The model based on lower crown samples is therefore recommended for use as density estimations are easier to obtain than direct sampling of the mid-crown. It is also applicable to any sample of which average insect age is known or can be approximated.

Sampling Procedure

Take three lower crown samples from 12-15 trees in 10 1-ha plots. Accessible limbs are sampled by beating the distal 45-cm of each branch over a drop cloth to dislodge insects. Determine the number of sample units with one or more tussock moths present and the proportion (p) of infested trees. The theoretical model is then used to calculate the mean number of insects per square meter of branch area to derive a mid-crown population estimate:

$$M = -17.754d^{-0.598} \ln (1 - p),$$

where d is the average age in days since egg hatch (if predominant instar is between classes use midpoint):

Instar I	5
Instar II	15
Instar III	25
Instar IV	35
Instar V	45
Instar VI	55
Pupae	60

Note

The models were developed for low density populations of *O. pseudotsugata*.

References

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

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

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.

Objectives

To develop a method of assessing egg mass density rapidly within non-defoliated stands; and to predict if significant damage will occur the following year.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Defoliation can often be severe and cause tree mortality during the first year of defoliation. Outbreaks erupt suddenly and often synchronously in patches over large forested areas. To reduce losses, early warning of potential outbreaks are necessary to schedule control operations.

A sequential egg mass sampling system, based on visual scanning of the lower branches of Douglas-fir, was designed. No consistent trend in egg mass density per branch could be found among crown levels, and no level proved superior as a representative of the whole tree. Therefore, the lower whorl of branches was selected for survey purposes because of sampling efficiency. The sampling system is designed to assess egg mass density rapidly within non-defoliated stands and predict defoliation levels for the following year.

The number of egg masses on three lower branches on each of 20 trees is examined, and a sequential graph is referenced (Fig. 2). As samples are taken, the cumulative number of egg masses is plotted over the number of trees sampled. Sampling continues until a decision is met and defoliation is predicted as none or little (0-0.7), noticeable (0.7-2.0), or severe ($\geq$2.0 egg masses per three branch sample).

Sampling Procedure

Autumn egg mass surveys provide the basis for a rough estimate of defoliation the following year, since there is considerable loss of egg masses during winter and early spring. However, this plan can be used as a tool to determine the potential of an outbreak. Its main advantage is the efficiency at which egg mass densities can be estimated, and the amount of advanced notice available for scheduling control programs over conventional sampling techniques.

Determine if egg masses are present, and then make a circuit to locate the center and extent of the infestation. Count the number of egg masses on three lower branches on each of 20 trees. Reference the sequential graph to determine the upper and lower stop sampling lines, representing the number of samples required to determine the density within 20% of the true mean 95% of the time (Fig. 2). As samples are taken, the cumulative number of egg masses is plotted over the number of trees sampled. At the point of crossing an upper or lower stop sampling line, a population estimate can be

made. If the total number of egg masses found is ≤4 or ≥40, stop sampling and calculate the average number of egg masses per tree. If the total number of egg masses is 5-39, sampling continues until a decision is met and defoliation is predicted as either none or little, noticeable, or severe.

Notes

This system is designed as an early detection tool to predict potential outbreaks in non-defoliated stands with branches low enough for visual observation of egg masses. Please refer to our review of Shepherd and others (1985) for more detailed information on defoliation classes.

Reference

* Shepherd, R. F.; Otvos, I. S.; Chorney, R. J. 1985. Sequential sampling for Douglas-fir tussock moth egg masses in British Columbia. Joint Rep. 15. Canadian Forest Service, Pacific Forest Research Centre. 7 p.

Figure

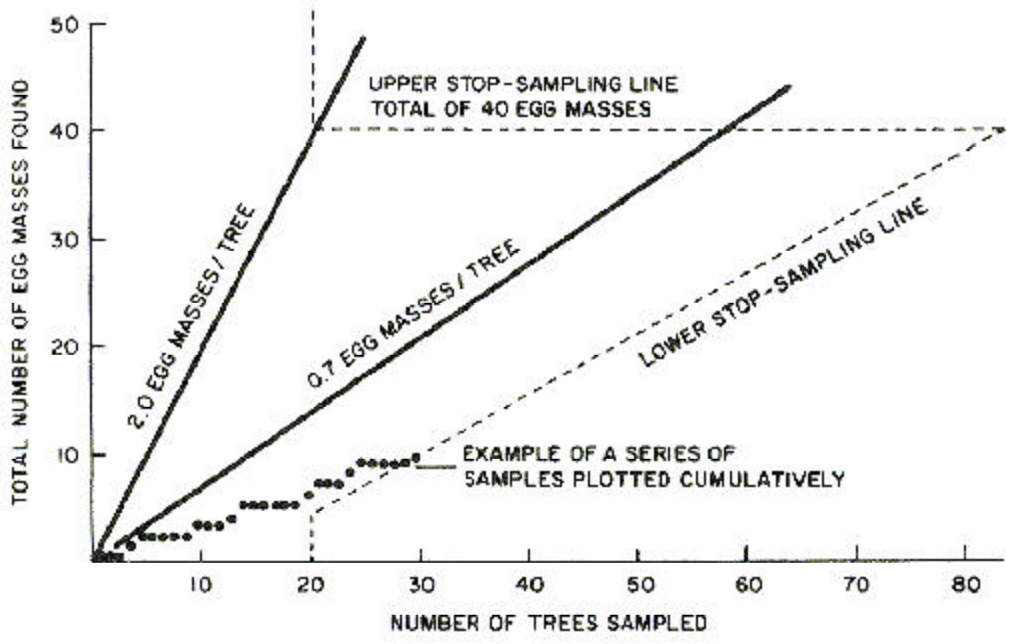

Fig. 2. Stop-line of cumulative number of egg masses to be sampled when density estimate is to be within 20% of the true mean, 95% of the time.

Figure 2 reprinted with permission of the Canadian Entomologist, January 15, 2001.

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

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

Objective

To determine densities of early instar larvae of *O. pseudotsugata* with known precision.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Defoliation can often be severe and cause tree mortality during the first year of defoliation. A sequential sampling system for estimating early instar larval density within 20% of the mean 95% of the time is presented. The system was used to measure lower crown densities equivalent to 4.3-130 larvae per square meter at mid-crown as part of an assessment system for control decision-making.

The number of larvae per three branch sample was determined and compared with the sequential sampling plan. Sampling was continued until a decision was met (Table 1). Above the upper stop-sampling line, noticeable defoliation is expected. Below the lower stop-sampling line, the larval density is at least one generation away from causing noticeable defoliation. A minimum of 10 trees was sampled before a decision was met.

Sampling Procedure

Incipient outbreaks are initially detected by sampling low level larval densities (Mason 1977) or by pheromone trapping and scouting for egg masses (Shepherd and others 1984). Once an infestation is located, select three branches randomly from each of 10 trees per plot, and beat the terminal portions over a 60 by 90-cm canvas trap to dislodge larvae. Record the number of larvae per sample. Sampling should coincide with an abundance of first and second instar larvae, and before new foliage has begun to change color. After 30 samples (10 trees), reference the sequential sampling plan (Table 1), and continue sampling until a decision is made. Larval populations will be classified as capable of producing noticeable defoliation or at least one generation away from causing noticeable defoliation.

Note

This system is designed to be used in stands that were not defoliated previously. The relationship between lower and mid-crown densities is discussed.

References

* 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.

* 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.

Table

Table 1. Densities of Douglas-fir tussock moth larvae where sampling is discontinued. A density below the lower stop-sampling line indicates that the larval density is at least 1 generation away from causing noticeable defoliation.

	Stop sampling when cumulative number of larvae is equal to or	
No. of trees	Less than	More than
10	17	68
12	23	64
14	29	61
16	35	59
18	41	58
20	47	57
22	53	56
24	59	55

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

Shepherd, R. F.; Gray, T. G.; Chorney, R. J.; Daterman, G. E. 1985. Pest management of Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae): monitoring endemic populations with pheromone traps to detect incipient outbreaks. Canadian Entomologist 117: 839-847.

Objective

To develop a trap-based monitoring system that follows population trends of *O. pseudotsugata* adults through endemic levels and predicts incipient outbreaks.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Defoliation can often be severe and cause tree mortality during the first year of defoliation.

The number of *O. pseudotsugata* adults caught in delta-shaped sticky traps baited with pheromone lures was compared with egg mass densities and subsequent defoliation. A lure containing 0.01% pheromone by weight was more effective at predicting population trends than baits having concentrations of 0.0001, 0.001, 0.1, or 1.0%. Trap saturation occurred at 40 moths per trap. To achieve a standard error of 30% of the mean, six traps were required at each site. A threshold density of 25 moths per trap provided a warning of potential outbreaks, causing defoliation up to 12-km from the trap site.

Sampling Procedure

Construct delta-shaped traps (695 cm^2) from 2 L orange, paper milk cartons with the interior coated with Tanglefoot™ (Tanglefoot Co., Grand Rapids, MI). Place six traps, with one 3 by 5-mm PVC lure containing 0.01% of *O. pseudotsugata* pheromone (*Z*-6-heneicosen-11-one) impaled to the roof interior, at each monitoring site. Hang traps >30 m apart on live host branches 2-2.5 m above ground.

A trap density threshold of 25 moths per trap is used to indicate that the population is about two years from outbreak, and should be followed up by more detailed egg mass surveys. Space survey plots 1-5 km apart the summer before defoliation is predicted to occur. The authors recommend a pre-outbreak warning system consisting of a continuous pheromone-trap monitoring system to follow population trends, and a sequential egg mass survey to identify concentrated areas of outbreak where defoliation can be expected (Shepherd and others 1984).

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.

Douglas-Fir Tussock Moth

Orgyia pseudotsugata (McDunnough)
Lepidoptera: Lymantriidae

Shepherd, R. F.; Otvos, I. S.; Chorney, R. J. 1985. Sequential sampling for Douglas-fir tussock moth egg masses in British Columbia. Joint Rep. 15. Canadian Forest Service, Pacific Forest Research Centre. 7 p.

Objective

To develop a sequential sampling plan designed to predict defoliation levels the following summer based on fall egg mass densities.

Abstract

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and true firs, *Abies* spp., in western North America. Defoliation can often be severe and cause tree mortality during the first year of defoliation. This field guide describes an easy-to-use survey for determining egg mass density and predicting defoliation levels.

The use of pheromone traps will provide a warning when *O. pseudotsugata* populations are approaching outbreak levels. However, pheromone traps do not pinpoint the exact location of an outbreak, or the level of expected defoliation. The latter information can be determined by a sequential egg mass sampling program (Shepherd and others 1984). This program is designed to determine the average number of egg masses per tree within 20% of the true mean 95% of the time. Defoliation predictions are based on mean egg mass totals per three lower crown branches, and are classified as either light, moderate, or severe.

Sampling Procedure

In the fall, after pheromone traps have indicated that *O. pseudotsugata* egg masses may be present, examine all susceptible stands with little or no defoliation in the general vicinity of the pheromone traps. Walk through each stand, looking on the lower side of branches for egg masses. Be careful not to confuse old egg masses or cocoons for new, viable egg masses. If egg masses are found, search for the area where egg mass density appears to be highest and mark the center of the infestation.

Select 20 Douglas-fir trees randomly around the center of the infestation with at least three full-sized lower branches close enough to the ground so that new egg masses can be seen easily. Record the number of egg masses on the three lower branches. Calculate the average number of egg masses per tree and determine the predicted defoliation class:

0-0.7 egg masses per three lower branches per tree: No or light defoliation as characterized by less than half of the trees suffering complete defoliation of current foliage in the upper crown and only minor damage to old foliage.

0.7-2.0 egg masses per tree: Noticeable defoliation characterized by most current foliage and almost half of the older foliage being damaged. Usually significant growth loss occurs, but only minor dieback and mortality is observed.

$\geq$2.0 egg masses per tree: Severe defoliation as characterized by most current foliage and more than half of the older foliage consumed. At least 20% of trees will be completely defoliated, and significant growth loss, dieback, and mortality will occur.

Note

It is the point of highest egg mass density within the stand that is surveyed so the resulting defoliation predictions are worst case scenarios and may not reflect stand means.

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.

Saddled Prominent

Heterocampa guttivitta (Walker)
Lepidoptera: Notodontidae

Grimble, D. G.; Kasile, J. D. 1974. A sequential sampling plan for saddled prominent eggs. Applied Forestry Research Inst. Rep. 15. Syracuse, NY: State University of New York, College of Environmental Science and Forestry; 15 p.

Objective

To develop a sequential sampling plan for *H. guttivitta* eggs to estimate defoliation levels in sugar maple stands.

Abstract

The saddled prominent, *Heterocampa guttivitta* (Walker), is a native defoliator of hardwood forests. Preferred hosts include sugar maple, *Acer saccharum* Marsh., and American beech, *Fagus grandifolia* Ehrh., but nearly all deciduous trees are attacked during outbreaks. This insect is also an important pest of sugarbushes in the northeastern USA and Canada. A sequential sampling plan was presented for evaluating the risk of defoliation in sugar maple stands.

The sample unit consisted of 10 individual leaf-clusters (about 40 leaves) removed by pole-pruners from a branch tip. By examining a series of foliage samples, field workers can predict the threat of defoliation as either negligible (<40%) or severe (>70%) based on the cumulative number of viable eggs and newly-hatched larvae. A minimum of nine samples is required, and a maximum of 30 are examined before sampling is discontinued, and defoliation is classified as undetermined until another sample can be conducted (i.e., 2-3 days later).

Sampling Procedure

Locate one plot per 10-14 ha in stands where sugar maple is the dominant species. Remove 10 individual leaf-clusters (about 40 leaves) randomly from a branch tip 61-cm in length located as high in the crown of sugar maple as can be reached with pole pruners. A leaf cluster is defined as that group of maple leaves (2-4) that develop from a single bud. Time sampling to occur at about 10% egg hatch (mid-June through early July).

Once the foliage samples are removed, record the total number of eggs (parasitized and viable) and larvae found. Eggs, which are light green in color when fresh and darken with age, are deposited singly on the underside of leaves. Take a minimum of nine branch samples, and calculate the cumulative number of *H. guttivitta* eggs and larvae. Reference the sequential sampling plan (Fig. 6), and continue sampling until a decision is met and defoliation is classified as light or severe. After a maximum of 30 samples, discontinue sampling and classify defoliation levels as undetermined. Visit each sampling location at least once during the late-larval feeding period to verify defoliation levels.

The distribution of *H. guttivitta* eggs follows a Poisson distribution. The errors of misclassifying defoliation were set at 0.10 (light) and 0.05 (severe). Investigators should be familiar with the lifecycle of *H. guttivitta* and be able to distinguish its eggs from those of other forest Lepidoptera.

Figure

Fig. 6. Decision lines for sequential sampling of saddled prominent eggs to predict defoliation.

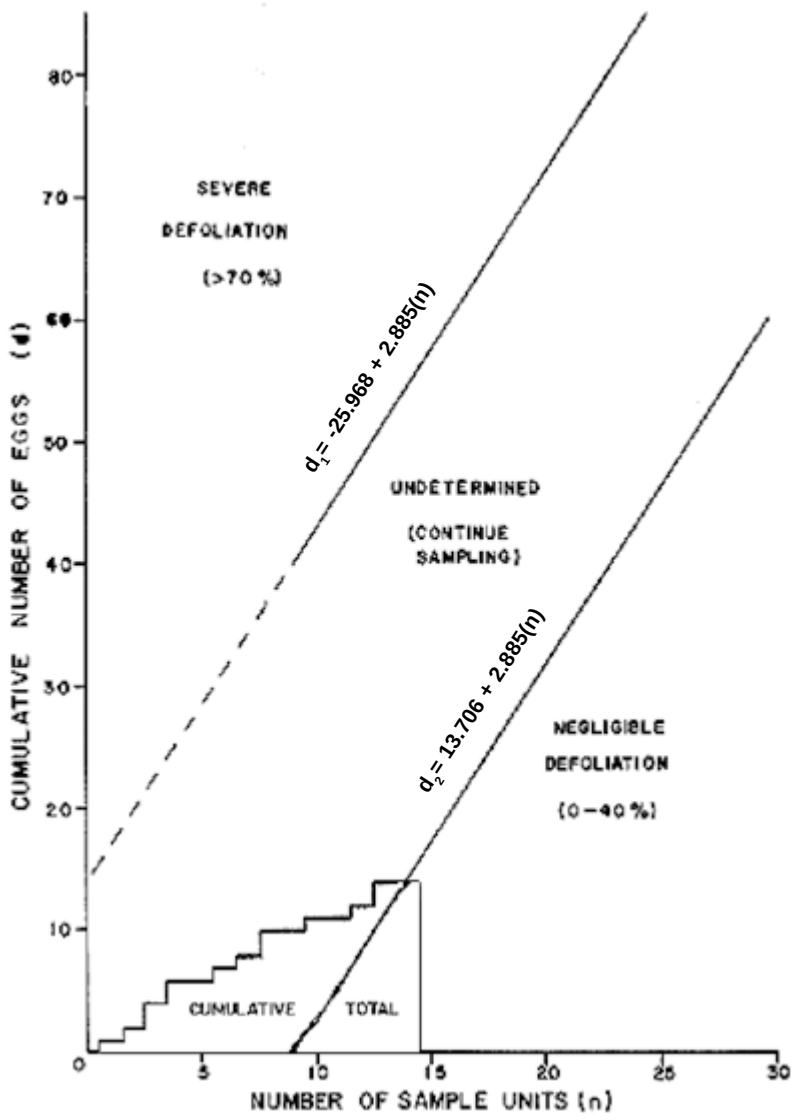

Figure 6 reprinted with permission from SUNY-Syracuse, January 15, 2001.

Orangestriped Oakworm

Anisota senatoria (J. E. Smith)
Lepidoptera: Saturniidae

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.

Objective

To determine if a monitoring program coupled with the establishment of an aesthetic injury level (AIL) could be used to manage *A. senatoria* with minimal insecticide inputs.

Abstract

The orangestriped oakworm, *Anisota senatoria* (J.E. Smith), is a native defoliator of various oaks, *Quercus* spp., in the eastern USA and Canada. In the 1980's, this species became a major pest of urban oak plantings along city streets in Norfolk, Virginia. Insecticide sprays were applied by city employees at the request of citizens to control this pest. In >50% of the citizen requests, trees had <5% defoliation. Justification for an urban pest management program for *A. senatoria* was based on the economic value of urban oak trees ($5,131 per tree), and the large insecticide volumes sprayed for control.

The authors established an AIL based on a citizens survey to measure defoliation levels that were acceptable to homeowners. Additionally, the effects of different levels of defoliation on tree vigor were measured by root starch content. Based on the citizens survey and root starch analyses, a 25% AIL threshold was used to determine if insecticide applications were required. Monitoring and establishment of the AIL resulted in a decrease in pesticide usage by 80% at a cost savings of 55%.

Sampling Procedure

Monitor trees during peak larval periods (mid-August through September), and estimate visually the defoliation by dividing the tree into four quadrants and summing the estimated percent defoliation in each quadrant. Apply insecticides only when trees have >25% defoliation at the time of monitoring. This simple monitoring technique results in an 80.3% decrease in pesticide usage, and a 55% cost reduction in materials and labor.

Note

The results are applicable to high-value oak stands.

Coffelt, M. A.; Schultz, P. B. 1994. Within-tree distribution and a fixed-precision level sampling plan for the orangestriped oakworm (Lepidoptera: Saturniidae). Journal of Economic Entomology 87: 382-388

Objective

To determine the minimum number of samples required to estimate within-tree population density of eggs and early instar larvae of *A. senatoria* with known sampling error.

Abstract

The orangestriped oakworm, *Anisota senatoria* (J. E. Smith), is a native defoliator of various oaks, *Quercus* spp., in the eastern USA and Canada. Outbreaks have recently become severe in some urban areas of Virginia, leading to the development of integrated pest management strategies (Coffelt and Schultz 1990). The within-tree distribution of *A. senatoria* was studied to develop a fixed-precision-level sampling plan for eggs and early instar larvae that determines the minimum number of branchlet samples to estimate within-tree density on pin oak, *Quercus palustris* Muench. (Fig. 1).

Sampling Procedure

Sample 30 cm of a branch tip for eggs and first and second instar larvae during the last two weeks of July. Sampling should be conducted in all cardinal directions beginning at the drip line and working inward. Estimate the number of eggs per egg mass to the nearest 25 by determining the area covered by an average-sized pin oak leaf and establishing a visual comparison on an area basis.

The number of samples necessary to estimate the population mean with known sampling error can be determined using the model presented in Fig. 1. Error levels of 20, 25, and 30% are given. The number of within-tree samples needed for these levels of precision at various egg and early instar densities can be calculated using the following equation

$$\log n = (\log \boldsymbol{a} - 2 \log D_0) - (2 - b) \log x$$

where, a is the slope value, b is the intercept, n is the required number of samples, and D_0 is the fixed level of error in terms of the SE/mean.

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.

Figure

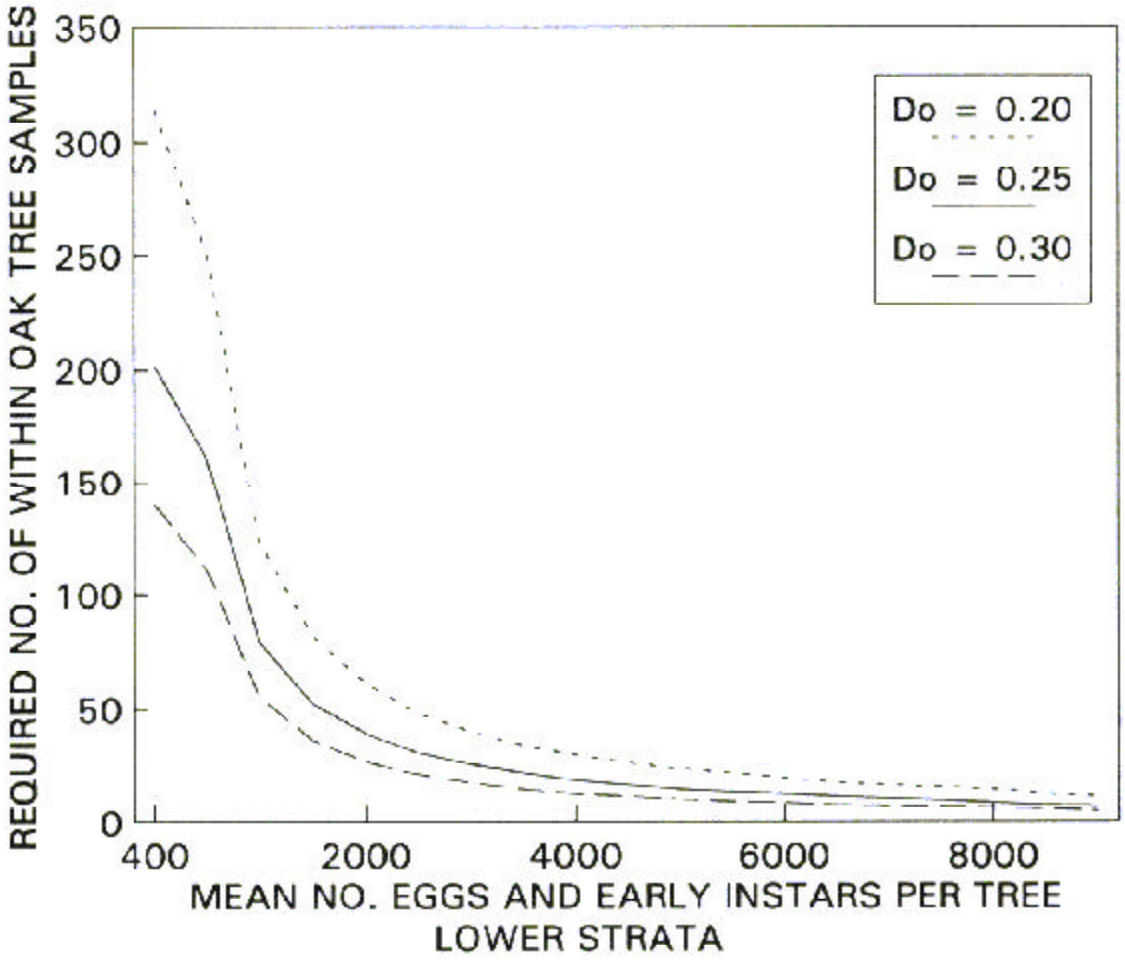

Fig. 1. Required number of within-oak-tree samples for *A. senatoria* eggs and early instars at the 0.20, 0.25, and 0.30 levels of precision (D_o).

Figure 1 reprinted with permission from the Journal of Economic Entomology, January 15, 2001.

Pandora Moth

Coloradia pandora Blake
Lepidoptera: Saturniidae

Schmid, J. M.; Bennett, D.; Young, R. W.; Mata, S.; Andrews, M.; Mitchell, J. 1982. Sampling larval populations of the pandora moth. Res. Note RM-421. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station; 5 p.

Objective

To develop an effective and efficient sampling method for determining larval densities of *C. pandora.*

Abstract

The pandora moth, *Coloradia pandora* Blake, is a pest of western pines, particularly ponderosa, *Pinus ponderosa* Dougl. ex Laws, lodgepole, *P. contorta* Dougl. ex Loud., and Jeffrey pine, *P. jeffreyi* Grev. and Balf. *Coloradia pandora* generally requires two years to complete its life cycle, but some individuals may take up to 6 years. Different combinations of trees per plot, branch samples per tree, and cardinal direction per sample were evaluated for estimating larval populations on ponderosa pine. The mean number of larvae per branch did not differ among sampling schemes. Aspect had a significant effect on larval density. Each plot consisted of sampling one branch from one tree. When larval counts averaged 2-4 larvae per branch, 50 trees must be sampled to achieve an estimate within 20% of the true mean (P = 0.05). The results are discussed in relation to operational sampling procedures for determining larval density with known precision.

Sampling Procedure

Collect one branch from each tree. Remove branch tips 40-60 cm long from 8-10 m aboveground with a pole-pruner. Include only one sample from the north aspect in every four samples. Branch tips should be well-foliated and consist of a distinct main stem with several lateral shoots (i.e., without excessive branching). Count and record the number of larvae.

When larval counts average 2-4 larvae per branch, sample 50 trees to achieve an estimate within 20% of the true mean ($P = 0.05$). If an estimate within 10% of the mean is required, then sample 200 trees. When larval counts average less than 1.5 per branch, more than 100 trees will need to be sampled to estimate larval densities within 20% of the true mean.

Two-Year Cycle Spruce Budworm

Choristoneura biennis Freeman
Lepidoptera: Tortricidae

Harris, J. W. E. 1963. Sampling the egg stages of the two-year-cycle spruce budworm near Babine Lake, British Columbia. Forestry Chronicle 39: 199-204.

Objective

To determine the most representative location to estimate egg mass densities of the 2-year cycle spruce budworm, *C. biennis*.

Abstract

The 2-year cycle spruce budworm, *Choristoneura biennis* Freeman, occurs exclusively in high elevation stands of alpine 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, where it overwinters. The second year, the fourth instars resume feeding, pupate, become adults, lay eggs, and their progeny develop until the second instar, where they overwinter to complete the 2-year life cycle. The last three larval instars of *C. biennis* (i.e., fourth, fifth, and sixth) cause most of the defoliation. Periodic outbreaks occur every 30 years and can last 5-10 years. A study was carried out 64-km east of Smithers, British Columbia, Canada, to determine the best location(s) to sample egg masses. All sites were located >900 m in elevation within alpine fir-white spruce stands. Egg mass densities were estimated for locality, tree species, crown side, crown level, stand level, and branch size.

When *C. biennis* densities were high, tree species, locality, and aspect did not explain a significant proportion of the variation in egg mass densities. A significant proportion of the variation in egg mass densities, however, was explained by sample tree, crown level, stand level, and branch size (whole branch or 45-cm tip) in the lower crown. An acceptable estimate of egg densities was obtained by sampling one 45-cm branch tip from the mid-crown portion of as many overstory trees as possible. When *C. biennis* densities were low, locality explained a significant proportion of the variation in egg mass density. Therefore, more localities need to be sampled to obtain representative estimates of *C. biennis* egg mass densities when budworm densities are at low population levels.

Sampling Procedure

Select as many sample trees as feasible from a representative area of the stand. For example, the authors suggest that 230 sample trees would give a sampling error of 10%. Sample trees should be limited to overstory alpine fir or white spruce. Cut a 45-cm branch tip from the mid-crown portion of each sample tree, and calculate the foliated area by multiplying the length of the branch by one-half of its width. Count the number of egg masses on each sample and divide by the area to obtain an estimate of egg density.

Note

Lower crown sampling is acceptable if for some reason it is impossible to sample the mid-crown.

Spruce Budworm

Choristoneura fumiferana (Clemens)
Lepidoptera: Tortricidae

Allen, D. C.; Dorais, L.; Kettela, E. G. 1984. Survey and detection. In: Schmitt, D. M.; Grimble, D. G.; Searcy, J. L. editors. Spruce budworm handbook: managing the spruce budworm in eastern North America. Agric. Handb. 620. Washington, DC: U.S. Department of Agriculture, Forest Service; 21-36.

Objective

To provide a summary of survey and detection, defoliation, impact assessment, and hazard rating methods for *C. fumiferana* populations.

Abstract

The 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 can last 5-10 years. The Canada-United States Spruce Budworms Program (CANUSA) published a compilation of current research findings related to the spruce budworm. Survey and detection methods, as well as defoliation estimation, for endemic and epidemic populations are presented.

Sampling Procedure

Sparse populations: Light traps and pheromone traps are commonly used to survey low-density populations and to detect if an outbreak is imminent. Black light traps are often used to obtain a relative estimate of budworm abundance and population trends in specific areas over time. This technique can be used to detect increasing populations well before defoliation becomes evident. To be effective, traps should be placed in areas having the highest budworm hazard.

Traps baited with Fulure (95:5 blend of (E)- and (Z)-11-tetradecendal) are very effective attractants when used in low density (i.e., less than 1 larva per 45-cm branch tip) populations. Place traps, equipped with a killing agent, in a single five-trap cluster (40 m between traps (Table 3.3) in stands of highest hazard. Suspend the pheromone lure below the cover of the trap.

Outbreak populations

Egg masses: Egg mass surveys are used most commonly to determine budworm population levels. Intensive surveys use one plot for every 1,000 to 12,000 ha whereas extensive ones use one plot every 15,000 ha or 40 km of road. The size of the sample unit as well as the number of samples collected varies by province and state. Egg mass density is expressed differently as well (see Tables 3.1 and 3.2 in the original publication). Refer to the original publication for more detail.

Overwintering second instar survey: This method is used most commonly to check results of egg mass surveys, adjust infestation forecasts, and identify stands that are candidates for control. The techniques used are forced emergence rearing and a sodium hydroxide (NaOH) wash. This technique has been described in detail in Sanders (1980). The method of expressing second instar survey data varies by province and state (Table 3.3).

Large larvae: Size as well as number of samples collected varies by province and state. Please refer to original publication and Sanders (1980) for details.

Defoliation assessment: Please refer to Sanders (1980) for details concerning the sampling procedure.

Note

Our review of Sanders (1980) in this publication covers the same techniques mentioned here. Please also refer to the original publication for more information.

Reference

* Sanders, C. J. 1980. A summary of current techniques used for sampling spruce budworm populations and estimating defoliation in eastern Canada. Rep. O-X-306. Canadian Forest Service, Great Lakes Forest Research Center; 34 p.

Table

Table 3.3. Relationship between number of overwintering spruce budworm larvae per branch and expected infestation level (from Dorais and Kettela 1982).

Geographic region	No. of larvae per whole branch	No. of larvae per 100 ft^2 (9.3 m^2) of foliage	Forecasted infestation
Maritimes	1 to 6	---	Low
	7 to 21	---	Medium
	21 to40	---	High
	>40	---	Extreme
Ontario	1 to 25	---	Low
	26 to 65	---	Medium
	>66	---	High
Quebec,	---	1 to 100	Low
Newfoundland	---	101 to 300	Medium
	---	301 to 650	High
	---	>651	Extreme
Maine	---	0 to 175	Low
	---	176 to 500	Medium
	---	502 to 1100	High
	---	>1100	Extreme

Allen, D. C.; Abrahamson, L. P.; Eggen, D. A.; Lanier, G. N.; Swier, S. R.; Kelley, R. S.; Auger, M. 1986. Monitoring spruce budworm (Lepidoptera: Tortricidae) populations with pheromone-baited traps. Environmental Entomology 15: 152-165.

Objective

To develop a trapping system that would reflect *C. fumiferana* densities accurately.

Abstract

The 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. A collaborative study was conducted in Canada and the northeastern USA to evaluate the effectiveness of four types of pheromone traps and two types of commercial lures as a population monitoring tool.

In most locations with most traps, the catch of male *C. fumiferana* moths was correlated positively with second and fourth instar populations. Covered funnel traps (Ramaswamy and Cardé 1982) baited with Conrel lures caught significantly more male *C. fumiferana* moths than those baited with Hercon lures. A five-trap cluster placed at least 40 m from an opening with a 40-m interval between traps provided the best compromise between sampling accuracy and practicality. Although not tested here, the authors recommended field testing of the Unitrap (International Pheromones, London) and the Multi-Pher trap (Les Services Biocontrole, Quebec) in further trapping studies because they appeared well designed for capturing *C. fumiferana* moths.

Sampling Procedure

This review describes the use of covered funnel traps. Please consult the original publication for the procedures used for other, less effective traps. Age Conrel pheromone lures (96:4 blend of (*E*)- and (*Z*)-11-tetradecenal plus 2% antioxidant) (Albany International, Needham Heights, Massachusetts) for 21 d prior to use to reduce trap saturation. Pin one lure in the top of each covered funnel trap (Ramaswany and Cardé 1982). At the bottom of each trap, place a killing agent to retain moths entering the trap.

Place a trap cluster every 60-m in the area of concern, 4-7 d prior to initiation of *C. fumiferana* moth flight. Clusters should be placed >40 m from an opening (field, meadow, etc.). Place one trap in each of the north, east, south, and west aspects, 40 m from a central trap, for a total of five traps per cluster. Suspend each trap from a branch 2-2.5 m above the ground. Trim all foliage within 30 cm to create unobstructed access to incoming moths. Retrieve traps about 7 weeks later, and count the number of moths.

Notes

It takes 30 minutes to set up a trap cluster. One trap cluster will suffice for monitoring 20 ha of susceptible host trees.

Reference

Ramaswamy, S. B.; Cardé, R. T. 1982. Nonsaturating traps and long-life attractant lures for monitoring spruce budworm males. Journal of Economic Entomology 75: 126-129.

Dobesberger, E. J.; Lim, K. P. 1983. Required sample size for early instar spruce budworm, *Choristoneura fumiferana* (Lepidoptera: Tortricidae), in Newfoundland. Canadian Entomologist 115: 1523-1527.

Objective

To determine the minimum sample size necessary for estimating the larval population density of *C. fumiferana* at various levels of precision.

Abstract

The 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. A study was carried out in Newfoundland, Canada to determine the minimum sample size needed for accurate estimation of second, third, and fourth instar larval populations.

The observed variances for both whole branch and 45-cm tip samples did not differ significantly with those expected from a negative binomial distribution. Similar sample sizes were predicted for both the whole branch and 45-cm tip samples. Therefore, the 45-cm tip sample was recommended for sampling second to fourth instar *C. fumiferana* because it is the easiest and cheapest sample size for collecting larvae. This sampling method was feasible for estimating *C. fumiferana* populations exceeding one larva per 45-cm branch tip.

Sampling Procedure

Table 1 describes appropriate sample sizes based on larval density, confidence levels, and sampling precision. Select the required number of dominant and codominant balsam fir trees (one branch per tree) randomly throughout each area of concern. The sample should be carried out when the majority of the budworm population is predicted to be second, third and fourth instar. Cut one 45-cm branch tip from the mid-crown of each sample tree, and count the number of budworm either in the field or later in the laboratory. If samples are to be processed in the laboratory, then store them in a cooler or freezer to reduce the likelihood of larvae molting before the samples can be assessed.

Note

This sampling method depends on previous knowledge of the larval population density of *C. fumiferana* in order to determine the appropriate number of samples to collect.

Table

Table 1. Required number of branch tip samples to estimate the population density of early instar (second to fourth instar) larvae of the spruce budworm, *Choristoneura fumerana* (Clemens).

Confidence level (α)												
Mean density	0.90				0.80				0.70			
	Standard error of mean				Standard error of mean				Standard error of mean			
	0.10	0.15	0.20	0.25	0.10	0.15	0.20	0.25	0.10	0.15	0.20	0.25
0.01	34819	15475	8705	5571	20149	8955	5037	3224	12602	5601	3151	2016
0.10	3683	1637	921	589	2131	947	533	341	1333	592	333	213
1	569	253	142	91	329	146	82	53	206	92	52	33
10	258	115	64	41	149	66	37	24	93	41	23	15
20	240	107	60	38	139	62	35	22	87	39	22	14
30	235	104	59	38	136	60	34	22	85	38	21	14
40	232	103	58	37	134	60	34	21	84	37	21	13

Refer to the original publication for SEM = 0.30.

Fowler, G. W.; Simmons, G. A. 1982. Spruce budworm egg mass density on balsam fir: low to extreme population levels (Lepidoptera: Tortricidae). Great Lakes Entomology 15: 277-286.

Objective

To determine the best sample location to estimate egg mass densities of *C. fumiferana*.

Abstract

The 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. A study was initiated in Michigan's Upper Peninsula to determine the best sampling locations for *C. fumiferana* egg masses. Two stands, each consisting of 10 extremely and 10 moderately defoliated fir trees were sampled in 1979. In 1980, five stands consisting of four lightly-defoliated balsam fir and white spruce trees (40 trees), were sampled. The live crown of each tree was divided into three levels (lower, mid- and upper crown) with each level being divided into quadrants representing the north, south, east, and west aspects.

Aspect did not explain a significant proportion of the variation in egg mass density. Overall, the majority of egg masses were found in the mid-crown of fir and spruce. In addition, egg mass density at the mid-crown position was higher than that of the entire tree. Because of the considerable variation in estimates encountered in this study, results should be treated with caution until further studies are conducted.

Sampling Procedure

Begin sampling shortly after *C. fumiferana* egg deposition is completed (i.e., early August). Randomly select the center of each group of trees to be sampled in a representative area of each stand. Groups of trees should be located 10-50 m from roads, trails or other groups of trees to be sampled. Trees should be ~9-18 m tall with no dead tops. Divide the live crown into lower, mid-, and upper crown levels if necessary. With a set of pole pruners, cut the appropriate-sized branch from the mid-point of each crown level, lowering the sample carefully to avoid losing any egg masses. Estimate the area of new and old foliage, and determine the number and location (new vs. old foliage) of egg masses, for each branch sampled. Egg mass density can be expressed by surface area of new versus old foliage, all foliage, etc., providing that methods are consistent from sample to sample.

Spruce Budworm

Choristoneura fumiferana (Clemens)
Lepidoptera: Tortricidae

Lynch A. M.; Fowler, G.W.; Simmons, G. A. 1990. Sequential sampling plans for spruce budworm (Lepidoptera: Tortricidae) egg mass density using Monte Carlo simulation. Journal of Economic Entomology 83: 1479-1484.

Objective

To develop and contrast three sequential sampling plans to estimate the egg mass density of *C. fumiferana*.

Abstract

The 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.

Three sequential sampling plans based on the negative binomial distribution were developed for estimating *C. fumiferana* egg mass densities in Michigan's Upper Peninsula. Each plan classified egg mass populations as either low or high based on whole branch samples of balsam fir. Wald's approximation, Monte Carlo estimates of actual values, and Monte Carlo estimates of final values were used to predict operational characteristics and average sample numbers for each of three plans. Each model had the flexibility to include economic constraints, time or labor constraints, regional *C. fumiferana* population levels, and hazard levels.

The number of samples required in Plan I<II<III. The time and labor costs required for Plan I<II<III. Plan II classified stands as having high egg mass densities more often than Plans I or III. Therefore, the practicality of each plan is dependent upon the management objectives, available resources, and forest values.

Sampling Procedure

Sampling methodologies were described previously by Fowler and Simmons (1982). Count all *C. fumiferana* egg masses on a whole branch taken from the mid-crown of each balsam fir tree sampled. Determine the foliated area, and then divide the number of egg masses found by the branch area to estimate egg mass density (number of egg masses per 10 m^2 of foliage). The number of egg masses needed for classifying *C. fumiferana* populations as low or high approximately doubles from Plan III to II and from Plan II to I. For each plan, Wald's approximate procedure, Monte Carlo estimates of actual values, and Monte Carlo estimates for the final test are estimated.

Reference

* Fowler, G. W.; Simmons, G. A. 1982. Spruce budworm egg mass density on balsam fir: low to extreme population levels (Lepidoptera:Tortricidae). Great Lakes Entomology 15: 277-286.

Régnière, J. J.; Sanders, C. J. 1983. Optimal sample size for the estimation of spruce budworm (Lepidoptera: Tortricidae) populations on balsam fir and white spruce. Canadian Entomologist 115: 1621-1626.

Objective

To determine the sample size required to estimate larval populations of *C. fumiferana* at 65% and 95% confidence levels and at various precision levels.

Abstract

The 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. A study was conducted near Black Sturgeon Lake, Ontario, Canada to determine the sample size needed to estimate the population density of third, fourth, and fifth instar *C. fumiferana* larvae on 45-cm branch tips of balsam fir and white spruce.

The distribution of larvae at densities <0.1 larvae per branch tip was nearly random but became aggregated at densities > 0.2 larvae per tip for both host species. This method of estimation works well up to a density of 50 larvae per tip. The suitability of this sampling method for estimating late instar larval density is discussed.

Sampling Procedure

To determine the number of samples needed, given the budworm density per 45-cm branch tip and the desired precision level, refer to Table 1. Select dominant and codominant balsam fir or white spruce in the most representative area(s) of the area of concern. With a set of pole pruners, cut a 45-cm branch tip from the mid-crown of each sample tree when larvae are third, fourth, and fifth instar. Place and store each branch in a brown paper bag. In the laboratory, examine the buds (and shoots) and record the number of larvae.

The sample size needed to achieve a given degree of precision is based on the estimates of the mean (X), variance (S^2) and the level of precision desired. When precision is expressed in terms of a confidence interval at the (1-α probability level, the half-width of which is selected as a constant proportion (C) of the mean, the optimal sample size (n) is given by

$$n = \left(\frac{Z_{\alpha/2}}{C}\right)^2 \frac{2.08}{\bar{X}^{0.73}}$$

where $z_{\alpha/2}$ is the upper $\alpha/2$ point of the standard normal distribution (under the assumption that the sample sizes involved are greater than 30). When sample sizes are small (<30), *t* can be used as the standard deviate corresponding to the desired probability level (Student's *t*).

Notes

The execution of this sampling plan requires that the user has prior knowledge of the larval density in the area(s) to be sampled. The distribution of larvae at higher densities (>50 larvae per 45-cm tip) approximates the negative binomial distribution, indicating that the 45-cm branch tip is either not a particularly appropriate sample unit or that a different expression of density is required to reduce sample variance.

Table

Table 1. Sample sizes required to achieve various levels of precision relative to the mean, based on the standard error of the mean (65% confidence intervals) or on 95% confidence intervals at various densities of spruce budworm larvae.

Density per 45-cm tip	Standard error of the mean			95% confidence interval		
	15%	20%	25%	15%	20%	25%
0.01	2923	1644	1052	11230	6317	4043
0.1	874	492	315	3359	1889	1209
0.25	520	292	187	1997	1123	719
0.5	156	88	56	597	336	215
1.0	92	52	33	355	200	128
2.5	47	26	17	179	101	64
5.0	28	16	10	106	60	38
10.0	16	9	6	63	36	23

Sanders, C. J. 1980. A summary of current techniques used for sampling spruce budworm populations and estimating defoliation in eastern Canada. Rep. O-X-306. Canadian Forest Service, Great Lakes Forestry Centre; 34 p.

Objectives

To provide a summary of population level estimates for various life stages of *C. fumiferana*; to summarize techniques for estimating defoliation levels; and to summarize two hazard prediction systems.

Abstract

The 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 by the Canadian Forestry Service and by provincial agencies in Ontario (ONT), Quebec (PQ), New Brunswick (NB), Nova Scotia (NS), Prince Edward Island (PEI) and Newfoundland (NF) up to 1980 are described for estimating population densities of the eggs, overwintering second instars, large larvae, pupae and adults, and defoliation levels. Methods dealing with extensive and intensive surveys are described in detail in this report.

The egg, larval and pupal surveys used either a 45-cm branch tip or a whole branch taken either from the mid-crown or from each of the upper, mid- and lower crown positions of host trees. Light, Malaise, and pheromone traps were used to determine population trends or to detect new budworm moth invasions. Tables are provided to assess budworm infestation levels for each survey method presented. Four methods were used to evaluate defoliation: aerial assessments, ground assessments with binoculars, and two ground assessments methods that are hands on examination of foliage (i.e., the Fettes and the Dorais-Hardy methods). A hazard prediction system based on current defoliation, previous damage, recovery and egg mass counts was presented.

Sampling Procedure

This document describes procedures specific to extensive and intensive sampling plans within plots only. The number of plots to be sampled depends upon the size of the area of concern.

Surveys for eggs: The egg mass survey is used widely for predicting budworm population levels. Egg mass sampling should be carried out as soon as possible following the end of oviposition. For extensive egg mass surveys, cut a whole branch from the mid-crown of each sample tree. For example, the maximum number of branches (trees) sampled at each plot is 5 for PQ, 3 for NB, and 6 for ONT. For intensive surveys, cut one whole branch from each of the lower, mid- and upper crown positions.

Estimate carefully the foliated area for each branch sampled. The most accurate method is to multiply the length of green branch by the width of green branch and divide this product by 2. Examine visually the foliage for all egg masses in the laboratory, and remove and count all egg-bearing needles. Keep a subsample of the egg-bearing needles to estimate the number of viable eggs per egg mass. UV light can also be used to detect egg masses, but this technique is time consuming. Each branch should be rechecked by another worker in case some egg masses were missed initially. It takes 60 and 120 minutes per branch to check for egg masses on balsam fir and spruce, respectively. Express egg mass density as the number of egg masses per 10 square meters pooled for all samples taken per plot. Egg mass densities are then classified as light (<25 egg masses/10 m^2), moderate (50-100 egg masses/10 m^2), or severe (>200 egg masses/10m2), or simply as low or high (Table 1).

Surveys for overwintering larvae: This survey is also used widely and tends to be less labor intensive than the egg survey. Sample any time from September to April of the next year. Sample a whole branch, or a 45-cm branch in PQ, from the mid-crown of host trees in extensive surveys. One branch should be sampled in each crown zone during intensive surveys. Five to 14 branches should be sampled per plot, depending on the mean to variance ratio (Table 3). Before processing branches to count second instar larvae, calculate branch area as described for the egg mass survey.

A sodium hydroxide (NaOH) wash (Miller and McDougall 1968, Miller and others 1971, Miller and Kettela 1972) or a forced emergence (Miller 1958), sometimes followed by a NaOH wash in intensive surveys, are two methods used widely by to extract second instar budworm from their hibernaculae.

> Sodium hydroxide wash: Washes can be conducted any time from September though April of the next year. Clip each branch into small pieces and place all in a paper bag labeled by plot, tree and branch number. If prolonged storage is necessary the foliage should be kept at 0°C. Wash each sample in a 10 L plastic pail and leave overnight in a warm room to thaw. Add 90 g of sodium hydroxide per pail and fill pail to the 9 L mark with 50°C water to make a 1% solution of NaOH. Keep foliage submerged with a weighted screen top. Let soak for 5 h, stirring every hour. Strain the liquid content of each pail through two sieves, one with a 0.8 mm mesh and a second with a 0.25 mm mesh. Place a wire basket in a tub (90 wide by 150 long by 9 cm deep, with a corrugated bottom and drain), and pour the remaining contents of the pail into the wire basket removing any larvae stuck to the sides of the pail. Wash foliage in the wire basket thoroughly and then discard. At this point, branches should be completely bare. Pour contents of the tub through both sieves and wash into a collecting jar. Pour contents of collecting jar, removing any larvae stuck to the sides of the jar, into a 5 L separating funnel. Add hexane to the funnel, creating a 3 mm layer on top of the aqueous solution. Shake this mixture vigorously to obtain thorough mixing and allow 5 minutes to settle. Approximately 99% of the larvae will settle at the hexane-water interface. Draw off plant debris that has settled at the bottom of the funnel, and draw off the hexane-water fraction into 400 ml beakers to be vacuum filtered. If there is much plant debris in this fraction, process only 100 ml at a time. Fit a Buchner funnel to the separating filter using a molded rubber diaphragm (Filtervac) and connect a filter pump. Pour debris onto a piece of grided (to be seen under microscope), wetted filter paper. 'Washed' budworm larvae have black heads and very light colored bodies. This technique requires 5 h soaking time and 30 min per branch for preparation and examination. Miller and others (1971) found the cost of this technique to be substantially higher than the beat method for large budworm larvae but only a third of the cost of counting egg masses.

Forced emergence: Diapause must be complete before this technique can be used. This usually occurs in early March in eastern Canada, however, samples can be collected earlier and stored until diapause requirements have been met. The enclosed box or paper cone methods can be used.

Any sealed, darkened container with a transparent, clear collecting vial would make an adequate emergence cage for the enclosed box method. Fill each container with foliage but do not pack tightly. Orient box so that the collecting vial is pointed upward, facing a bank of lights that serve to attract larvae to this vial. Count and remove the larvae in the collecting vials periodically during the emergence period. A modification of this technique is used in PQ. A 45-cm branch tip is placed in a small polystyrene ice bucket with a closed top. The bucket is painted black to reduce light transmission. A transparent vial is fitted into the bottom of each bucket, and all buckets are placed on a wire fence with the vials facing the light. Vials are checked for 10 d, after which time budworms have become third and fourth instars. Branches are then removed from the buckets, and the number of larvae remaining in the bucket are counted. Alternatively, branch tips can be left in the bucket (with no clear vial) until most larvae are either third or fourth instar, and then the foliage can be removed and beaten (as for large larvae below) to dislodge all larvae.

The paper cone method involves wrapping branches with paper towel and hanging each branch separately by the proximal end, suspending all samples by a string under a strong light. Collect larvae as they crawl up the paper and string. Some larvae will drop off the branch, so to collect these larvae place a piece of paper below each branch. Ring the edge of each sheet of paper with Tanglefoot (The Tanglefoot Co., Grand Rapids, MI) to prevent escape. The string is also ringed with Tanglefoot approximately 30 cm up from the branch. Spray branches with water periodically to prevent drying. This method is messier (due to Tanglefoot), and requires more time and space, than the box method. Information on relationships between the density of overwintering second instar budworm and the population level of large larvae, or of defoliation potential, can be found in Miller and others (1971) and Miller and Kettela (1972).

Surveys for large larvae: To determine how many samples are needed for the large larvae survey, see either Table 4, 5, or 6 (original publication) depending on the chosen survey method or method of expressing budworm population levels. Sampling should coincide with the predicted peak of the third through sixth instar stages. Collect a 45-cm branch tip or a whole branch for extensive or intensive surveys, respectively. For extensive surveys, remove one branch tip from the mid-crown of each sample tree. For intensive surveys, remove one whole branch from each crown level of each sample tree if population levels appear moderate to high. If populations appear low, remove one whole branch from the mid-crown of each sample tree. If trees have been sprayed with insecticides, then remove branches from both the upwind and downwind sides of the tree.

In the laboratory, count the number of current shoots to determine the potential number of feeding sites. Examine visually the foliage for presence of large larvae, otherwise, larvae can be extracted from foliage by a drum or a beating technique. Third and fourth instars are usually found in buds or staminate flowers but fifth and sixth instars can be found anywhere on the branch, including the bag where the branch was stored.

To sample fifth and sixth instars in the field, use either a basket attachment below the cutting head of the pole pruners, or a tarp below the branch being lowered from the sample tree. Populations are classified as either low or high based on the cumulative counts of budworm from 45-cm branch tips (Table 7). The drum technique, a method to separate larvae from foliage, is summarized as follows:

4.7 Drums

The drum technique evolved from earlier attempts to speed up larval counting by extracting larvae from samples by various mechanical and chemical techniques.

The equipment now used in many parts of eastern Canada consists essentially of the following six parts:

(1) a galvanized steel drum, 60 cm (24 in.) deep and 48 cm (18 in.) in diameter

(2) a perforated cap (for 16 oz (can 500 ml) screw top widemouth glass jar) welded close to the bottom end to fit a 5 cm (2 in.) hole, and a handle fixed near the point of balance on the opposite side of the drum

(3) a removable rectangular iron screen tray 59 x 45 cm (23.2 x 18 in.), made of mesh 1.25 cm (0.5 in.) framed with a welded steel rod .63 cm (0.25 in.) in diameter

(4) a 16 oz (ca 500 ml) collecting jar

(5) a paint brush (7 cm wide)

(6) a folding wooden stand built so as to keep the drum at the required angle and height when in operation, and fitting inside the drum during transportaiton

The separation of the insect material from the foliage by the drum technique is done in three steps: (1) beating of the branch sample vigorously agains the screen table and the side of the drum (30 strokes in all), (2) brushing down the screen and the inside of the drum to direct larvae into the jar, and (3) removing the jar for examination of contents.

The beating technique is used to obtain indices of population density for extensive surveys. Beat with a stick 1 m^3 of foliage at ground level from two sides of each of 10 trees (20 samples total), counting the number of larvae falling onto a 1-m^2 cloth tray situated below the 'beat' area. For larval densities of less or greater than 5 per cubic meter, refer to Table 8 in the original publication to determine the number of additional samples needed. If densities are less than 1 larva per cubic meter then sample until one larva is found.

Surveys for pupae: Sample during the predicted peak pupal stage of the population or shortly after adult emergence. Collect either a 45-cm branch tip or a whole branch for extensive and intensive surveys, respectively. The sampling intensity and method of branch examination is the same as the large larval survey. The drum technique may also be used in extensive surveys, but this technique damages some pupae and is not recommended if pupae are to be reared to adults. Populations are classified as either low or high based on the cumulative counts of pupae from 2-10 45-cm branch tips per sample tree (Table 9).

Surveys for adults: Light, Malaise, and pheromone traps are used to develop population indices for budworm moths. Light traps can be used to forecast population trends for a period of years in the same location and can also be used to indicate moth invasions into new areas. Miller and others (1979) found that catches of female moths in light traps suspended in the forest canopy, coupled with density estimates of resident female pupae, can be used as a crude estimate of budworm egg mass densities over a broad area. This method is considerably cheaper than egg mass surveys. As of 1980, Malaise and pheromone traps were not in operational use as tools to determine budworm population levels.

Surveys to estimate defoliation: Budworm defoliation can be determined by aerial, ground with binocular, Fettes and Dorais-Hardy assessments. Aerial assessments can be made from aircraft with reasonable accuracy by trained observers (Waters and others 1958). Use binoculars from <50 m on the ground to determine the percentage of new growth remaining in the upper two-fifths of the live crown. Rate trees as excellent (>75% new growth remains), very good (50-75%), good (25-50%), poor (<25%), very poor (only if some new shoots are found on entire crown) or nil (0%).

The Fettes method (Fettes 1950) involves obtaining branches from the mid-crown of balsam fir and then visually estimating the percentage of needles removed from each current-year shoot on the branch (Fig. 2 in original publication). Estimates are averaged to provide a defoliation level for the whole branch. The Dorais-Hardy method is used for branches that were so defoliated that normal bud development was prevented. This method accounts for damage to buds and foliage, however, they are not cut from the tree as in the Fettes method. Instead they are labeled and defoliation levels assessed both before and after an insecticide treatment. Before treatment, record the presence of terminal buds on the three terminal shoots of the branch (Fig. 3 in the original publication). Also, estimate defoliation, based on the Fettes method, for each of the three terminal shoots, and then record the average of the three estimates. Because a new year of growth has been added in the time between the before and after treatment estimates of defoliation, the new set of buds must be evaluated for presence as well as the same shoots evaluated earlier (bottom of Fig. 3 in the original publication). An index can be calculated from this data that indicates recovery potential. However, the Dorais-Hardy method does not account for the production of adventitious buds, which may be produced by heavily defoliated trees.

Hazard mapping: A method of assessing hazard is described in Prebble (1975). Determination of hazard is based on four criteria: egg mass counts, current defoliation, previous damage, and recovery; the last 3 of which can be estimated when conducting the egg survey. Each criterion is then assigned a numerical value and each value is added to determine hazard levels (Table 10). Most reliance is placed on the egg mass counts because they predict the severity of defoliation and damage for the following year. If egg mass density in a given area is 0 (nil), 1-99 (light), 100-239 (moderate), 240-399 (severe) or >400 (extreme) eggs per square foot, then assign the appropriate hazard value (Table 10).

Defoliation is assessed during the ground survey but can also be estimated during aerial surveys, or a combination of both techniques. Estimate defoliation using the Fettes method (Table 10). Assign a nil (0%), light (1-25%), moderate (25-65%), and severe (>65%) rating as appropriate.

Examine the defoliation of each age class of foliage and assess the health of the crown of each tree sampled for egg masses to estimate previous damage. Assign a nil (no apparent damage), light (defoliation evident on 1-year old shoots), moderate (defoliation evident on 1- and 2-year-old shoots and crown appearing thin) or severe (crown noticeably thin and grayish with >60 cm of bare top) hazard value.

Trees weakened by budworm attack vary in their ability to recover. Assign a nil (no current shoots), poor (a small crop of current shoots), fair (moderate crop of current shoots) and good rating (current foliage crop apparently normal) to each tree sampled as appropriate to define recovery.

Once the hazard value has been determined for each of the four criteria above, add each value to determine overall hazard levels. Assign a low (0-7), moderate (8-10), severe (11-14) and extreme(>15) rating as appropriate. These data can then be plotted on appropriate maps to help identify the areas in most need of control measures.

Quebec uses a similar method of hazard determination except that only the current year egg mass survey data and a 4-yr defoliation history are used to determine hazard levels that would provide justification of control measures.

Note

Please refer to original publications for more details regarding these survey methods.

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Prebble, M. L. 1975. Aerial control of forest insects in Canada. Ottawa: Canadian Forest Service; 330 p.

Waters, W. E.; Heller, R. C.; Bean, J. L. 1958. Aerial appraisal of damage by the spruce budworm. Journal of Forestry 56: 269-276.

Tables

Table 1. Sequential sampling of spruce budworm eggs. Sample unit is one mid-crown branch per tree from balsam fir.

No. of sample units	Balsam fir	
	Population category	
	Low	High
	(Cumulative egg-masses per 100 ft.^{2} (~10 m^2)	
1	---	313 or more
2	138 or less	469
3	293	624
4	448	779

Table 3. Tentative estimates of variance-mean relationships for overwintering second-instar larvae on mid-crown branches of balsam fir, and required sample size for 20% precision.

Mean	Variance	Required no. of branches
2	2.3	14
4	5.4	8
6	10.5	7
8	17.1	7
10	25.0	6
>10	---	5

Table 7. Sequential sampling of spruce budworm larvae developed for New Brunswick. Sample unit is one 45 cm tip per tree from fir, and one from spruce.

Number of sample units	Balsam fir		Red spruce	
	Population category		Population category	
	Low	High	Low	High
	(Cumulative larvae)		(Cumulative larvae)	
1	---	28 or more	---	34 or more
2	---	36	---	47
3	2 or less	43	3 or less	60
4	9	50	7	74
5	16	58	11	87

Table 9. Sequential sampling of spruce budworm pupae developed in New Brunswick. Sample unit is two 45 cm tips per tree from balsam fir, and four from red spruce (*Picea rubens* Sarg.)

Number of sample units	Balsam fir		Red spruce	
	Population category		Population category	
	Low	High	Low	High
	(Cumulative pupae)		(Cumulative pupae)	
1	---	33 or more	---	9 or more
2	1 or less	50	1 or less	12
3	5	66	4	15
4	10	83	8	19
5	14	100	11	23

Table 10. Hazard values assigned to tree condition and budworm abundance, New Brunswick (from Prebble [1975]).

Category	Hazard value	Category	Hazard value
Current defoliation		Recovery	
Nil	0	Good	-3
Light	1	Fair	-2
Moderate	2	Poor	-1
Severe	3	Nil	0
Extreme	---	---	---
Previous damage		Egg-mass density	
Nil	0	Nil	0
Light	3	Light	1
Moderate	6	Moderate	2
Severe	9	Severe	3
		Extreme	4

Simmons, G. A.; Fowler, G. W. 1984. Considerations when sampling spruce budworm egg masses on balsam fir in the Lake states: low to extreme population levels. Great Lakes Entomology 17: 87-95.

Objectives

To examine the effects of sampling balsam fir branches from different areas of the same tree; to compare effects of a range of egg mass densities in terms of bias and variance; and to examine the influence of branch size on accuracy and precision of egg mass density estimation.

Abstract

The 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 from 5-10 years. A study was carried out in five spruce-fir stands in Michigan's Upper Peninsula to study egg mass densities and distributions.

There was considerable tree to tree and plot to plot variation in egg mass densities, which resulted in high sampling error. However, the most optimal sample unit in terms of accuracy and precision was to select two to four whole branches from the mid-crown position of each tree.

Sampling Procedure

Select and remove with pole pruners two to four whole branches randomly from the mid-crown position of balsam fir. Count and record the number of egg masses and measure the foliated area of each branch sampled. Egg mass density is expressed as either the number of egg masses per square meter or the number of egg masses per branch.

Notes

This paper is third in a series of papers that attempt to improve egg mass sampling techniques (Fowler and Simmons 1982, Simmons and Fowler 1982). Even though sampling from the mid-crown yields the most precise and accurate estimates, the distortion of probability statements is maximized.

References

* Fowler, G. W.; Simmons, G. A. 1982. Spruce budworm egg mass density on balsam fir: low to extreme high levels. Great Lakes Entomology 15: 277-286.

Simmons, G. A.; Fowler, G. W. 1982. Spruce budworm egg mass density on balsam fir and white spruce: low population levels. Great Lakes Entomology 15: 287-296.

Spruce Budworm

Choristoneura fumiferana (Clemens)
Lepidoptera: Tortricidae

Waters, W. E. 1974. Sequential sampling applied to forest insect surveys. In: Proceedings of IUFRO / SAF / SUNY symposium on monitoring forest environment through successive sampling. June 24-26; Syracuse, NY; 290-311.

Objective

To develop a sequential sampling plan for prediction of second and third instar *C. fumiferana* densities.

Abstract

The 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 of *C. fumiferana* cause most of the defoliation. Periodic outbreaks occur every 30 years and epidemics can last 5-10 years. A study was carried out in northern Maine to develop a sequential sampling plan for second and third instars. These surveys can be used to supplement egg survey information, which is the standard means of predicting budworm population levels.

Five 38-cm branch tips collected in the mid-crown of each of five trees per survey point was the recommended sample size for this survey. The density of budworm per 38-cm twig needed to classify infestations as light, medium, and heavy was <5, 10-15 and >20, respectively. If after sampling 25 twigs a decision is not met, then select the classification level closest to the density estimate (Fig. 3).

Sampling Procedure

Select sample points over a representative portion of the area of concern. Cut five 38-cm twigs from each of five trees at each survey point. Search the staminate flowers, needles, and closed buds for budworm larvae. Once the cumulative number of budworm found reaches a decision boundary discontinue sampling. If 25 twigs are examined without a decision, sampling discontinues and the decision line nearest the count is chosen (Fig. 3).

Figure

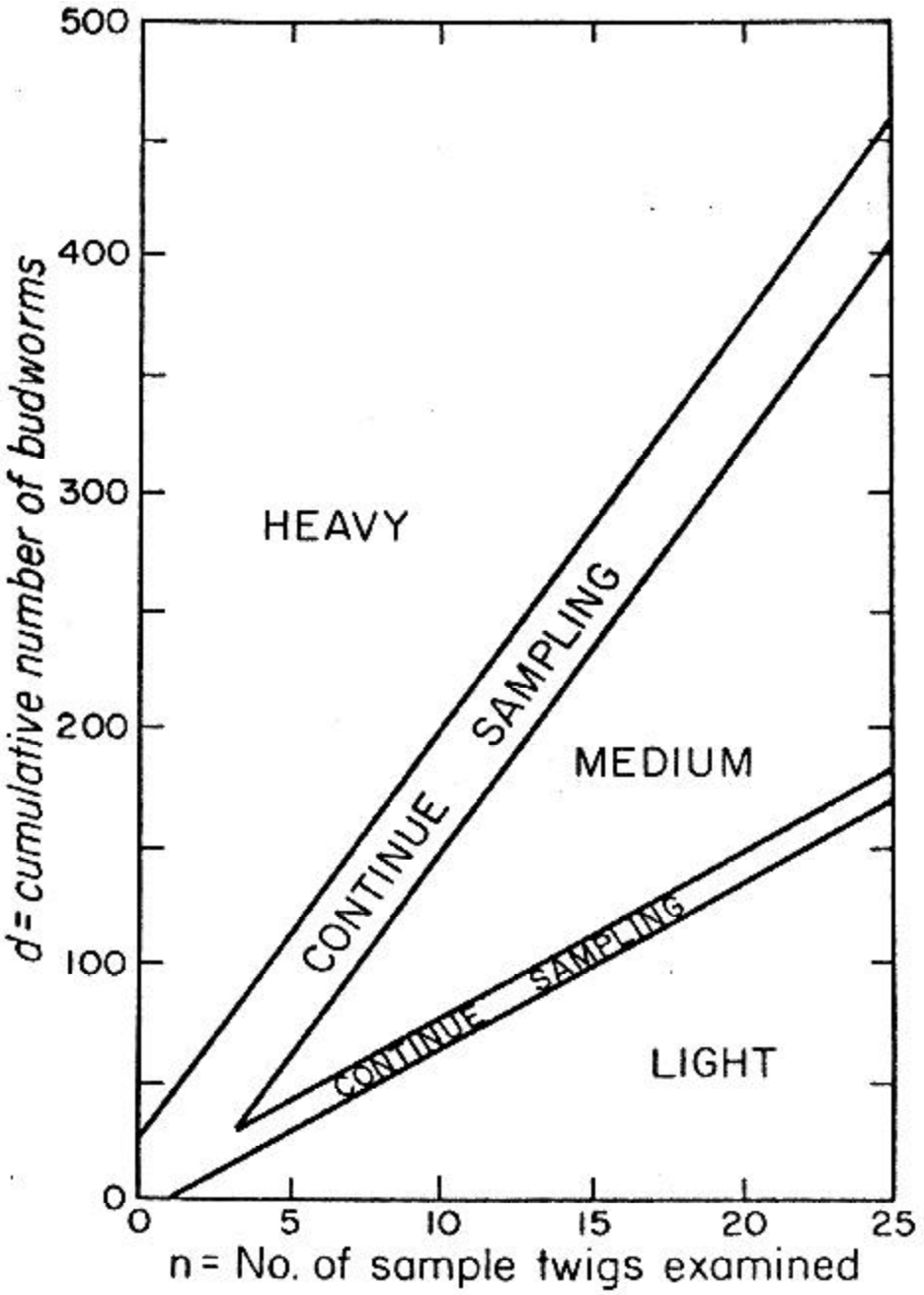

Figure 3. Sequential graph for sampling spruce budworm larvae (2nd-3rd instars) on balsam fir.

Figure 3 reprinted with permission from the IUFRO / SAF / SUNY symposium, January 15, 2001.

Spruce Budworm

Choristoneura fumiferana (Clemens)
Lepidoptera: Tortricidae

Wilson, L. F. 1959. Branch "tip" sampling for determining abundance of spruce budworm egg masses. Journal of Economic Entomology 52: 618-621.

Objective

To develop an efficient and accurate sampling technique, based on area stratification, for estimating *C. fumiferana* egg mass densities on balsam fir, *Abies balsamea* (L.) Mill.

Abstract

The spruce budworm, *Choristoneura fumiferana* (Clemens), is the most destructive defoliator of balsam fir and white spruce, *Picea glauca* (Moench) Voss, in eastern North America. The last three larval instars (i.e., fourth, fifth and sixth) cause most of the defoliation. Periodic outbreaks occur every 30 years and epidemics can last 5-10 years. A study was carried out in Superior National Forest, Minnesota to determine if reliable estimates of egg mass density could be obtained by conducting partial samples based on area stratification. This sample plan is a modification of methods developed previously whereby sample sizes are decreased without reducing greatly the accuracy.

The majority of egg masses were found within the first 8 cm of new growth. Thus, the technique called for separating the tips of the shoots from the rest of the branch. The number of egg masses per tip (Y) was related positively to the number of egg masses per branch (X) ($Y = 1.167X-0.055$) ($R = 0.99$, $P = 0.05$, $n = 145$). To adjust the density of budworm egg masses on branch tips to reflect the density of egg masses per branch, add 16% to the total number of egg masses per tip. Depending upon the size of the branch, the time saved by this technique ranges from 25-40% over previous techniques. Branches of all sizes from all crown levels can be examined using this technique. However, this sample method is not feasible on branches with severe or complete defoliation because females ovipositing on these branches tend to place their eggs adjacent to the main stem.

Sampling Procedure

Cut either a 38-cm long branch tip or a whole branch from the live crown of balsam fir. Refer to the description below and Fig. 1 for a graphical representation of the stratification procedure (letters A-F correspond with those in Fig. 1).

A. Remove a balsam fir branch.

B. Cut nodal branchlets from the main stem and put aside for further treatment.

C. Remove the terminal shoot 10 cm below the main bud if foliated, and 10 cm below the defoliated area if defoliation has occurred. Put aside for counting of egg masses.

D. Cut short internodal branchlets (2.5 - 12.5 cm) at their center and put aside for counting. Cut long internodal branchlets in same way as nodal branchlets and put aside for further treatment. Discard remaining foliage.

E. Assemble nodal and long internodal branches (see Fig. 1).

F. Cut apical twigs from nodal and internodal branches; cut lateral twigs less than 7.5 cm in length at their base and lateral twigs greater than 7.5 cm at their center. Put aside for counting of egg masses. Discard remaining foliage.

Count and record the number of egg masses for each sample. Sample an appropriate number of trees per stand to give an average representation of the whole stand.

Note

This sampling plan is based merely on 145 samples taken from all parts of the live crown and from different sized branches. Therefore, use this plan with caution.

Figure

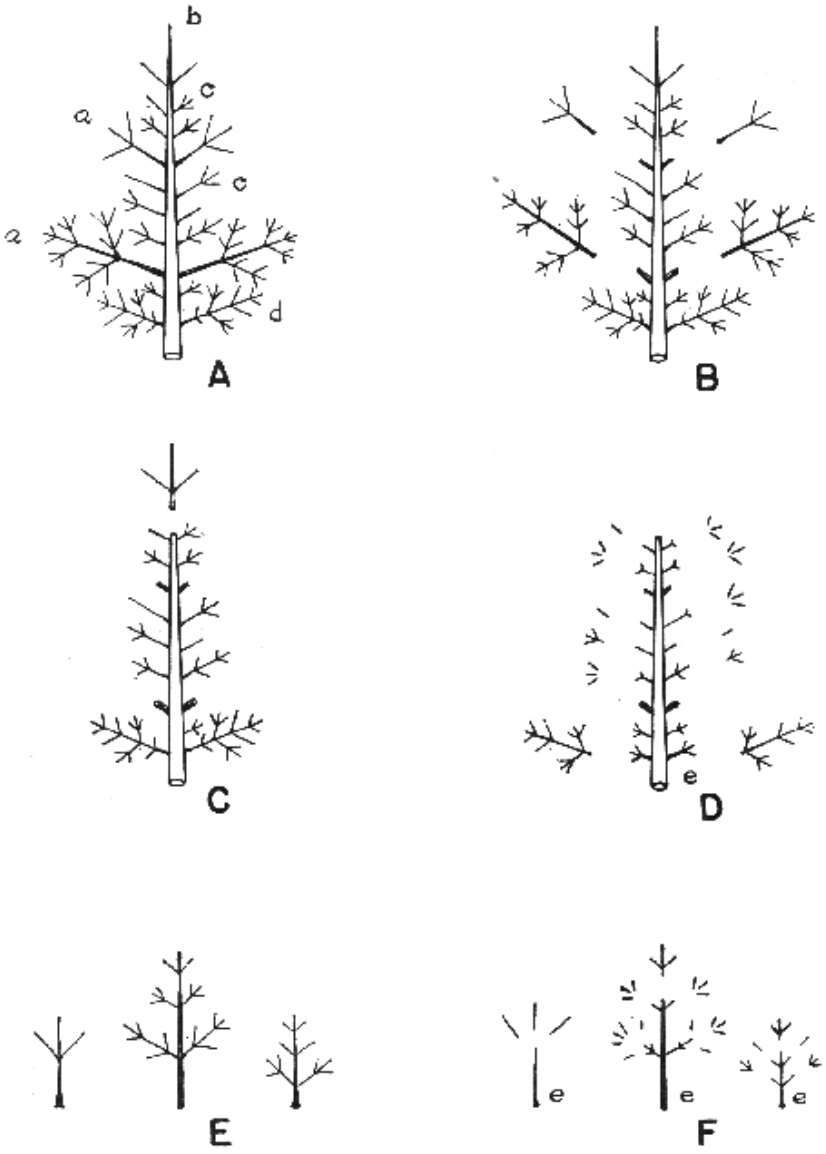

Fig. 1. Branch "tip" sampling technique showing the proper sequence of sampling. Small letters in drawings A, D, and F denote the following: a, nodal branchlet; b, apical branch tip; c, short internodal branchlets; d, long internodal branchlets; e, discard material.

A. Cut balsam fir branch.
B. Cut nodal branchlets from main stem and put aside for further treatment.
C. If terminal shoot of main stem is not defoliated, cut it 4 inches behind bud; if defoliated, cut 4 inches behind defoliated area. Put aside for counting egg masses.
D. Cut short internodal branches (1 to 5 inches long) at their center and put aside for counting. Cut long internodal branchlets in same way as nodal branchlets and put aside for further treatment. Discard remaining (e) foliage.
E. Assemble nodal and long internodal branchlets.
F. Cut apical twigs from nodal and internodal branchlets; cut lateral twigs (less than 3 inches) at their base; cut lateral twigs (more than 3 inches) at their center. Put aside for counting egg masses. Discard remaining (e) foliage.

Figure 1 reprinted with permission from the Journal of Economic Entomology, January 15, 2001.

Carolin, V. M.; Coulter, W. K. 1972. Sampling populations of western spruce budworm and predicting defoliation on Douglas-fir in eastern Oregon. Res. Pap. PNW-149. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 38 p.

Objectives

To develop a method of predicting defoliation of current growth Douglas-fir; and applying this method in area-wide surveys.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco), true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex. Englem., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality. Douglas-fir that is defoliated severely or top-killed is often subsequently attacked by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins.

A compilation of studies on sampling *C. occidentalis* in Oregon is presented for developing forecasting methods to predict defoliation levels of current growth Douglas-fir. Budworm density in non-feeding stages was tested for predicting the density of larvae in buds and the subsequent defoliation level. In addition, egg mass density was evaluated as an index of defoliation. Sampling cost and efficiency was emphasized in selecting appropriate sample units, sizes, and allocation of samples.

A cluster design appeared to be the best solution for sampling non-feeding stages. For low, medium, and high populations, number and size of clusters per stand, and number of stands, were determined with a sampling error of 20% of the mean, and also for other precision levels. Sampling sizes were particularly large for low egg and medium larval densities. Tables were developed using regression equations to show egg mass density, corresponding larval density, and expected degree of defoliation.

Sampling Procedure

The sampling procedures described in this paper are detailed and lengthy. We recommend you refer to the original publication for specific information on how to use these techniques in the field. In general, sample dominant and codominant Douglas-fir in second-growth stands. For egg sampling, collect one whole branch from the mid-crown by climbing. For larval sampling, collect four 38-cm twigs with a 10.7 m pole-pruner for each designated crown level. Locate and record the number of eggs and larvae. Multistage analysis, involving variance and costs, is used to determine optimum size and allocation of samples for these life stages.

Notes

The predictive relationships are based on initial estimates of egg mass density and are specific to Douglas-fir in the Blue Mountains of Oregon. The relationship between egg mass and larval density is likely to vary among regions as evidenced by the fact that egg mass size varies accordingly (Carolin and Honing 1972).

Reference

Carolin, V. M. Jr.; Honing, F. W. 1972. Western spruce budworm. Pest Leafl. 53. Washington, D.C. US Department of Agriculture, Forest Service; 8 p.

Cole, W. E. 1960. Sequential sampling in spruce budworm control projects. Forest Science 6: 51-59.

Objective

To develop a sequential sampling plan to estimate populations of *C. occidentalis* larvae before and after control techniques are applied.

Abstract

The western spruce budworm, *Choristoneura occidentalis* (Freeman), is an important defoliator of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco in northwestern North America. The last three larval instars of *C. occidentalis* cause most of the defoliation of Douglas-fir. Epidemic populations can last 5-10 years in duration.

Intensive sampling of *C. occidentalis* is often required to determine if control measures are warranted and successful. A sampling method was developed to predict pre- and post-spray population levels of *C. occidentalis*. The pre-spray larval count was obtained by determining the number of larvae on a 38-cm twig collected from each of five trees per plot, on each of 10 plots. A total of 50 twigs was sampled. Populations were classified as Class I (light, $\leq$2 larvae per twig), Class II (medium, 3-5 larvae per twig) or Class III (heavy, $\geq$6 larvae per twig) prior to treatment. The post-spray larval count was obtained by sampling two twigs per tree in the same plots as the pre-spray count, for a total of 100 twigs sampled. Control was classified as either successful or unsuccessful if $\leq$0.35 or $\geq$0.50 larvae were found per twig, respectively. This type of sequential sample is suspected to improve predictions of *C. occidentalis* population levels before and after control is applied.

Sampling Procedure

To conduct the pre-spray survey, establish a plot every 100 m, for a total of 10 plots, along a transect running perpendicular to the proposed spray swath or across elevation contours in the block. The transect(s) should be placed in an area that is representative of the entire spray block. Collect one 38-cm twig from the mid-crown of each of five Douglas-fir trees per plot for each of 10 plots per transect line, for a total of 50 twigs sampled. Count the number of larvae found on each twig, adding the counts of successive twigs to the total. After sampling five twigs, compare the cumulative number of *C. occidentalis* larvae found with the values listed in Table 3. If the count falls between those listed for each class, then sample another five twigs and compare the cumulative count to the values listed in Table 3. Continue until a class designation is determined. If all 50 twigs have been sampled and no decision has been reached, then the infestation level is a combination of the two classifications (i.e., light-medium).

post-spray before conducting the sample to ensure maximum mortality of *C. occidentalis* larvae. Collect a maximum of two twigs from each of the sample trees, for a total of 100 twigs sampled. After the number of living larvae has been determined from the first 15 twigs, compare this number with the values listed in Table 4. Continue sampling, five twigs at a time, until the cumulative count falls below (satisfactory control) or rises above (unsatisfactory control) the numbers listed in Table 4. If after sampling 100 twigs no decision is reached, then the infestation is classified as being equal to 95% reduction.

Both types of sequential samples have a sampling error of 10%. The number of samples, sample trees and plots can be varied according to time and labor constraints.

Notes

Areas to be sprayed are selected by some other types of surveys, such as egg or overwintering second instar surveys (Wilson 1959, Waters 1974). The pre-spray sample occurs before the most damaging, fourth, fifth, and sixth instar *C. occidentalis* are present in the population.

References

* Wilson, L. F. 1959. Branch "tip" sampling for determining abundance of spruce budworm egg masses. Journal of Economic Entomology 52: 618-621.

* Waters, W. E. 1974. Sequential sampling applied to forest insect surveys. In: Proceedings of IUFRO/SAF/SUNY symposium on monitoring forest environment through successive sampling. June 24-26, Syracuse, NY; pp. 290-311.

Tables

Table 3. Sequential table for field use in precontrol sampling of spruce budworm larval populations.

No. of twigs	Cumulative number of budworm larvae							
		Class I	*vs.*	Class II		Class II	*vs.*	Class III	
5	Class I	5	Continue Sampling	19	Class II	27	Continue Sampling	48	Class III
10		17		32		34		75	
15		30		44		62		103	
20		42		56		89		130	
25		54		68		116		158	
30		67		81		144		185	
35		79		93		171		212	
40		91		105		198		240	
45		103		118		226		267	
50		116		130		253		294	

Table 4. Sequential table for field use in postcontrol sampling of spruce budworm larval populations.

Number of twigs examined	Cumulative number of budworm larvae				
	Satisfactory vs. Unsatisfactory				
15	*Satisfactory Control*	---	*Continue Sampling*	12	*Satisfactory Control*
20		2		14	
25		4		17	
30		6		19	
35		8		21	
40		11		23	
45		13		25	
50		15		27	
55		17		29	
60		19		31	
65		21		34	
70		24		36	
75		26		38	
80		28		40	
85		30		42	
90		32		44	
95		34		46	
100		36		48	

Western Spruce Budworm

Choristoneura occidentalis Freeman
Lepidoptera: Tortricidae

Harris, J. W. E. 1977. Egg-sampling for western spruce budworm on Douglas-fir. Res. Notes 33. Canadian Forest Service; 26-27.

Objective

To determine if sample unit size and crown level explained a significant proportion of the variation in egg mass density.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex. Englem., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality. Douglas-fir that is defoliated severely or top-killed is often subsequently attacked by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins.

Traditional methods of sampling *C. occidentalis* egg masses involve a choice of branches, or parts of branches, from different crown levels. Carolin and Coulter (1972) used a sample unit of 61-cm long branch tips, but did not test the reliability and accuracy of smaller sizes that would reduce sampling costs. A 25-cm branch tip, 46-cm branch tip, and a longitudinal half of each branch were compared for estimating egg mass density in the lower, mid- and upper crown. There were significant between-tree, between-crown level, and between-sample unit differences indicating no single sample unit could provide absolute estimates of whole-tree populations. The 25-cm branch tips yielded comparable results at all crown levels. However, they were subject to zero counts at low density levels. The authors recommended the use of the 46-cm branch tip sample from either of the upper two crown levels.

Sampling Procedure

Remove two branches from each of 20 trees per plot (mid- or upper crown), and count and record the number of egg masses per 46-cm branch tip. Branch length should be measured from the base of the foliage to the tip. Branch width is measured perpendicular from the midrib to the outermost edge. Estimate foliated area per branch by dividing the product of length and width by two. Determine the number of egg masses per 0.645 m^2. The number of samples can be reduced to 15 trees if three branches are examined, or 10 trees if five are examined.

Reference

* Carolin, V.M. and W.K. Coulter. 1972. Sampling populations of western spruce budworm and predicting defoliation on Douglas-fir in eastern Oregon. Res. Pap. PNW-149. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 38 p.

Western Spruce Budworm

Choristoneura occidentalis Freeman
Lepidoptera: Tortricidae

Mason, R. R.; Wickman, B. E; Paul, H. G. 1989. Sampling western spruce budworm by counting larvae on lower crown branches. Res. Note PNW-486. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 8 p.

Objectives

To develop a nondestructive method of sampling *C. occidentalis* larvae after they have abandoned the buds; and to determine its suitability as an alternative to mid-crown estimates.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex Engelm., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality. Douglas-fir that is defoliated severely or top-killed is often subsequently attacked by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins.

A technique is described for sampling *C. occidentalis* larvae after bud flush by beating three 45-cm branches in the lower crown. Sample data were collected from 32 plots representing a wide range of budworm densities, and indicated that larvae were less aggregated in the lower crown than at the same density in the mid-crown. In an independent sample of 12 plots, estimates of larval density in the mid-crown were 2.5 times higher than, and correlated positively with, density estimates in the lower crown. Sampling the lower crown is more efficient and cost-effective than sampling the mid-crown, and therefore was recommended for estimating larval densities of *C. occidentalis*. For most situations, 25-50 trees will yield a reliable density estimate. Lower crown larval densities were converted to mid-crown densities by multiplying by a factor of 2.41.

Sampling Procedure

Time samples to occur after bud flush, and to coincide with the predicted peak abundance of third through fifth instar larvae (Beckwith and Kemp 1984, Wickman 1988). Sample Douglas-fir and grand fir, *A. grandis* (Dougl.) Lindl., without preference, except each tree must have foliage that can be reached from the ground. Beat three 45-cm branch tips against a handheld dropcloth to dislodge larvae. Each branch should be rapped 10-12 times, and the total number of larvae recorded for the three branch sample. Determine the mean number of larvae per sample unit for each plot by dividing the sum of all larvae found in the three branch samples by the number of trees sampled.

The number of trees *n* needed for different levels of precision can then be estimated using Fig. 3. Multiply the number of larvae per sample unit by 3.10 to adjust to the number of larvae per square meter (Mason 1987). For most situations, sampling 25-50 trees will yield reliable estimates.

References

Beckwith, R. C.; Kemp, W. P. 1984. Shoot growth models for Douglas-fir and grand fir. Forest Science 30: 743-746.

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

Wickman, B. E. 1988. Seasonal variation of degree-day accumulation in relation to phenology of western spruce budworm, Douglas-fir tussock moth, and host trees in northeastern Oregon. Res. Note PNW-482. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 11 p.

Figure

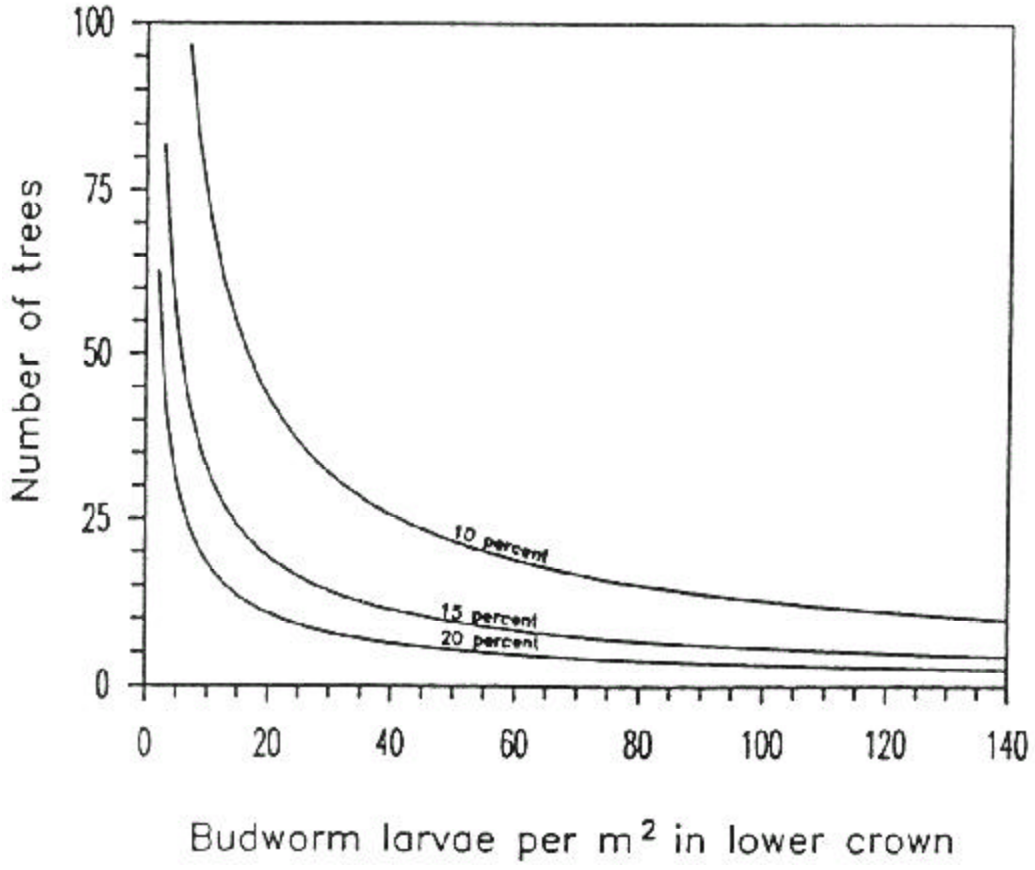

Figure 3. Sample sizes required to estimate larval density on a plot with a standard error of 10, 15, or 20 percent of the mean.

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.

Objectives

To estimate population densities of *C. occidentalis*; and to predict defoliation classes for the following year using a sequential sampling plan.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex. Englem., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality. Douglas-fir that is defoliated severely or top-killed is often subsequently attacked by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins.

A sequential plan is presented for sampling *C. occidentalis* infestations on Douglas-fir in the Rocky Mountains. Population estimates were based on the number of new egg masses per 61-cm branch tip, and used to predict defoliation levels the following year. Thresholds for undetectable (<5%), undetectable to light (5-35%), light to moderate (35-65%) and moderate to heavy (>65%) defoliation were <0.25, 0.275-1.0, 1.5-5.0 and >5.5 egg masses per sample, respectively.

Sampling Procedure

The sampling unit is a 61-cm branch taken from the mid-crown with pole-pruners. The area of the sample unit is approximately 0.161 m^2, and can be converted to the number of egg masses per 0.645 m^2 of foliage by multiplying by four.

Sample two branches from a minimum of 25 Douglas-fir trees, 15-21 m tall, and without top kill or severe defoliation. Branches that brush several live branches when falling from the tree should be discarded. Count all new egg masses, which can be differentiated by their erect, transparent, and shiny appearance as opposed to older egg masses that appear collapsed, opaque, and dull. After 25 trees have been sampled (50 branches), reference the sequential sampling table (Table 2), and continue sampling until a decision is met and populations are classified in one of four classes:

Class	New egg masses per 61-cm branch	Defoliation prediction
1	≤0.250	Undetectable (<5%)
2	0.275-1.0	Undetectable to light (5-35%)
3	1.5–5.0	Light to moderate (35-65%)
4	≥5.5	Moderate to heavy (>65%)

Most populations can be classified using 300 samples (150 trees). This sequential plan can also be used to estimate current year defoliation with little effort. Collect 100 shoots at random from the foliage collected during egg mass counts, and record the number of undamaged shoots. Refer to Table 3 for defoliation estimates based on the percent of undamaged shoots (McKnight 1969).

Note

The sequential plan is intended for use on Douglas-fir in the central and southern Rocky Mountains. It may not be applicable to other host species without adjustments for differences in these relationships.

Reference

McKnight, M. E. 1969. Estimating defoliation of Douglas-fir and white fir by the western budworm. Res. Note RM-144. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 2 p.

Tables

Table 2. Sequential table for sampling egg masses of the western spruce budworm on 24-inch branches.

Number of 24-inch branches examined	Infestation class				Number of 24-inch branches examined	Infestation class			
	1	2	3	4		1	2	3	4
	- - - Number of new egg masses - - -					- - - Number of new egg masses - - -			
					172	[1]41	49 to 205	218 to 872	[2]931
					174	41	50 207	221 883	942
					176	42	51 210	223 893	952
					178	42	51 212	226 904	963
50	[1]9	18 to 55	68 to 223	[2]292	180	43	52 215	228 914	973
52	9	19 57	71 243	302	182	43	52 217	231 925	984
54	10	19 60	73 254	313	184	44	53 220	233 935	994
56	10	19 62	76 264	323	186	44	53 222	235 946	1005
58	11	20 65	78 275	334	188	45	54 224	238 956	1015
60	11	20 67	81 285	344	190	45	54 227	240 967	1026
62	12	21 69	83 296	355	192	46	55 229	243 977	1036
64	12	21 72	85 306	365	194	46	55 232	245 988	1047
66	13	22 74	88 317	376	196	47	56 234	248 998	1057
68	13	22 77	90 327	386	198	47	56 237	250 1009	1068
70	14	23 79	93 338	396	200	48	57 239	253 1019	1078
72	14	23 82	95 348	407	202	49	57 242	255 1030	1089
74	15	24 84	98 359	417	204	49	58 244	258 1040	1099
76	15	24 87	100 369	428	206	49	58 247	260 1051	1110
78	16	25 89	103 380	438	208	50	59 249	263 1061	1120
80	16	25 92	105 390	449	210	51	59 252	265 1072	1131
82	17	26 94	108 401	459	212	51	60 254	267 1082	1141
84	18	26 97	110 411	470	214	52	60 256	270 1093	1152
85	18	27 99	112 421	480	216	52	61 259	272 1103	1162
88	19	27 101	115 432	491	218	53	62 261	275 1114	1173
90	19	28 104	117 442	501	220	53	62 264	277 1124	1183
92	20	29 106	120 453	512	222	54	63 265	280 1135	1194
94	20	29 109	122 463	522	224	54	63 269	282 1145	1204
96	21	30 111	125 474	533	226	55	64 271	285 1156	1215
98	21	30 114	127 484	543	228	55	64 274	287 1166	1225
100	22	31 116	130 495	554	230	56	65 276	290 1177	1236
102	22	31 119	132 505	564	232	56	65 279	292 1187	1246
104	23	32 121	135 516	575	234	57	66 281	295 1198	1256
106	23	32 124	137 526	585	236	57	66 283	297 1208	1267
108	24	33 126	140 537	596	238	58	67 286	299 1219	1277
110	24	33 129	142 547	606	240	58	67 288	302 1229	1288
112	25	31 131	144 558	617	242	59	68 291	304 1240	1298
114	25	32 133	147 568	627	244	59	68 293	307 1250	1309
116	26	32 135	149 579	638	246	60	69 296	309 1261	1310
118	26	33 138	152 589	648	248	60	69 298	312 1271	1330
120	27	35 141	154 600	659	250	61	70 301	314 1282	1340
122	27	36 143	157 610	669	252	62	70 303	317 1292	1351
124	28	37 146	159 621	680	254	62	71 306	319 1302	1361
126	29	37 148	162 631	690	256	63	71 308	322 1313	1372
128	29	38 151	164 642	701	258	63	72 311	324 1323	1382
130	30	38 151	167 652	711	260	64	73 32t	327 1334	1393

CONTINUE SAMPLING

Table 2. (continued)

Number of 24-inch branches examined	Infestation class				Number of 24-inch branches examined	Infestation class			
	1	2	3	4		1	2	3	4
	- - - Number of new egg masses - - -					- - - Number of new egg masses - - -			
132	30	39	156	169	262	64	73	315	329
134	31	40	158	172	264	65	74	318	331
136	31	40	160	174	266	65	74	320	334
138	32	41	163	176	268	66	75	323	336
140	32	41	165	179	270	66	75	325	339
142	33	42	168	181	272	67	76	328	341
144	33	42	170	184	274	67	76	330	344
146	34	43	160	186	276	68	77	333	346
148	34	43	163	189	278	68	77	335	349
150	35	44	165	191	280	69	78	338	351
152	35	44	189	194	282	69	78	340	354
154	36	45	183	196	284	70	79	343	356
156	36	45	185	199	286	70	79	345	358
158	37	46	188	201	288	71	80	347	361
160	37	46	190	204	290	71	80	350	363
162	38	47	192	206	292	72	81	352	366
164	38	47	195	208	294	73	81	355	368
166	39	48	197	211	296	73	82	357	371
168	40	48	200	213	298	74	82	360	373
170	40	49	202	216	300	74	83	362	376

Number of 24-inch branches examined	Infestation class				Number of 24-inch branches examined	Infestation class			
	1	2	3	4		1	2	3	4
	- - - Number of new egg masses - - -					- - - Number of new egg masses - - -			
262	64	73	315	329 1344	1403				
264	65	74	318	331 1355	1414				
266	65	74	320	334 1365	1424				
268	66	75	323	336 1376	1435				
270	66	75	325	339 1386	1445				
272	67	76	328	341 1397	1456				
274	67	76	330	344 1407	1466				
276	68	77	333	346 1418	1477				
278	68	77	335	349 1428	1487				
280	69	78	338	351 1439	1498				
282	69	78	340	354 1449	1508				
284	70	79	343	356 1460	1519				
286	70	79	345	358 1470	1529				
288	71	80	347	361 1481	1540				
290	71	80	350	363 1491	1550				
292	72	81	352	366 1502	1561				
294	73	81	355	368 1512	1571				
296	73	82	357	371 1523	1582				
298	74	82	360	373 1533	1592				
300	74	83	362	376 1544	1603				

[1] or fewer

[2] or more

Table 3. Estimation of percent defoliation of current growth on Douglas-fir and white fir from counts of undamaged shoots.

Percent undamaged shoots	Percent defoliation		Percent undamaged shoots	Percent defoliation		Percent undamaged shoots	Percent defoliation		Percent undamaged shoots	Percent defoliation	
	Douglas-fir	White fir		Douglas-fir	White fir		Douglas-fir	White fir		Douglas-fir	White fir
0	89	76									
1	87	75	26	51	41	51	25	18	76	8	4
2	86	73	27	50	40	52	24	17	77	7	4
3	84	72	28	49	39	53	23	17	78	7	4
4	82	70	29	47	38	54	22	16	79	6	3
5	81	69	30	46	37	55	21	15	80	6	3
6	79	67	31	45	36	56	21	14	81	5	3
7	78	66	32	44	35	57	20	14	82	5	3
8	76	64	33	43	34	58	19	13	83	5	3
9	75	63	34	42	33	59	18	13	84	4	2
10	73	62	35	41	32	60	17	12	85	4	2
11	72	60	36	39	31	61	17	11	86	4	2
12	70	59	37	38	30	62	16	11	87	3	2
13	69	58	38	37	29	63	15	10	88	3	1
14	67	56	39	36	28	64	15	10	89	3	1
15	66	55	40	35	27	65	14	9	90	2	1
16	64	54	41	34	26	66	13	9	91	2	1
17	63	52	42	33	25	67	13	8	92	2	1
18	62	51	43	32	24	68	12	8	93	2	1
19	60	50	44	31	24	69	11	7	94	1	1
20	59	49	45	30	23	70	11	7	95	1	1
21	58	47	46	29	22	71	10	6	96	1	1
22	56	46	47	28	21	72	10	6	97	1	1
23	55	45	48	27	20	73	9	6	98	1	1
24	54	44	49	26	20	74	9	5	99	0	1
25	52	43	50	26	19	75	8	5	100	0	1

Western Spruce Budworm

Choristoneura occidentalis Freeman
Lepidoptera: Tortricidae

Shore, T. L.; Alfaro, R. I.; Harris, J. W. E 1988. Comparison of binocular and cut-branch methods for estimating budworm defoliation of Douglas-fir. Journal of the Entomological Society of British Columbia 85: 15-20.

Objective

To compare observations with binoculars to cut-branch estimates for classifying defoliation levels.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex. Englem., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality. Douglas-fir that is defoliated severely or top-killed is often subsequently attacked by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins.

Defoliation caused by *C. occidentalis* was estimated on 91 Douglas-fir trees with binoculars and by examination of cut-branches. Binocular estimates of defoliation (*Y*) were related positively to cut-branch estimates of defoliation of current-year foliage *(X)* ($Y = -13.3+1.09X$, $R^2 = 0.67$) and of all age classes of foliage *(X)* ($Y = -7.1+0.942X$, $R^2 = 0.78$). Twelve and 7.5% defoliation of the current year's foliage and foliage of all ages, respectively, was detected by the cut-branch method before any defoliation was detected using binoculars. When trees were assigned into broad defoliation classes of light (1-25%), moderate (26-65%) and severe (66-100%), as used in forest insect surveys in British Columbia, the results agreed 89% of the time for current-year foliage and 68% for foliage of all ages. The binocular method was recommended as a quick and useful means of classifying stands into broad defoliation classes, but was not suitable if a high degree of precision was needed.

Sampling Procedure

For binocular estimations, scan the upper half of each tree crown using 7 by 50 mm binoculars, and separate defoliation estimates to the nearest 5%. For the cut-branch technique, cut two 50-cm branches from opposite aspects of the upper half of each tree crown. Assign each shoot a defoliation class based on increments of ten percentage points (0, 1-10, 11-20, 21-30, etc.). Average the defoliation estimates of both branches to yield a single estimate for each tree.

Western Spruce Budworm

Choristoneura occidentalis Freeman
Lepidoptera: Tortricidae

Srivastava, N.; Campbell, R. W.; Torgersen, T. R.; Beckwith, R. C. 1984. Sampling the western spruce budworm: fourth instars, pupae, and egg masses. Forest Science 30: 883-892.

Objectives

To predict average densities of each life stage of *C. occidentalis* per square meter of foliage; and to develop a sampling program based on a predictive equation linking branch tip estimates to whole-tree and whole-plot densities.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex Engelm., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality.

Foliage samples were collected from the lower, mid-, and upper crowns of Douglas-fir and grand fir, *A. grandis* (Dougl.) Lindl., in Washington, Oregon, Idaho, and Montana. Populations of *C. occidentalis* larvae were sampled during the fourth instar larval stage and also during the egg and pupal stages. A sampling scheme based on a predictive equation that links whole-tree density of *C. occidentalis* to densities found on 45-cm branch tips was presented for each life stage.

No significant differences were found between distributions of eggs, larvae or pupae between Douglas-fir and grand fir. Mid-crown samples of fourth instars and egg masses were good predictors of density in the whole stand. Whole-stand density (WS_L , WS_E) per square meter of foliage was related positively to average density on terminal tips (X_M) taken from the mid-crown ($WS_L = 0.238\ (X_M)$, $R^2 = 0.98$; $WS_E = 0.82\ (X_M)$, $R^2 = 0.88$). Lower crown, terminal tip samples for pupae (X_L) were also related positively to density of the whole stand (WS_P) per square meter of foliage ($WS_P = 0.629\ (X_L)$, $R^2 = 0.89$).

Sampling Procedure

Select a minimum of 15 trees, 7-14 m in height, randomly within a 5-ha plot. Remove two sample branches with pole pruners from the mid-crown if sampling fourth instars and egg masses, and lower crown if sampling pupae. Branch length should be measured from the base of the foliage to the tip. Branch width is measured perpendicular from the midrib to the outermost edge. Estimate foliated area per branch by dividing the product of length and width by two ((W * L)/2). After measuring each branch, remove a 45-cm terminal tip from the branch. Count and record the number of each life stage present.

In dense populations (i.e., 100 fourth instars, 10 egg masses per tip, or 40 pupae per square meter of foliage), a precision of ± 20% can be obtained by sampling one tip from each of 15 trees (fourth instars), 48 trees (egg masses), and 9 trees (pupae).

Western Spruce Budworm

Choristoneura occidentalis Freeman
Lepidoptera: Tortricidae

Twardus, D. B. 1985. Surveys and sampling methods for population and damage assessment. In: Brookes, M. H.; Bolbert, J. J.; Mitchell, R. G.; Stark, R. W., editors. Managing trees and stands susceptible to western spruce budworm. Tech. Bull. 1695. Washington, DC: U.S. Department of Agriculture, Forest Service; 27-40.

Objective

To provide a comprehensive review of sampling techniques used to describe *C. occidentalis* populations and defoliation levels.

Abstract

The western spruce budworm, *Choristoneura occidentalis* Freeman, is an important pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, true firs, *Abies* spp., Englemann spruce, *Picea englemannii* Parry ex. Englem., and larch, *Larix occidentalis* Nutt., in the western USA and Canada. Infestations in mature stands cause growth loss, top kill, and occasional tree mortality. Douglas-fir that is defoliated severely or top-killed is often subsequently attacked by the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins. A review of sampling techniques used to describe *C. occidentalis* populations and defoliation levels is presented. Defoliation estimates are based on aerial surveys, ground based surveys with binoculars, and mid-crown branch samples. The sampling of egg masses, third and fourth instar larvae, late instar larvae, and pupae provided reliable estimates of population density.

Sampling Procedure

Defoliation assessments

Sketch-map surveys: This is the most common aerial survey method used to detect, delineate, and provide crude estimates of defoliation levels. Time surveys to occur during peak damage expression, which is typically during late July through early August. Surveys are conducted by fixed-wing aircraft at speeds of 130-180 km/h several hundred meters above ground. Reference the table below to connect the appearance of defoliated stands to actual defoliation from ground surveys.

Aerial defoliation class	Appearance from the air	Ground defoliation (%)
None	No visible change in foliage	<10%
Light	Light browning of crown	20-40%
Moderate–Heavy	Orange to light brown cast to foliage	50-100%
Severe	Entire crown appears gray; top kill and tree mortality observed	50-100%

Aerial photography: This method is used to map and evaluate budworm-caused defoliation, which is evident as color changes on the photograph.

Whole-tree or binocular assessment: This method is a ground-based estimate that is subjective, but allows for rapid classification of defoliation levels. Divide the tree crown visually into thirds, and assign a defoliation code to each level (lower, mid-, upper):

Class	Percent defoliation
1	0
2	1-25
3	26-50
4	51-75
5	76-99
6	100

Express defoliation for each tree as an average of the three levels.

Mid-crown branch samples: This is the most common method used to estimate branch defoliation. Clip 46-cm branch samples from the mid-crown of trees 7-14 m tall. Each of 25 apical shoots per branch is rated using the six-class system described above. Estimates are based only on current year's defoliation.

Population assessments

Egg-mass sampling: This method is one of the most common techniques used for estimating populations, and can be conducted over large areas without excessive time restrictions. Planning insecticide treatments requires considerable advanced notice, and egg mass densities are used to predict subsequent defoliation for decision-making procedures. The positive linear relationship between egg mass density and subsequent infestation class allows egg mass densities to be used to predict population density the following year (Carolin and Coulter 1972). Density increases with crown height, but equations are available for estimating whole-plot density based on mid-crown samples (Srivastava and others 1984).

A sequential sampling plan is available that predicts subsequent defoliation based on new egg mass counts obtained from 61-cm branch samples (McKnight and others 1970). Sample a minimum of 25 Douglas-fir trees, 15-21 m in height, and without top kill or severe defoliation. Collect two branches from each tree, and count all new egg masses. After 25 trees have been sampled (50 branches), reference the sequential sampling table (McKnight and others 1970), and continue sampling until a decision is met and populations are classified in one of four categories:

Class	New egg masses per 61-cm branch	Defoliation prediction
1	≤0.250	Undetectable (<5%)
2	0.275-1.0	Undetectable to light (5-35%)
3	1.5-5.0	Light to moderate (35-65%)
4	≥5.5	Moderate to heavy (>65%)

Sampling overwintering larvae: Several methods have been developed, but none receive significant application.

Sampling early-instar larvae: Time surveys to coincide with the predicted peak of the third and fourth instar stages. Select a minimum of 15 trees randomly, 7-14 m in height, within a 5-ha plot. Remove two sample branches from the mid-crown. Branch length should be measured from the base of the foliage to the tip. Branch width is measured perpendicular from the midrib to the outermost edge. Estimate foliage surface area per branch by dividing the product of length and width by two. After measuring each branch, remove a 45-cm terminal tip, and count and record the number of larvae present. Srivastava and others (1984) found that whole-plot density (WS_L) per square meter of foliage was related positively to average density of *C. occidentalis* per plot (X_M) (WS_L + 0.238 (X_M), $R^2 = 0.98$).

To conduct a quick sample, collect 45-cm terminal tips sequentially from the mid-crown of each tree. Density is classified relative to a predetermined threshold:

Larvae per 45-cm tip	Infestation class
0-3	Light
4-7	Moderate
≥8	Heavy

Alternative sampling plans distinguish between light and moderate-to-heavy infestations (Table 5-5), and light-to-moderate and heavy infestations (Table 5-6).

Sampling late instar larvae: This is the most common method used for evaluating the efficacy of insecticide treatment, which is timed near the predicted peak of the fifth instar stage of *C. occidentalis*. Sample three 45-cm branches at the bottom of the crown on each of 25 trees per plot. Beat each branch against a hand-held cloth to dislodge larvae, and count and record the number of larvae. Refer to Figure 5-5 to relate beat sample counts to the number of larvae per square meter of foliage.

Sampling pupae: Pupae are most vulnerable to predation, and therefore samples should be conducted after natural mortality has occurred. Select a minimum of 15 trees randomly, 7-14 m in height, within a 5-ha plot. Remove two sample branches from the lower crown. Measure branch area as described above. After measuring each branch, remove a 45-cm terminal tip, and count and record the number of pupae present. Whole plot density (WS_P) per square meter foliage is related positively to the average density per plot (X_L) (WS_P= 0.629 (X_L), R^2 = 0.89) (Srivastava and others 1984).

Sampling Adults: The attraction of moths to light traps is used to monitor population changes in low density infestations. Pheromone-baited sticky traps may have promise for forecasting future stand risks.

Note

This review describes briefly several techniques available for monitoring *C. occidentalis* populations. We refer you to the original publication if more detailed information is desired.

References

* Carolin, V. M.; Coulter, W. K. 1972. Sampling populations of western spruce budworm and predicting defoliation on Douglas-fir in eastern Oregon. Res. Pap. PNW-149. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 38 p.

* 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.

* Srivastava, N.; Campbell, R. W.; Torgersen, T. R.; Beckwith, R. C. 1984. Sampling the western spruce budworm fourth instars, pupae, and egg masses. Forest Science 30: 883-892.

Figure and Tables

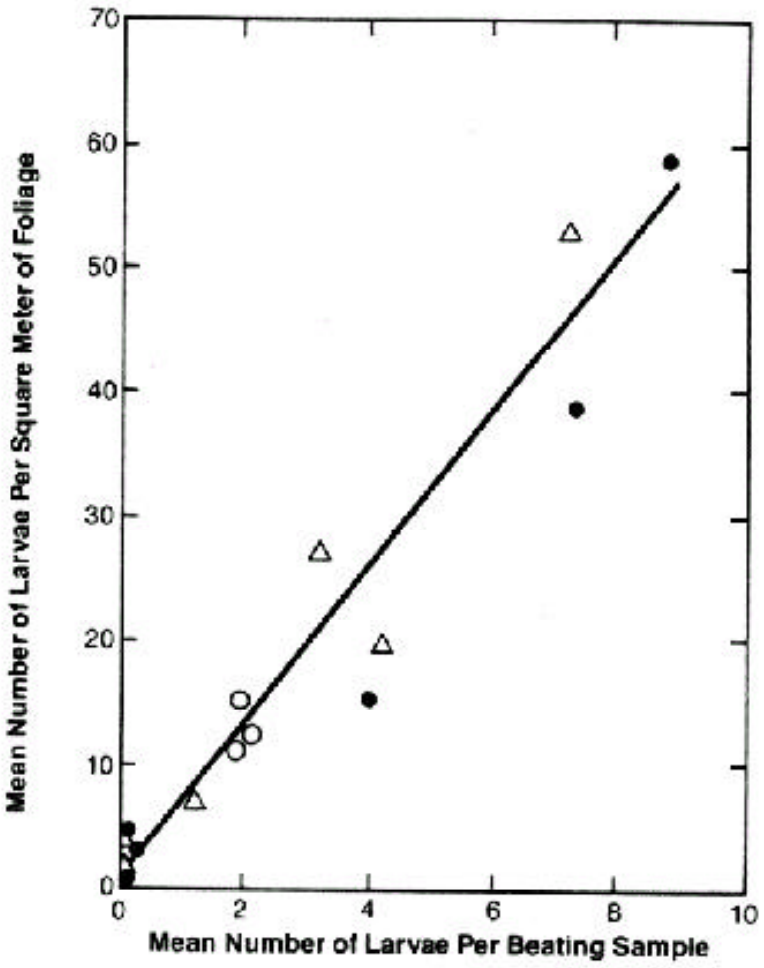

Figure 5-5. Relation of larvae from lower crown branch beating to larvae from midcrown branch samples.

Table 5-5. Sequential classification scheme for separating light from moderate-to-heavy populations of fourth instars at 95 percent confidence level (adapted from Srivastava and Campbell 1983 unpubl).

Number of trees	Cumulative number of budworm larvae[1]	
	Light	Moderate to heavy
5	< 1	> 37
10	< 10	> 64
15	< 20	> 90
20	< 31	>114
25	< 43	>138
100	<235	>477

[1] If a count falls between the limits in the two columns, continue sampling.

Table 5-6. Sequential classification scheme for separating light-to-moderate from heavy populations of fourth instars at 95 percent confidence level (adapted from Srivastava and Campbell 1983, unpublished)

Number of trees	Cumulative number of budworm larvae[1]	
	Light to Moderate	Heavy
5	< 11	> 51
10	< 36	> 117
15	< 64	> 165
20	< 92	> 212
25	< 121	> 258
100	< 592	> 917

[1] If a count falls between the limits in the two columns, continue sampling.

Batzer, H. O.; Jennings, D. T. 1980. Numerical analysis of a jack pine budworm outbreak in various densities of jack pine. Environmental Entomology 9: 514-524.

Objective

To determine if stand density influences the density of *C. pinus.*

Abstract

The jack pine budworm, *Choristoneura pinus* Freeman, is an important pest of jack pine, *Pinus banksiana* Lamb., and to a lesser extent 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.

A life table study of *C. pinus* was superimposed on a stocking level study of dense jack pine in northern Minnesota to determine if *C. pinus* density was related to stand density; and to provide a useful technique for sampling *C. pinus* egg masses. The number of eggs per hectare was estimated from branch samples by first expressing them as numbers per meter of foliated branch. Based on the data collected from 205 felled trees, an equation was developed to estimate total foliated length per tree ($Y = 5.54X_1 - 1.45X_2 - 1.11$). The number of eggs per egg mass (Y) was related positively to egg mass length (X) when an egg mass had two ($Y = 5.28X - 12.06$, $R^2 = 0.87$) or three ($Y = 6.50X - 11.76$, $R^2 = 0.87$) rows.

Sampling Procedure

Sample three trees from each 2.5 cm diameter class among those closest to the center of a 400-m^2 plot (6-18 trees). Clip one branch from the lower crown and another from the upper crown, and be careful not to dislodge egg masses. Estimate the number of eggs per ha by first expressing them as numbers per meter of foliated branch. Multiply this value by the estimated total foliated length per tree (Y) given by the equation:

$$Y = 5.54X_1 - 1.45X_2 - 1.11 \ (R^2 = 0.91)$$

where Y is in m, X_1 represents diameter at 1.3 m (d.b.h.; cm), and X_2 represents tree height (m).

Estimate the number of eggs per mass (Y) by the following regression equations based on egg mass length in mm (X) and number of egg rows

$$Y = 5.28X - 12.06 \text{ (2 egg rows)}$$
$$Y = 6.50X - 11.76 \text{ (3 egg rows)}$$

Three row egg masses were those in which over half the length of the egg mass has more than two

Jack Pine Budworm

Choristoneura pinus Freeman
Lepidoptera: Tortricidae

Foltz, J. L.; Knight, F. B.; Allen, D. C.; Mattson, W. J., Jr. 1968. A technique for sampling populations of the jack-pine budworm. Forest Science 14: 277-281.

Objective

To provide a method of sampling *C. pinus* populations in all life stages except the adult stage.

Abstract

The jack pine budworm, *Choristoneura pinus* Freeman, is an important pest of jack pine, *Pinus banksiana* Lamb., and to a lesser extent 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.

Larvae and pupae of *C. pinus* are more prevalent near branch tips and may be concentrated in one crown level. For this reason, a sampling method of estimating population density consists of counting the number of budworms and shoot tips on the first 91 cm of two branches from the mid-crown, and two branches from the lower crown. The number of budworm on a whole branch ($Y_{1,2}$) was related positively to the average number of budworm found on 100 branch tips (X) in low ($Y_1 = 0.52\ X + 0.17$, $R^2 = 0.61$) and high ($Y_2 = 1.00\ X - 1.34$, $R^2 = 0.99$) density populations.

Sampling Procedure

Collect and inspect 40 branches from a sample cluster of 10 trees per stand. Cut two distal 91-cm branch tips randomly from the mid-crown and two from the lower crown of jack pine. Count and record the number of budworms present in each sample. Express the population as the number of budworm per 100 tips (X). The population density for the entire branch (Y_1) is calculated by

$$Y_1 = 0.52\ X + 0.17 \text{ for low density populations}$$
$$Y_2 = 1.00\ X - 1.34 \text{ for high density populations}$$

Use the first equation if $X < 3.146$ and use the second equation if $X > 3.147$. The average density of the two branch sample is an estimate of the population density within the crown level. Use the number of tips per tree and the number of trees per ha to convert estimated populations densities for the entire branch $((Y_1 + Y_2)/2)$ to the number of budworms per ha. To predict the number of tips per tree use the following equation

$$\text{Log (tips per tree)} = 0.06269\ (\text{crown diameter (ft)}) + 2.84186$$

Notes

Sampling is conducted in a relatively homogeneous stand of jack pine at least 4 ha in area. For statistics concerning the regression equations provided in this review, please consult the original publication.

Kulman, H. M.; Hodson, A. C. 1962. A sampling unit for the jack-pine budworm, *Choristoneura pinus*. Journal of Economic Entomology 55: 801-802.

Objectives

To identify a sampling unit for estimating larval density of *C. pinus*, which would also facilitate the forecasting of defoliation levels.

Abstract

The jack pine budworm, *Choristoneura pinus* Freeman, is an important pest of jack pine, *Pinus banksiana* Lamb., and to a lesser extent 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.

A sampling unit for estimating *C. pinus* larval populations was determined from examination of the distal cluster of new shoots. A consistent ratio was found between larval density in the distal cluster of new shoots and the population of the next 10 lateral clusters. The number of larvae on the next 10 lateral shoots (Y) was related positively to the number of larvae on the distal cluster of new shoots (X) ($Y = 0.459 + 0.475X$).

Sampling Procedure

Sample the distal cluster on new shoots of three branches per tree, and count and record the number of larvae. There is a consistent relationship between the larval population on the distal cluster of new shoots, and the population of the next cluster of older shoots of approximately 3:1. This relationship can be described by the equation:

$$Y = 0.459 + 0.475X$$

where, X represents the number of larvae on the distal cluster of new shoots and Y represents the number on the next 10 lateral shoots.

Notes

The relationship described here was established during low population levels and may not reflect those during higher ones. Further studies are needed to determine the number of shoot clusters that would need to be sampled to estimate defoliation levels.

Jack Pine Budworm

Choristoneura pinus Freeman
Lepidoptera: Tortricidae

Nealis, V. G.; Lysyk, T. J. 1988. Sampling overwintering jack pine budworm, *Choristoneura pinus pinus* Free. (Lepidoptera: Tortricidae), and two of its parasitoids (Hymenoptera). Canadian Entomologist 120: 1101-1111.

Objective

To develop a sampling method for estimating overwintering larval populations of *C. pinus.*

Abstract

The jack pine budworm, *Choristoneura pinus* Freeman, is an important pest of jack pine, *Pinus banksiana* Lamb., and to a lesser extent 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.

Data on the distribution of *C. pinus* collected between 1985-1987 in northern Ontario, Canada were used to develop guidelines for sampling overwintering larvae. Counts of the number of *C. pinus* per m of branch and the number per square meter of branch bark surface area for three crown levels and each cardinal direction were conducted. An entire branch was recommended as a sample unit because the 60-cm branch tip sections underestimated actual densities. The number of larvae per square meter of bark surface (Y) was related positively to the number of larvae per m of branch (X) ($Y = 110.8 + 29X$, $R^2 = 0.92$, $P < 0.01$, $n = 250$).

Sampling Procedure

Sample one branch randomly from the lower crown of codominant jack pine in late autumn through early spring when larvae are still overwintering. Record the branch length and butt diameter to estimate bark surface area. Larvae are forced out of the hibernacula using the forced emergence method (Miller 1958). Place bundles of branches and foliage in paper towels and suspend them over water basins to maintain high levels of humidity. Remove emerging larvae and record each larva found on the paper towel. Density is expressed as the number of insects per square meter of branch bark surface area. The optimal sample sizes for three levels of precision are provided in Table 3.

The relationship between the number of larvae per meter of branch (X) and the number of larvae per square meter of bark surface (Y) can be calculated by $Y = 110.8 + 29X$.

Reference

Miller, C. A. 1958. The measurement of spruce budworm populations and mortality during the first and second larval instars. Canadian Journal of Zoology 36: 409-422.

Table

Table 3. Number of branch samples required at different levels of precision and increasing density of *C*. *pinus*, using two methods to express their density.

Density of overwintering budworm larvae		Precision (%)					
		90%		85%		80%	
Per meter	Per m^2	Per meter	Per m^2	Per meter	Per m^2	Per meter	Per m^2
5	250	44	34	20	15	11	9
10	400	34	29	15	13	8	7
15	550	29	25	13	11	7	6
25	850	25	21	11	9	6	5
50	1550	20	17	9	7	5	4
75	2300	18	14	8	6	4	4
100	3000	16	13	7	6	4	3
125	3750	15	12	7	5	4	3

Pendrel, B. A. 1985. Population distribution of Jack pine budworm—1984 described through pheromone trapping. Tech. Note 133. Canadian Forest Service, Maritimes Forest Research Centre; 4 p.

Objective

To determine if pheromone-baited traps are useful for monitoring *C. pinus* populations.

Abstract

The jack pine budworm, *Choristoneura pinus* Freeman, is an important pest of jack pine, *Pinus banksiana* Lamb., and to a lesser extent 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.

The pattern of capture of *C. pinus* moths using pheromone-baited traps during 1984 resembled closely the expected distribution in both New Brunswick and Nova Scotia. The range of numbers caught and distribution suggest this trapping system may be an excellent tool for monitoring *C. pinus* populations. This system can be used to indicate where *C. pinus* populations are likely increasing, thus serving as an indication that defoliation may occur the following year.

Sampling Procedure

Place Pherocon II, or the larger capacity Pherecon 1C (Zoecon Corp., Palto Alto, CA), sticky traps baited with pheromone lures in the area of interest. Pheromone lures (90% 85/15 E/*Z*11-14:AC and 10% 85/15 E/*Z*11-14:OH) in concentrations of 0.003, 0.03 or 0.3% in polyvinyl chloride (PVC) rods are suitable (Silk and others 1985). The author suggests that in its present state this system can be used to indicate where *C. pinus* populations are likely increasing, thus serving as an indication that defoliation may occur the following year.

Note

No information is provided regarding trap density or placement.

Reference

Silk, P. J.; Kuenen, L. P. S.; Tan, S. H.; Roelofs, W. L.; Saunders, C. J.; Alford, A. R. 1985. Identification of sex pheromone components of the jack pine budworm, *Choristoneura pinus pinus* Freeman. Journal of Chemical Ecology 7: 159-167.

PIERCING AND SUCKING INSECTS AND MITES

Hemlock Rust Mite

Nalepella tsugifolia Keifer
Acari: Tetranychidae

Sidebottom, J. R. 1995. Rust mites in Christmas trees. Christmas Tree Notes. Raleigh, NC: N.C. Agricultural Extension Service, North Carolina State University; 2 p. (http://www.ces.ncsu.edu/nreos/forest/xmas/ctn_034.html)

Objective

To develop a scouting program for *N. tsugifolia* that aids in control decision-making for Christmas tree plantations.

Abstract

The hemlock rust mite, *Nalepella tsugifolia* Keifer, is a frequent springtime problem on hemlock, *Tsuga* spp., eastern white pine, *Pinus strobus* L., and Fraser fir, *Abies fraseri* L., grown in the foothills of western North Carolina. Heavy feeding causes premature needle loss. Infested needles have a dusty, rust-colored appearance that reduces the aesthetic quality of ornamental and Christmas trees.

A survey method was developed to determine if *N. tsugifolia* populations were high enough to warrant control measures. If 80% of all shoots sampled and at least eight mites are present on a single needle, then control measures were warranted. The action threshold can be modified depending on the grower's costs and tree values.

Sampling Procedure

To scout for *N. tsugifolia*, select 24-49 trees per hectare, concentrating on trees that were damaged the previous year. If no previous damage is evident, then choose trees at random. On white pine, sample needle cluster on the upper third of the tree in the southeast aspect where *N. tsugifolia* is found most often. Mites are usually concentrated near the follicle. In Fraser fir, examine shoots of current growth in the upper whorls and some from the lower ones. Scan both the upper and lower surfaces of the needles with a hand lens. If the buds have opened recently, then examine both the new and previous year's growth.

Generally, if 80% of the shoots are infested and if there are at least eight mites present on a single shoot, then control is warranted.

Notes

Populations can increase quickly during favorable weather conditions. Therefore, scout weekly during critical periods in the spring. If the action threshold is not reached by early June, then sampling may be discontinued. Continue sampling for *N. tsugifolia* when activity resumes in the fall.

Spruce Spider Mite

Oligonychus ununguis (Jacobi)
Acari: Tetranychidae

Sidebottom, J. R. 1995. The spruce spider mite in Fraser fir. Christmas Tree Notes. Raleigh, NC: N.C. Agricultural Extension Service, North Carolina State University; 4 p. (http://www.ces.ncsu.edu/nreos/forest/xmas/ctn_029.html)

Objective

To provide a sequential sampling system for estimating *O. ununguis* densities and timing insecticide applications before significant damage occurs.

Abstract

The spruce spider mite, *Oligonychus ununguis* (Jacobi), can be a significant pest of Fraser fir, *Abies fraseri* L., Christmas trees in western North Carolina particularly on windy ridges, southern exposures, and during periods of drought. Infested needles become yellow-spotted and webbed together after which time they turn brown and fall prematurely from infested trees. Growers often depend on pre-budbreak insecticide applications for control of the balsam woolly adelgid, *Adelges picea* (Ratzeburg), to also provide season long *O. ununguis* control. However, mite populations rebound quickly following spring applications and subsequent treatments may be warranted.

A detailed sequential sampling system for estimating *O. ununguis* populations and damage was developed. This method was derived from previous sampling methods developed by McGraw and Hain (1979). The economic thresholds for control decision-making were based on the percentage of trees that have mites, and varied depending on tree value and cost of control. If trees are greater than 1 m tall and 40% are infested, then control was warranted. As trees approach marketability, economic thresholds decreased accordingly. If threshold levels are not reached, the author indicates when scouting should resume based on a detailed set of criteria.

Sampling Procedure

The rigid block scouting method is used for sampling *O. ununguis* populations. Enter the block two to four rows from one corner and record that location on the scouting form so that on your next visit you will be able to initiate surveys one to two rows above or below this point. Walk the full length of the row, scanning from side to side up to five rows in each direction depending on tree size and visual obstructions. When you encounter an off-color, symptomatic tree go to that location to sample, but return to your original row to continue sampling. When you reach the end of the row, step over 6 to 10 rows and continue this pattern until you have covered the entire block.

Scout all Fraser fir stands from the year after planting through harvest to determine if mite numbers are great enough to cause damage. The number of times a field is scouted depends on tree size, mite prevalence, and prevailing weather conditions. For trees that do not receive a spring insecticide treatment for *A. picea* control, mite scouting should begin in mid-April. For trees that receive spring treatment, scouting efforts should begin in early June. Continue scouting until the first hard frost.

To examine for *O. ununguis*, pull a single shoot of the most current growth from the suspect tree and look for the presence of mites, mite eggs, or mite damage with a magnifying lens. Sample the majority of shoots from the bottom 61 cm of the tree, but also check a few shoots near the top of each tree. Look at small shoots from inside the tree canopy since this is where *O. ununguis* is most often found.

If any mites or eggs are found, then count the shoot as infested, and discontinue sampling as there is no need to count the number of mites or eggs. If no mites or eggs are found, count it as uninfested. Limit sampling to one shoot per tree. If you walk 15.5 m without seeing any trees that have symptomatic damage, pull a shoot from a tree at random and continue an additional 9 m before sampling another tree. Continue sampling at least one tree every 15-18 m and at least 37 shoots per hectare.

Calculate the percentage of infested shoots. The economic thresholds for *O. ununguis* are simply based on the percentage of trees that have mites, but vary depending on tree value and cost of control. The following thresholds are provided:

Size of the Tree	**Economic threshold (ET)**
1. Less than waist high	40%
2. Waist high to year before sale	20%
3. Year of sale	10%

If damage has not reached threshold levels, then scouting should resume according to the following criteria:

1. If no mites or eggs are found and no damage is seen, return in 6 to 8 weeks.

2. If less than 10% of the shoots have mites or eggs, or if new *O. ununguis* damage has occurred since the last sample, return in 4-5 weeks.

3. If greater than 10% of the shoots have mites or eggs, but it is less than the treatment threshold, return in 2 weeks.

4. If there are greater than 10 days of hot, dry weather, return in less than 2 weeks. Mite reproduction and life spans increase rapidly under these conditions.

5. If trees are marketable, scout at least once a month.

Hot spot scouting can be used during hot, dry periods to determine how the weather is affecting mite activity in problematic areas. The hot spot becomes a representation of the rest of the block, and is identified through previous scouting methods. If mite activity is increasing in these hot spots, then go back and resurvey the entire block using the rigid block scouting method.

A sample scouting form for all Fraser fir pests is available through your local county extension office. For more information on scouting for mites, see the video, Detection and Control of the Spruce Spider Mite, which is available for the North Carolina Agricultural Extension Service.

Reference

McGraw, J. R.; Hain, F. P. 1979. Spruce spider mite sampling system. Forest Res. Note. Raleigh, NC: N.C. Agricultural Extension Service, North Carolina State University; 6 p.

Eastern Spruce Gall Adelgid

Adelges abietis (L.)
Homoptera: Adelgidae

Fidgen, J. G.; Teerling, C. R.; McKinnon, M. L. 1994. Intra- and inter-crown distribution of the eastern spruce gall adelgid, *Adelges abietis* (L.), on young white spruce. Canadian Entomologist 126: 1105-1110.

Objective

To determine both the intra- and inter-tree distribution of *A. abietis* on young white spruce, *Picea glauca* (Moench.) Voss., that were open-grown or undergoing crown closure.

Abstract

The eastern spruce gall adelgid, *Adelges abietis* (L.), forms pineapple-shaped galls on the shoots of white and Norway, *P. abies* L., spruce. When populations are high, they cause shoot deformation and reduced growth. In most cases, the damage is negligible except in Christmas tree plantations or ornamental trees where aesthetic losses render trees unmarketable. Extensive sampling was conducted to determine the within and between tree distribution of *A. abietis* so that an efficient sampling scheme could be developed. The trees sampled in this study were 1-4 m in height and from 9-15 years old.

Adelgid galls were found mainly on lateral shoots within the mid-crown of open grown trees. After crown closure, most galls were found in the upper crown, above the point where branches of adjacent trees overlapped. The inter-tree distribution of *A. abietis* did not differ significantly from the negative binomial distribution, indicating a high degree of aggregation among trees. Therefore, a stratified random sampling plan using the first 20 lateral shoots of an open grown, mid-crown branch was recommended for monitoring *A. abietis* populations.

Sampling Procedure

Select every fifth to tenth tree in every fifth to tenth row systematically in the area of concern, and inspect mid-crown branches for presence of *A. abietis*. Because *A. abietis* populations are usually clumped, a mid-crown branch of each adjacent tree should also be assessed (i.e., eight neighboring trees adjacent to the sample tree). On each tree, select either a west- or south-facing open-grown, mid-crown branch and count the number of *A. abietis* galls in the first 20 lateral shoots examined. Express *A. abietis* damage as the percentage of lateral shoots infested per tree.

Note

The sample unit was designed primarily for use in Christmas tree plantations or forests less than 15 years old.

Cooley Spruce Gall Adelgid

Adelges cooleyi (Gillette)
Homoptera: Adelgidae

Lasota, J. A.; Shetlar, D. J. 1986. Assessing seasonal and spatial abundance of *Adelges cooleyi* (Gillette) (Homoptera: Adelgidae) by various sampling techniques. Environmental Entomology 15: 254-257.

Objective

To evaluate four sampling methods for assessing seasonal and spatial distributions of *A. cooleyi* on Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco.

Abstract

The Cooley spruce gall adelgid, *Adelges cooleyi* (Gillette), is serious pest in nurseries, Christmas tree plantations, and forests throughout northern North America. The primary host is spruce, *Picea* spp., although winged adults fly to Douglas-fir which is the alternate host. Feeding causes distortion, spotting, and premature needle abscission. Four sampling methods (1-min, 3-min, 5-branch, and 15-branch) were evaluated for accuracy in estimating *A. cooleyi* populations on Douglas-fir in Pennsylvania.

The 3-min counts produced the greatest number of *A. cooleyi* while the 5-branch counts produced the least. Comparisons between the 1-min and 15-branch counts differed significantly on only one sample date. Early in the season, *A. cooleyi* populations were high and thus all four sampling techniques produced similar accuracy. However, as populations declined, the larger sample units (3-min and 15-branch counts) were generally more accurate at estimating *A. cooleyi* densities than the smaller ones. The most representative area to sample was in the upper half of the crown regardless of the time of year. The 1-min count was most useful to commercial growers or others that have little time to sample.

Sampling Procedure

Sample 1 to 2 shoots from the upper half of the live crown from each of 10-20 Douglas-fir 1.5-1.8 m tall. Northern and eastern aspects should give the most representative sample regardless of the time of year. Count all *A. cooleyi* found on the current year's growth for 1-min (time constrained sampler) or 3-min (detailed sampler). Conduct sampling procedures three times annually to assess changes in population density.

Note

This method also applies to forested and urban areas.

Balsam Woolly Adelgid

Adelges piceae (Ratzeburg)
Homoptera: Adelgidae

Amman, G. D. 1969. A method of sampling the balsam woolly aphid on Fraser fir in North Carolina. Canadian Entomologist 101: 883-889.

Objective

To develop a method of sampling adelgid populations, which would provide a means of assessing mortality factors and population density.

Abstract

The balsam woolly adelgid, *Adelges piceae* (Ratzeburg), is an introduced species first recorded in North America in Maine in 1908. It has since spread throughout the native range of balsam, *Abies balsamea* (L.) Mill., and Fraser, *A. fraseri* (Pursh) Poir., fir and is also found in the Pacific Northwest. Mortality occurs quickly in trees suffering from extensive stem attacks, which appear as white woolly masses. A study was conducted on Mt. Mitchell, North Carolina in a dense stand of Fraser fir with dominants and co-dominants 7.6-10.7 m tall. Populations of *A. picea* were sampled without replacement.

A sample of 2 to 16 pieces of bark (depending on the observed density), 1.27 cm in diameter from the lower bole of each of 10 trees yielded a standard error of ±10% of the mean. An acceptable level of precision was obtained by taking 77 samples 1.4-1.7 m and 71 samples 0.8-1 m along the bole (n = 148 samples). During winter and from mid-July through mid-August, sampling intensity could be reduced to 40 pieces of bark.

Sampling Procedure

Select randomly 10 trees of similar diameter. Take eight pieces of bark with a 1.27 cm diameter cork punch from at least two different cardinal directions at 0.8-1 and 1.4-1.7 m along the bole of each tree. Once the bark is cut, use a knife to remove (pry) the bark until the cambium layer is reached. This procedure will minimize pitch flow. Store samples in vials, and count and record the number of *A. picea* under a dissecting microscope in the laboratory.

Dimond, J. B. 1974. Sequential surveys for the pine leaf chermid, *Pineus pinifoliae*. Tech. Bull. 68. Orono, ME: University of Maine, Agricultural Experiment Station; 15 p.

Objective

To develop field procedures for the classification of white pine damage produced by *P. pinifoliae,* and to relate infestation levels to tree damage.

Abstract

The range of the pine leaf adelgid, *Pineus pinifoliae* (Fitch), coincides with that of red, *Picea rubens* Sarg., and black, *P. mariana* (Mill.), spruce, its primary hosts, wherever they grow in proximity to eastern white pine, *Pinus strobus* L., its alternate host. Infestations on spruce result in terminal, compact galls that have the appearance of true cones consisting of many chambers each containing a single adelgid. Populations on white pine cause growth reduction and tree mortality in cases of extreme infestation.

A sequential survey procedure was described for determining infestation levels of *P. pinifoliae* as well as for classifying damage to white pine. Damage classes are based on the degree of needle stunting and needle color. Sampling of white pine was conducted until late-June. Galls on red and black spruce were sampled beginning around mid-May when galls can be differentiated easily from uninfested buds.

Sampling Procedure

Table 1 shows the degree of damage caused by *P. pinifoliae* at several life stages and population densities. There is one method to estimate *P. pinifoliae* damage and two methods to estimate population levels.

Estimating Damage

Needle length: Remove one branch from the mid-crown of 20 white pine trees, and remove a twig from the mid-portion of the branch. Remove 10 current-year fascicles from the mid-portion of the twig and record needle length. Record the reduction in needle length for all fascicles less than 70 mm in length (i.e., if fascicle is 58 mm, then record 12). Add the total length of needle reductions for all 20 fascicles, reference the sequential sampling plan (Table 2) for a two twig sample, and continue sampling until a decision is met. Damage will be classified as either tolerable, critical, or intolerable based on the cumulative stunting of needles (Table 2). Sampling should be conducted when needle elongation is complete (i.e., end of September in this study).

Estimating Population Levels

Sampling the gallicola migrans stage: Sample this stage on white pine during June, or after the gallicolae have settled. Collect twigs as above, sampling one year old internodes, and counting and recording them as infested or uninfested. Continue sampling twigs from the same branch until 100 fascicles have been counted and then calculate the percentage of fascicles infested by *P. pinifoliae*. Reference the sequential sampling plan (Table 3) and continue sampling until a decision is met. Populations will be classified as either tolerable, critical, or intolerable based on the cumulative percentage of infested fascicles (Table 3).

Sampling for galls on red and black spruce in mixed stands: Sample around mid-May when galls can be differentiated easily from uninfested buds. Red and black spruce should be sampled in proportion to their relative abundance in the stand. Remove one branch from the second crown quarter from the top of the tree. Count and record the number of galls. Reference the sequential sampling plan (Tables 4), and continue sampling until a decision is met. Damage will be classified as either tolerable, critical, or intolerable based on the cumulative number of galls per branch (Tables 4).

Notes

A working knowledge of the complex biology of *P. pinifoliae* is required to successfully implement these sampling methods (Balch and Underwood 1950). Make sure not to sample edge trees where within-tree distribution of *P. pinifoliae* may not be uniform as in the infested stand.

Reference

Balch, R. E.; Underwood, G. R. 1950. The life history of *Pineus pinifoliae* (Fitch) (Homoptera: Adelgidae) and its effect on white pine. Canadian Entomologist 82: 117-123.

Tables

Table 1. Classification of degrees of damage produced by the pine leaf chermid on white pine and population levels of several life stages that produce those degrees of damage.

Damage category	Damage description	No. of neosistens per cm of shoot	No. of gallicolae/10 fascicles on pine shoots	% fascicles infested by gallicolae	Galls per branch; stands mostly pine	Galls per branch; stands mostly spruce
Tolerable	Needles normal length, >70 mm, or slightly stunted, up to 5 mm	<5	<0.06	<5.5	<5	<1
Critical	Needles moderately stunted, 15-25 mm; (needle length 45-55 mm), some shoots chlorotic or dead	12-38	1.7-5.5	10.4-30.1	13-20	3-7
Intolerable	Needles heavily stunted, >35 mm; (needle length <35mm), many shoots chlorotic or dead.	>165	>25	>65	>28	>10

Table 2. Sequential table for classifying pine leaf chermid damage on white pine, using needle stunting as the criterion. Calculated at 90% confidence level, using equations for a normal distribution.

No. of twigs examined (n)	Cumulative stunting (<70 mm) in mm					
	Tolerable-d_1		Critical-d_2	Critical-d_3		Intolerable-d_4
1	---		---	---		43
2	7		33	47		73
3	17	C	43	77	C	103
4	27	O	53	107	O	133
5	37	N	63	137	N	163
6	47	T	73	167	T	193
7	57	I	83	197	I	223
8	67	N	93	227	N	253
9	77	U	103	257	U	283
10	87	E	113	287	E	313
11	97		123	317		343
12	107	S	133	347	S	373
13	117	A	143	377	A	403
14	127	M	153	407	M	433
15	137	P	163	437	P	463
16	147	L	173	467	L	493
17	157	I	183	497	I	523
18	167	N	193	527	N	553
19	177	G	203	557	G	583
20	187		213	587		613
$d_1 = 10n-13.18$			$d_2 = 10n+13.18$	$d_3 = 30n-13.18$		$d_4 = 30n+13.18$

Table 3. Sequential table for classifying damage potential of the gallicolae migrans stage of the pine leaf chermid on pine. Calculated at 90% confidence level, using equations for a binomial distribution.

No. of twigs examined (n)	Cumulative % infested fascicles					
	Tolerable-d_1		Critical-d_2	Critical-d_3		Intolerable-d_4
1	---		---	---		---
2	---		---	---		---
3	---	C	---	---	C	249
4	7	O	52	52	O	292
5	15	N	59	95	N	335
6	22	T	66	138	T	378
7	30	I	74	181	I	421
8	37	N	81	224	N	464
9	44	U	89	267	U	507
10	52	E	96	310	E	550
11	59		103	353		593
12	66	S	111	396	S	636
13	74	A	118	439	A	679
14	81	M	126	482	M	722
15	89	P	133	525	P	765
16	86	L	140	568	L	808
17	104	I	148	611	I	851
18	111	N	155	654	N	894
19	118	G	163	697	G	937
20	126		170	740		980
$d_1 = 7.39n-22.06$			$d_2 = 7.39n+22.06$	$d_3 = 43n-119.9$		$d_4 = 43n+119.9$

Table 4. Sequential table for classifying damage potential of galls produced by the pine leaf chermid on spruce, where pine is a greater component of the stand than spruce. Calculated at 90% confidence level for tolerable vs. critical and at 70% level for critical vs. intolerable, using equations for a negative binomial distribution. Common k=0.901.

No. of twigs examined (n)	Cumulative number of galls per branch					
	Tolerable-d_1		Critical-d_2	Critical-d_3		Intolerable-d_4
1	---		---	---		95
2	---		---	---		119
3	1		---	---		144
4	9	C	---	---	C	168
5	17	O	---	---	O	193
6	25	N	69	75	N	217
7	32	T	77	100	T	241
8	40	I	85	124	I	265
9	48	N	93	148	N	290
10	56	U	100	173	U	314
11	64	E	108	197	E	339
12	71		116	221		363
13	79	S	124	246	S	387
14	87	A	131	270	A	412
15	95	M	139	294	M	436
20[a]	134	P	178	416	P	558
25	173	L	217	538	L	680
30	212	I	256	660	I	801
35	251	N	295	782	N	923
40	290	G	335	903	G	1045
45	329		374	1025		1167
50	368		413	1147		1289
$d_1 = 7.81n-22.21$			$d_2 = 7.81n+22.21$	$d_3 = 24.3n-70.8$		$d_4 = 24.3n+70.8$

[a] Missing values between 21 and 49 can be calculated using equations at bottom of columns.

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Painted Maple Aphid

Drepanaphis acerifoliae (Thomas)
Homoptera: Aphididae

Dreistadt, S. H.; Flint, M. L. 1995. Landscape pest monitoring methods and training managers to use them. Journal of Arboriculture 21: 1-6.

Objective

To describe a monitoring method for *D. acerifoliae* useful to urban foresters in control decision-making.

Abstract

The painted maple aphid, *Drepanaphis acerifoliae* (Thomas), is a common pest of maples, *Acer* spp., growing in urban areas. Infestations result in dieback and aesthetic damage. Honeydew, a waste product excreted from the posterior of the insect, drips from infested leaves and is often considered a nuisance. Aphid populations can be monitored effectively in urban environments by using a type of water sensitive, yellow paper that turns blue when in contact with honeydew droplets (Dreistadt 1987). This monitoring technique was described in relation to controlling the painted maple aphid on silver maple, *Acer saccharinum* L., in California. Control measures were warranted whenever honeydew drop densities exceeded 1-2 drops/cm^2/4 h.

Sampling Procedure

To monitor *D. acerifoliae* populations, a water sensitive, yellow card is used to detect the presence of aphids. These cards produce a dark blue dot whenever honeydew lands on the surface. Tape each card to a piece of cardboard, which is attached to a bent wire coat hanger. Hang each card 46 cm beneath lower crown foliage. Place a card in each cardinal direction weekly. Deploy cards for 4 h, retrieve, and determine the number of dots per square centimeter. Control is warranted if densities exceed 1-2 drop/cm^2 on any one card.

Note

Aphid populations are distributed normally and occur in urban environments where honeydew production is undesirable.

Reference

Dreistadt, S.H. 1987. Monitoring honeydew excretion in the field as a method of sampling *Illinoia liriodendri* (Homoptera: Aphididae) infesting *Liriodendron tulipiferia.* Journal of Economic Entomology 80: 380-383.

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.

Objective

To compare methods for determining infestation levels of *M. abietinus* in Christmas tree plantations.

Abstract

The balsam twig aphid, *Mindarus abietinus* Koch, causes distortion and loss of needles on balsam fir, *Abies balsamea* (L.), Christmas trees. This study, conducted in balsam fir Christmas tree plantations of central Wisconsin, compared two sampling methods (beating discs and visual counts of infested shoots) to monitor aphid densities and make informed decisions regarding control.

The beat disc method was most effective at detecting *M. abietinus* before and during budbreak, while the visual count method was most effective after budbreak. A minimum of 15 trees in each stand was the recommended sample size for both methods. For monitoring purposes, growers should sample before budbreak by using the beat disc method, and limit insecticide applications to trees with greater than two fundatrices per sample.

Sampling Procedure

Beat disc method: Use a 53.4-cm^2 circular beating disc for sampling aphid numbers. Each disc consists of a piece of black velvet glued to the inside of a 17 cm diameter plastic embroidery ring. Place the ring within the outer mid-crown of each tree and beat the foliage five times with a gloved hand to dislodge insects onto the disc. Aspirate all aphids and place in vials containing 70% ethyl alcohol for later identification and tally. Conduct the sample at or before budbreak (i.e., mid-May in this study). Beat samples should be processed immediately to ensure proper timing of control measures in the current year.

Visual count method: Count the number of infested and uninfested shoots on a 20 cm long mid-crown branch on each of 15 trees previously unsampled. Calculate the proportion of infested shoots. The visual count sample should coincide with the peak of wingless, spring females (i.e., late May), winged adults (i.e., early June), and after egg laying (oviposition) has occurred (i.e., early July). On the last sample date, count and record the number of shoots with no curling, slight curling (needles slightly twisted) or extensive curling (permanent).

After shoots emerge and become infested, visual counts of infested shoots are reliable indicators of future damage. For current year control decision-making, growers should monitor aphid populations by the beat disc method and apply registered insecticides when high infestation levels occur (i.e., greater than two or three fundatrices per sampling disc).

Saratoga Spittlebug

Aphrophora saratogensis (Fitch)
Homoptera: Cercopidae

Wilson, L. F. 1987. Saratoga spittlebug—its ecology and management. Agric. Handb. No. 657. Washington, DC: U.S. Department of Agriculture, Forest Service; 56 p.

Objective

To provide survey procedures useful for assessing spittlebug populations and predicting population trends.

Abstract

The Saratoga spittlebug, *Aphrophora saratogensis* (Fitch), is the most destructive sap-sucking forest pest of pines, *Pinus* spp., in eastern North America. Nymphs feed on alternative hosts, typically sweetfern, until mid-summer and adults feed on pines until autumn. The most obvious signs of infestation are spittle-like masses on alternate hosts, reddish-colored branches on host trees, and tan or brown flecks on the outer bark. Heavy infestations cause top kill, stem deformity, growth loss, and tree mortality. The greatest impact occurs in young plantations of red, *Pinus resinosa* Ait., and jack, *Pinus banksiana* Lamb., pine in the Lake States and Canada.

Two types of surveys are available to assess changes in *A. saratogensis* density and to predict stand risk or hazard. If a feeding scar survey indicated that the average number of scars was less than 25, then no further surveys were warranted. If the survey value was 20-25, then a feeding scar survey should be conducted the following fall. If the survey value was greater than 25, then a nymph survey should be conducted the following spring. A density of one nymph per tree-unit indicated a 25% reduction in tree growth. In areas with greater than one nymph per tree and with visible flagging or defoliation, control was recommended for the same year. A risk rating system was developed for *A. saratogensis*.

Sampling Procedure

You may stop the survey after any step if feeding injury is seen or the insect is collected and verified. When infestations are too low to show injury, you may need to sample several trees or alternate hosts before locating *A. saratogensis.*

Feeding scar survey: This survey estimates the severity of adult feeding which predicts whether a more detailed nymphal survey is warranted the following spring. Sample areas of moderate to high risk in autumn based on presence of alternate hosts. Determine the number of samples you will take according to the area at risk: <4.5 ha (20 samples), 4.5-8.1 ha (25 samples), 8.1-20.2 ha (30 samples), and >20.2 ha (>35 samples). Conduct a survey systematically at specified intervals in order to get adequate stand coverage. At each sample point, select a tree of average height and remove a 10-cm section of two-year-old growth from an upper whorl. Remove the bark with a knife and record the number of scars (red flecks) on the sapwood and then average the number of scars from the samples. If the value is less than 25, no further surveys are required. If the average is between 20-25, the stand should be scar surveyed again the following fall. If the average is greater than 25, the stand should be surveyed for nymphs in the spring.

Nymph survey: The survey of *A. saratogensis* nymphs determines the current threat of injury. Begin looking for nymphs in spittlemasses the second week of June and tally when most appear to be late instars (third to fifth) which more accurately reflect the adult population and subsequent damage. The first to fourth instars are black and red whereas fifth instars are chestnut brown. If a current lack of spittle-masses does not warrant concern, no further sampling needs to be done that year. However, surveys should be scheduled periodically until crown closure occurs.

Select the number of 400-m^2 (0.1 acre) plots to cover the area in question: 0.4-2 ha (1 plot), 2.4-4 ha (2 plots), 4.5-8.1 ha (3 plots), 8.5-16.2 ha (4 plots) and >16.2 ha (5 plots). Determine the number of trees in each plot, average number of whorls per tree, and height of 10 trees scattered throughout the plot. Calculate and record the tree-units for the plot (A) by multiplying the number of trees by the average number of whorls by the average tree height. Count the number of nymphs in a plot 63.5 by 63.5 cm using a sampling frame to delineate plot boundaries. When you find one nymph, stop sampling and record that sample as a (+). If no nymphs are found after examining all host plants record the sample as a (-). After taking all 50 samples, count the (+) and multiply by 2 to determine the percentage of samples infested with nymphs, which provides an estimate of the number of nymphs per 400-m^2 plot (B). Calculate the number of nymphs per tree-unit (C) by taking the number of nymphs per plot (B) and dividing by the number of tree-units per plot (A). This value (C) is used to predict probable damage (Table 12) and the need for future surveys and control (Table 13).

Tables

Table 12. Damage level categories for adult spittlebug feeding.

Damage level	Nymph/tree unit	Potential growth reduction (%)
Very low – lateral terminal growth differences	0.25	2
Low – up to 4 yr of growth reduction	0.50	6
Moderate – up to ten yr of growth reduction, scattered flagging, some degradation	1.00	26
High – whole branch flagging, dead tops, extensive degradation, some dead trees	2.00	41
Very high – dead tops, extensive degradation, many dead trees	6.00	66

Table 13. Key to action recommended after nymphal appraisal survey[1]

0a.	Nymphs/tree-unit less than 1.0 – see no. 1
0b.	Nymphs/tree-unit 1.0 or more – see no. 8
1a.	Trees shorter than 10 ft – see no. 2
1b.	Trees 10 ft or taller – see no. 4
2a.	Nymphs/tree-unit less than 0.15 – evaluate again in 3 years
2b.	Nymphs/tree-unit 0.15 or more – see no. 3
3a.	Nymphs/tree-unit more than 0.25 – evaluate next year
3b.	Nymphs/tree-unit 0.15 to 0.25 – evaluate in 2 years
4a.	Trees from 10 to 12 ft – see no. 5
4b.	Trees taller than 12 ft – see no. 7
5a.	Nymphs/tree-unit more than 0.15 –see no. 6
5b.	Nymphs/tree-unit 0.15 or less – no need to reevaluate
6a.	Nymphs/tree-unit more than 0.25 – evaluate next year
6b.	Nymphs/tree-unit 0.15 to 0. 25 – evaluate in 2 years
7a.	Nymphs/tree-unit more than 0.40 – reevaluate next year
7b.	Nymphs/tree-unit 0.40 or less – no need to reevaluate
8a.	Nymphs/tree-unit 1.0 to 2.0 – if there is flagging or noticeable degradation, control this year; if not, reevaluate next year
8b.	Nymphs/tree-unit more than 2.0 –control this year

[1]Given near threshold values, use indicators of the previous year's feeding injury to help make a control decision. The previous year's feeding scars persist to add to the present year's injury; thus, use presence of feeding scars, flagging, and the previous insect evaluation, if available, to decide if control is warranted.

Dreistadt, S. H.; Flint, M. L. 1995. Landscape pest monitoring methods and training managers to use them. Journal of Arboriculture 21: 1-6.

Objective

To describe a method of monitoring *C. pseudomagnoliarum* populations to determine when control measures should be applied.

Abstract

The citricola scale, *Coccus pseudomagnoliarum* (Kuwana), often infests hackberry, *Celtis* spp., in urban plantings in California. Infestations cause dieback and a proliferation of honeydew, a waste product that forms a sticky residue on anything below infested trees. Populations can be monitored effectively in urban landscapes with sticky tape traps designed to sample the crawler stage. If control treatments are warranted, insecticides or oils are applied after peak crawler emergence or after a sharp increase in the number of crawlers caught per trap (i.e., 40 crawlers per traps).

Sampling Procedure

Monitor *C. pseudomagnoliarum* crawlers using double-sided transparent tape available in any stationary store. To make traps, a twig or small branch (9-13 mm in length) is wrapped tightly with a strip of tape about 12 cm in length. Double over the free end of each sticky band to make a handle to facilitate tape removal. Newly-hatched crawlers will get stuck in the tape traps as they search for new feeding sites.

Deploy two or three traps per tree before crawlers are expected (i.e., late April in this study). Once deployed, monitor and change traps with new material weekly in the same location. Count the number of crawlers from each monitoring date to determine peak crawler emergence. Apply treatment during peak crawler emergence or when a sharp increase in crawler number is noticed in the traps, or both.

Notes

The reader must be able to identify *C. pseudomagnoliarum* life stages. This technique is very efficient and took one person 1 h per week during spring to collect and replace 22 traps.

SEED AND CONE INSECTS

Spruce Cone Maggot

Strobilomyia neanthracina Michelsen
Diptera: Anthomyiidae

Sweeney, J. D.; Miller, G. E.; Ruth, D. S. 1990. Sampling seed and cone insects in spruce. In: West, R. J., editor. Proceedings of the cone and seed pest workshop. 1989 October; St. John's, Newfoundland. Inf. Rep. N-X-274. Canadian Forest Service; 63-75.

Objectives

To determine if the percentage of damaged seeds per cone is positively related to *S. neanthracina* density per conelet; to determine what sample size is necessary to estimate *S. neanthracina* egg density; and to determine what infestation levels are required to justify control.

Abstract

The spruce cone maggot, *Strobilomyia neanthracina* Michelsen, is a destructive, seed-eating cone fly of spruce, *Picea* spp., in Canada. One egg is laid per cone and after hatching the larva feeds on the developing seeds while spinning around the cone axis. A study was conducted in the interior of British Columbia, Canada, to determine if seed damage to white, *Picea glauca* (Moench) Voss., and Engelmann, *P. engelmannii* L., spruce was positively related to *S. neanthracina* infestation level and density per conelet. These data were used to develop recommendations for sampling *S. neanthracina* to determine if control measures were warranted. The percentage of seeds damaged per cone was positively related to both the percentage of cones infested and density of *S. neanthracina* per cone. The number of sample trees required to estimate egg density with 90% confidence and 10% error was from 218 to 542. This sampling intensity was considered too large to be practical for field applications. The optimal number of conelets to sample per tree was two. Control measures were warranted if *S. neanthracina* egg densities exceeded 0.3 per conelet.

Sampling Procedure

Systematically select from 218 to 542 trees to be sampled in the area of concern. At each tree, collect two conelets from the upper to mid-crown when conelets are about half pendant. Conelets can be bulked and stored at -10 ºC until dissected. The number of person-days required to sample this many conelets ranged from 5 to 12.

Dissect conelets with a pair of fine forceps under a stereoscopic microscope at 10 power magnification. Starting from the base of each cone and working towards the tip, pull each cone scale away from the conelet, looking for presence of eggs, larvae, and feeding damage. Eggs are white and oblongate (about 1.4 by 0.5 mm) and are laid between the cone scales. Immature larvae are more difficult to see if they have just hatched from the egg. Look for hatched, flattened eggs with signs of feeding nearby and the small white translucent larva with its pair of black mouth hooks.

Spruce Cone Maggot

Strobilomyia neanthracina Michelsen
Diptera: Anthomyiidae

Sweeney, J. D. 1998. Sequential sampling of spruce conelets to predict the category of seed loss due to spruce cone maggots. Unpublished Report, Canadian Forest Service, Natural Resources Canada, P.O. Box 4000, Fredericton, NB. Canada, E3B 5P7.

Objective

To develop a method of predicting seed orchard seed losses from *S. neanthracina* before significant losses occur. This method indicates when control measures are needed.

Abstract

The spruce cone maggot, *Strobilomyia neanthracina* Michelsen, is a destructive, seed-eating cone fly of spruce, *Picea* spp., in eastern Canada. Usually, one egg is laid per cone. After hatching, the larva feeds on the developing seeds while spinning around the cone axis.

A method of determining the need for control of *S. neanthracina* in white, *Picea glauca* (Moench) Voss., or Engelmann, *P. engelmannii* L., spruce seed orchards was presented. The optimum sampling intensity for *S. neanthracina* was one conelet from each of 100 trees when conelets on most trees were about half pendant. Infestations were classified as light (≤8%), moderate (12-35%), or heavy (≥40% of conelets infested).

Sampling Procedure

Collect one conelet from each of 100 trees when conelets on most trees are about half pendant. Select trees systematically to ensure adequate coverage across the entire block or orchard being sampled. Bulk all conelets into one sample. Process samples as soon as possible.

First, dissect 20 conelets with a pair of fine forceps under a stereoscopic microscope at 10 power magnification. Starting at the base of each cone and work towards the tip, pulling each cone scale away from the conelet while searching for the presence of eggs, larvae, and feeding damage. Eggs are white and oblong (about 1.4 by 0.5 mm) and are laid between the cone scales. Immature larvae are more difficult to see if they have just hatched from the egg. Look for hatched, flattened eggs with signs of feeding nearby and the small white translucent larva with its pair of black mouth hooks. Once a cone maggot has been found, record the conelet as infested. Compare the number of infested conelets in your first 20 conelets dissected with the numbers in Table 1. If you find 7 or more infested cones out of 20, then at least 12% loss of filled seed is predicted. If 15 or more infested cones are found, then 40% loss of filled seed is predicted. If fewer than 9 of 20 cones are infested, dissect another 10 cones and reference Table 1 again. Continue dissecting conelets in bunches of 10 until the cumulative number of infested conelets per number of conelets dissected corresponds to ≤8%, 12-35% or ≥40%. Dissect a maximum of 100 cones. If the cumulative number of infested conelets does not fall into one of the damage classes, you can predict crudely the percentage of seed loss as follows:

$$\% \text{ seed loss} = \% \text{ infested conelets} \times 0.69$$

Note

This sampling plan requires up to 1 day to complete, depending on the level of infestation.

Table

Table 1. Sampling plan for predicting the percentage of seeds lost to *S. neanthracina* feeding on *P. glauca*.

No. cones dissected	Seed loss:	Cumulative no. cones with eggs or larvae ≤8%		12-35%		≥40%
20		-		7		≥18
30		0		8 - 12		≥25
40		≤ 2		10 - 18		≥31
50		≤ 3		11 - 25		≥37
60		≤ 5		13 - 31		≥43
70		≤ 6		14 - 37		≥49
80		≤ 8		16 - 43		≥55
90		≤ 9		17 - 49		≥61
100		≤11		19 - 55		≥68

Continue sampling ***Continue sampling***

Douglas-Fir Cone Gall Midge

Contarinia oregonensis Foote
Diptera: Cecidomyiidae

Miller, G. E. 1986. 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.

Objectives

To examine the distributions of *C. oregonensis* eggs within and among trees, and to develop an egg population sampling technique.

Abstract

The Douglas-fir cone gall midge, *Contarinia oregonensis* Foote, is a serious pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, seed in forests and seed orchards of western North America. Efficient sampling procedures for estimating egg densities of *C. oregonensis* were developed from data collected in Douglas-fir seed orchards on Vancouver Island, Canada, 1978-1981.

Aspect, conelet density per branch, conelet position from branch tip, or conelet length and color did not influence the oviposition preferences of *C. oregonensis*. However, egg density was positively correlated with the total number of conelet scales in all orchard-years ($P < 0.05$). The optimum sampling pattern was to sample one conelet on 120 trees from the mid-point of the cone-bearing portion of the crown. Sampling required a processing time of up to 120 h, depending on the egg densities encountered.

Sampling Procedure

Collect one conelet from each of 120 trees to provide an estimate of the average number of eggs per conelet with a standard error of 10% and a confidence of 90%. Dissect, count, and record the number of eggs. The following recommended sample sizes are also provided and adjusted for crop size:

Number of producing trees	50	100	200	500	1000
Number of sample trees	18	40	76	80	93

In Douglas-fir seed orchards in British Columbia, normally ≤90 samples are required involving a sampling time of up to 90 h when egg densities are high, because of the limited number of cone-producing trees in any one year. Conelets can be stored at 0°C for 2-3 months and retain their suitability for egg counts.

Notes

The effectiveness of this technique in non-orchard situations is unknown. Consult our review of Miller (1986) for more details concerning damage predictions resulting from *C. oregonensis* infestations.

Reference

* Miller, G. E. 1986. Damage prediction for *Contarinia oregonensis* Foote (Diptera: Cecidomyiidae) in Douglas-fir seed orchards. Canadian Entomologist 118: 1297-1306.

Douglas-Fir Cone Gall Midge

Contarinia oregonensis Foote
Diptera: Cecidomyiidae

Miller, G. E. 1986. Damage prediction for *Contarinia oregonensis* Foote (Diptera: Cecidomyiidae) in Douglas-fir seed orchards. Canadian Entomologist 118: 1297-1306.

Objective

To develop a sequential sampling plan for classifying infestations based on the relationship between egg-infested conelets in the spring and the number of damaged seeds per cone at harvest.

Abstract

The Douglas-fir cone gall midge, *Contarinia oregonensis* Foote, is a serious pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, seed in forests and seed orchards of western North America.

Damage by *C. oregonensis* was correlated positively with the number of egg-infested scales per conelet in the spring. Two methods that determine the number of samples required to estimate populations of *C. oregonensis* accurately are presented. The optimum sample size for estimating densities of egg-infested scales in seed orchards was one conelet per tree from each of 154 trees per orchard. Cones were sampled halfway up the cone-bearing portion of the crown. A sequential sampling plan relative to a critical density was also developed for control decision-making. An average of 2.6 egg-infested scales per conelet was determined to cause 10% seed loss assuming 85% insecticide efficacy. If the average number of egg-infested scales ≥2.6, then control was warranted.

Sampling Procedure

Fixed sample size plan: The optimal number of conelets per tree is determined using procedures presented in the original publication (Table 2). Sample one conelet from each of 154 trees (90% confidence and 10% error), which should take approximately 17.5 h.

Sequential sampling plan:

> Individual trees: Sample cones halfway up the cone-bearing portion of the crown. Dissect, count, and record the number of infested scales, referencing the sequential sampling plan (Fig. 4). Continue sampling until a decision is met or 97 cones are sampled. If the cumulative total number of egg-infested scales drops below the lower line, control is not warranted. If the cumulative total of egg-infested scales falls above the upper line, control is warranted.
>
> Seed orchards: Sample one conelet per tree halfway up the cone-bearing portion of the crown. Dissect, count and record the number of infested scales, and reference the sequential sampling plan (Fig. 5). The maximum number of trees to be sampled is 154.
>
> This sequential sampling plan has been used operationally in British Columbia since 1981. During this period most orchards were sampled and decisions reached by the time 100 conelets had been processed with an average processing time of 7-8 h.

Notes

A larger than expected sampling error may be realized. This technique was developed in seed orchards and may require modification for clonal orchards if variation to *C. oregonensis* susceptibility exists among cones.

Table and Figures

Table 2. Components of total variance contributed by among- and within-tree variances, optimum number of conelets per tree (n_i), and, when estimating average number of egg-infested scales per conelet and $n_i - 1$, coefficient of variation (cv) and numbers of trees per orchard required to obtain two levels of confidence and precision.

					$n_i = 1$				
						Confidence			
		Source of variation*				90%		80%	
					cv	% sampling error		% sampling error	
Year	Orchard	Among	Within	n_i	(%)	10	20	10	20
1978	Koksilah	0.0072	0.0064	0.6	24	19	6	11	4
	Quinsam	0.0093	0.0066	0.6	50	70	19	43	12
1980	Koksilah	0.0012	0.0033	1.1	55	84	23	52	14
1981	Lake Cowichan	0.0001	0.0049	6.6	3	3	2	2	2
	Quinsam	0.0057	0.0047	0.6	59	97	26	59	16
	Snowdon	0.0021	0.0048	1.0	67	124	33	76	20
1984	Dewdney	0.0149	0.0035	0.3	63	110	29	67	18
	Snowdon	0.0033	0.0027	0.3	15	9	4	6	3
	$\bar{x}$ ‡	0.0055	0.0046	1.4	42	50	14	31	9

* Data transferred by $\chi^{0.466}$ prior to analyses.

† cv(%) = $\left(\frac{\sqrt{s_t^2}}{\bar{x}}\right)$ 100.

‡ Arithmetic average.

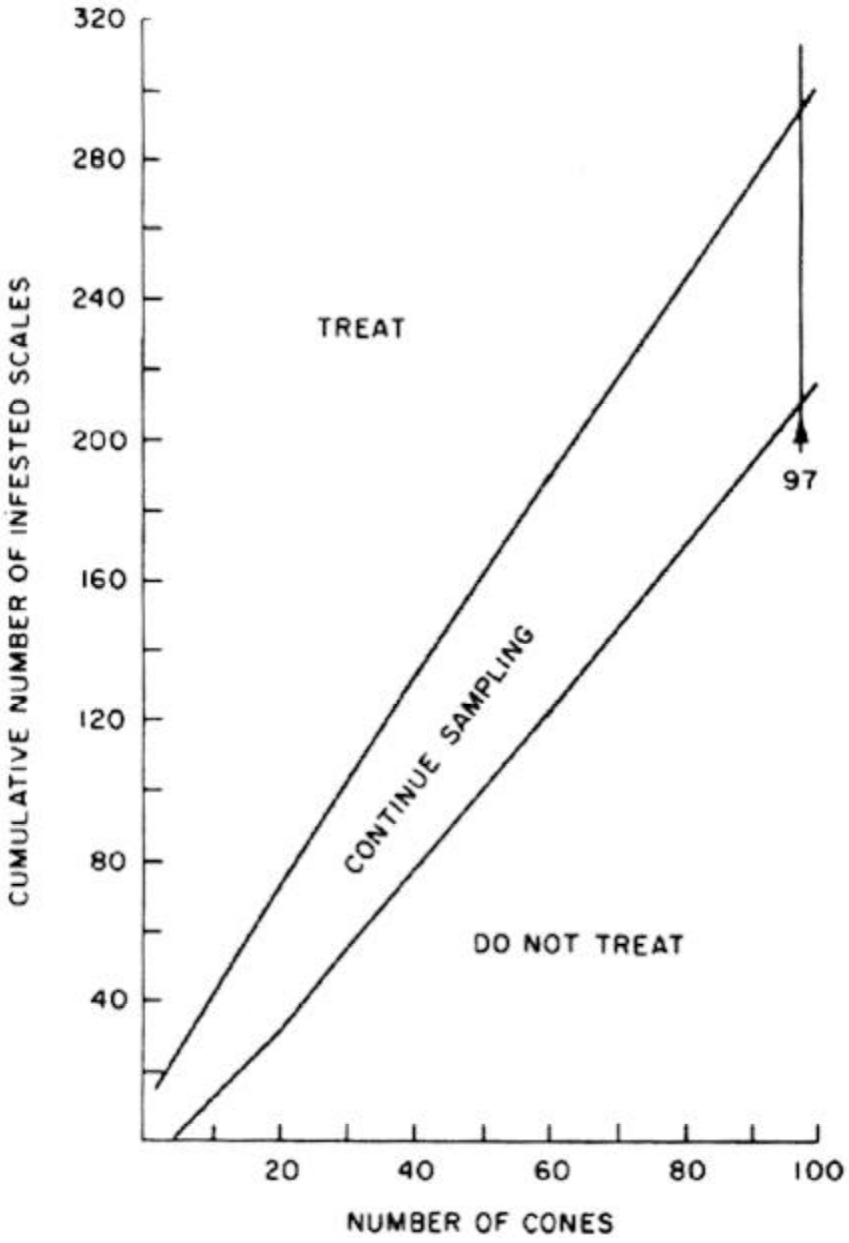

Fig. 4. Sequential sampling graph for individual trees with 10% sampling error and 90% confidence using a critical density equivalent to 10% seed loss. Conelets should be collected from the midpoint of the conelet-bearing region.

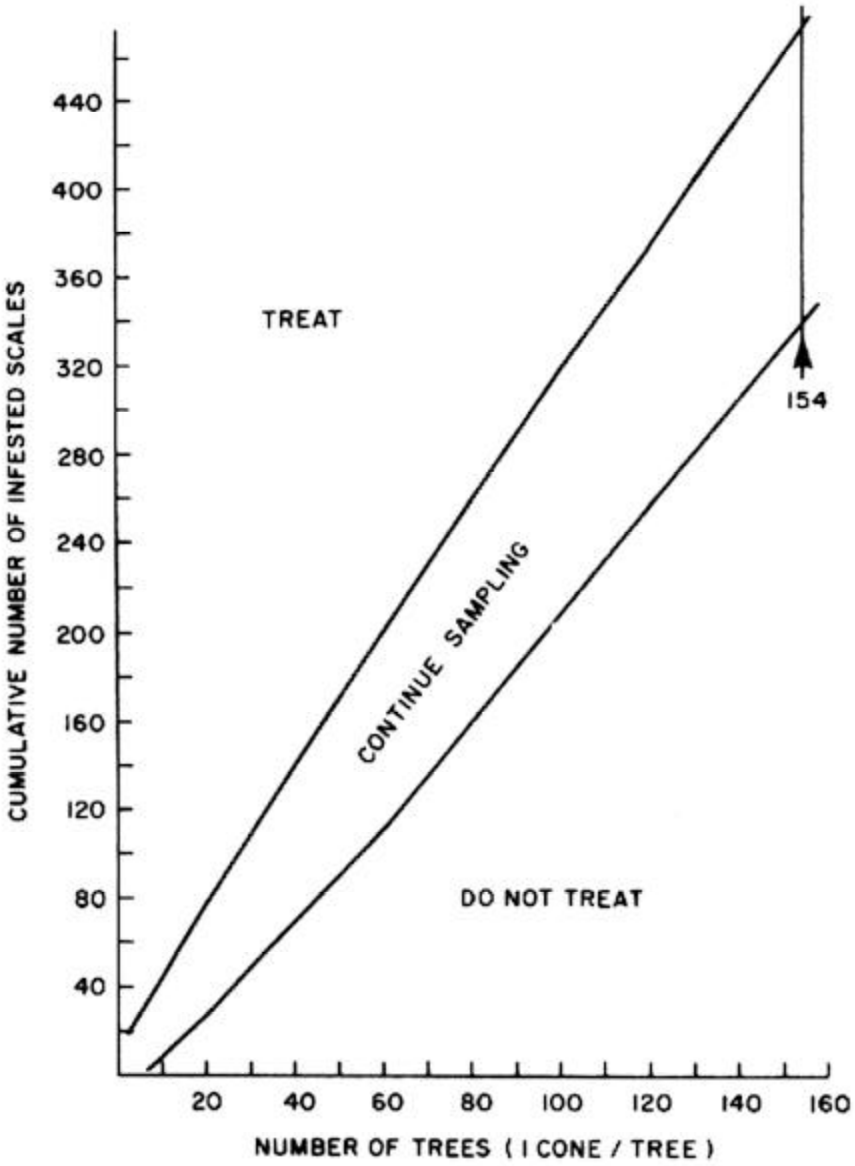

Fig. 5. Sequential sampling graph for an orchard taking one conelet per tree, at the midpoint of the conelet bearing reagion, with 10% sampling error and 90% confidence using a critical density equivalent to 10% seed loss (2.6 egg-infested scales per conelet).

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Douglas-Fir Cone Moth

Barbara colfaxiana (Kearfott)
Lepidoptera: Tortricidae

Sweeney, J. D.; Miller, G. F. 1989. Distribution of *Barbara colfaxiana* (Lepidoptera: Tortricidae) eggs within and among Douglas-fir crowns and methods for estimating egg densities. Canadian Entomologist 121: 569-578.

Objective

To develop a sequential sampling plan that predicts when *B. colfaxiana* populations are high enough to cause a 10% loss of Douglas-fir seed.

Abstract

The Douglas-fir cone moth, *Barbara colfaxiana* (Kearfott), is the most prevalent pest of Douglas-fir, *Pseudotsugae menziesii* (Mirb.) Franco, seed in British Columbia. The spatial frequency distributions of *B. colfaxiana* eggs in Douglas-fir trees and stands were determined by dissecting 13,262 conelets collected from 81 trees at three sites in 2 years.

Sampling Procedure

Collect Douglas-fir conelets after they have begun to turn down, following pollination and the oviposition period of *B. colfaxiana*, but before they become pendant. Sample at least 10 trees 4-14 m tall, collecting three conelets per tree. Consult the sequential sampling table (Fig. 2), and continue sampling until a decision is met. If the cumulative number of eggs exceeds the upper decision limit, then the population is expected to cause greater than 10% seed loss. When the number of eggs falls below the lower decision limit, damage is expected to be minimal. Sample a maximum of 59 trees, and calculate mean egg densities to compare with the critical density (10% seed loss). Sampling time ranges from 3 to 18 h.

Notes

The relationship between the mean and variance is similar in both natural stands and seed orchards. This sequential sampling plan is quite reliable for classifying *B. colfaxiana* egg density except when densities approach the critical level, which results in 10% seed loss.

Figure

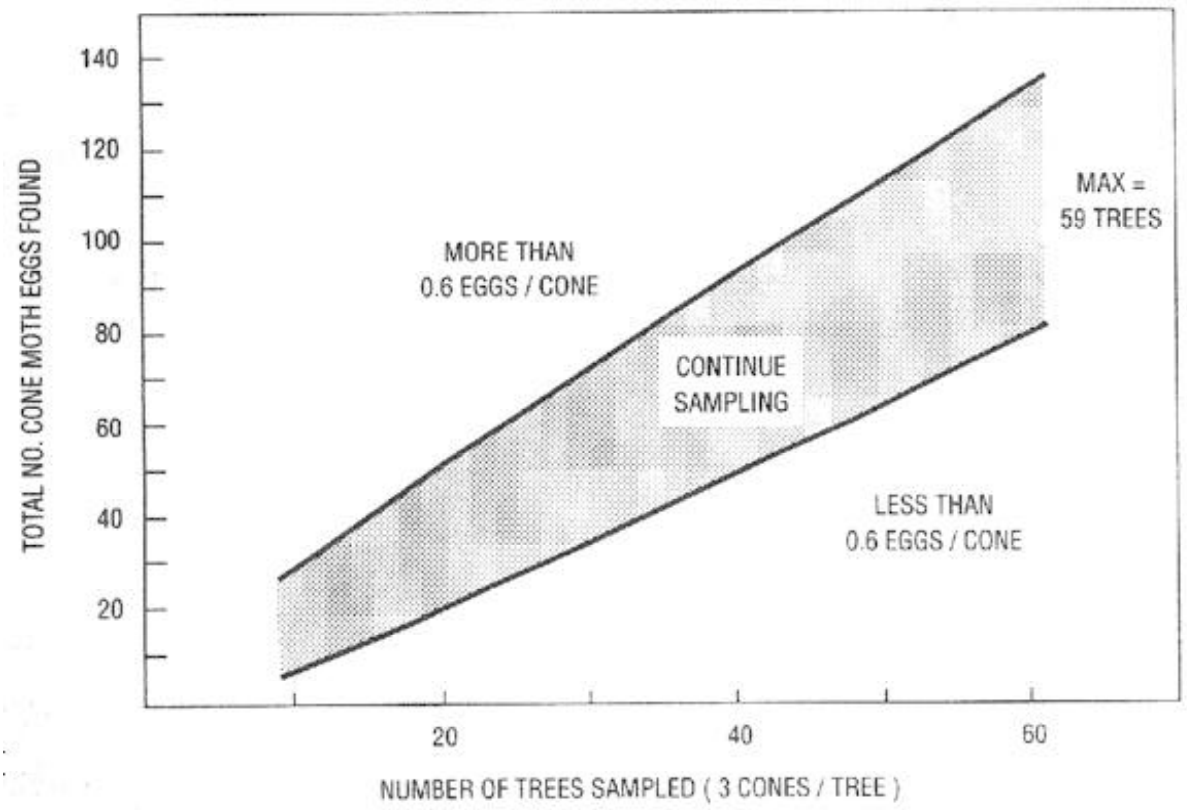

Fig. 2. A two-stage sequential sampling plan for classifying the mean density of Douglas-fir cone moth eggs per conelet relative a critical level defined as 0.6 per conelet. Three conelets are sample per tree, the minimum number of trees to sample is 10, and the maximum is 59. The normal confidence level is 98% (but see Fig. 3).

Figure 2 reprinted with permission from the Canadian Entomologist, January 15, 2001.

Spruce Seed Moth

Cydia strobilella (L.)
Lepidoptera: Tortricidae

Sweeney, J. D.; Miller, G. E.; Ruth, D. S. 1990. Sampling seed and cone insects in spruce. In: West, R. J., editor. Proceedings—cone and seed pest workshop. 1989 October. St. John's, Newfoundland. Inf. Rep. N-X-274. Canadian Forest Service; 63-75.

Objectives

To determine if the percentage of damaged seeds per cone was related to *C. strobilella* density per conelet; to determine what sample size was necessary to estimate egg density; and to determine what infestation level was required to justify the use of control measures.

Abstract

The spruce seed moth, *Cydia strobilella* (L.), is an important pest of seed orchards in Canada. The primary hosts are Engelmann, *Picea engelmannii* L., and white spruce, *P. glauca* (Moench) Voss, spruce although other species can be attacked. A study was conducted in interior British Columbia to determine if seed damage to white and Englemann spruce was related positively to *C. strobilella* infestation level and density per conelet.

The percentage of seeds damaged per cone was directly related to both the percentage of cones infested and density of *C. strobilella* per cone. Control measures were warranted if *C. strobilella* egg densities exceeded 0.8 per conelet. The optimal number of conelets to sample per tree was two. The number of sample trees required to estimate egg density with 90% confidence and 10% error was 223 to 509. This sampling intensity was practical for detailed, scientific studies only.

Sampling Procedure

Select 223 to 509 trees systematically from the area of concern. At each tree, collect two conelets from the upper to mid-crown when conelets are about half pendant. Conelets can be bulked and stored at -10°C until dissected. The number of days required to sample this many conelets ranges from 5 to 12.

Dissect conelets with a pair of fine forceps under a stereoscopic microscope at 10 power magnification. Starting from the base of each cone, work distally pulling each cone scale away from the conelet searching for the presence of *C. strobilella* eggs, larvae, and damage. Seeds damaged by *C. strobilella* are packed with frass and easily distinguished from those fed upon by other seed pests.

Fatzinger, C. W.; Muse, H. D.; Miller, T.; Bhattacharyya, H. T. 1988. Estimating cone and seed production and monitoring pest damage in southern pine seed orchards. Res. Pap. SE-271. Asheville, NC: U. S. Department of Agriculture, Forest Service, Southern Research Station; 30 p.
http://www.srs.fed.us/pubs/rp/rp_se271.pdf

Objective

To estimate orchard yields of female strobili and seeds; to quantify pest damage; to determine time of year when losses occur; and to develop life tables for female strobili.

Abstract

Field sampling procedures and computer programs are described for monitoring seed production and pest damage in southern pine seed orchards. The system estimates total orchard yields of female strobili and seeds, quantifies pest damage, determines times of year when losses occur, and produces life tables for female strobili. Four types of samples that are generally conducted were reviewed. An example is included to illustrate the sampling procedures and the operations of user-friendly computer programs.

Sampling Procedure

The sampling procedure described is intended to generate data for entering into an accompanying computer program. Due to their detail and our inability to present the computer program and appendixes from the original publication, only a survey of the sampling procedure is presented here. Please see the original publication (Fatzinger and others 1984) if further details are required.

Four distinct types of samples are obtained:

Selecting sample trees within the orchard: Sample 42 trees per orchard, consisting of 14 sample clones with three ramets (primary sampling units) per clone.

Sampling female strobili in different portions of the crowns of sample trees: Count all clusters of first-year female strobili (secondary sampling unit) on each sample tree. Accuracy is very important and can be improved by dividing the crown of each sample tree by aspect. Timing is also important and should coincide with female flowers emerging through the bud scales. Select and tag a 10% sample of flower clusters randomly in the southeast quadrant for subsequent observations.

Making periodic observations: Periodic observations are taken three times a year (late winter, late spring, and fall) to estimate the number and conditions of female strobili. A more intensive subsample on one of the three sample ramets in each sample clone is made during periods when major losses are known to occur.

Collecting seed samples: Collect six healthy cones from the tagged clusters in the southeast-crown quadrant from each sample tree at harvest (total = 252 cones). Identify each cone by tree and cluster

number and store until they open. Some cones may need to be kiln-dried to facilitate opening. Remove all seeds and place in a paper envelope to be radiographed at a later date. Data are collected on number of seeds per cone, viability, proportion damaged, and cause of damage.

Note

A decision support system is available for evaluating different pest management strategies in slash pine, *Pinus elliottii* Engelm., seed orchards. Please refer to Fatzinger and Dixon (1986) for this information.

References

Fatzinger, C. W. 1984. Monitoring pest-caused losses of cones and seed in southern pine seed orchards. In: Yates, H. O. III., editor. Proceedings, cone and seed insects working party conference, IUFRO 1983 Athens, GA. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station; 43 p.

Fatzinger, C. W.; Dixon, W. N. 1986. User's guide for seedcalc: a decision support system for integrated pest management in slash pine seed orchards. Gen. Tech. Rep. SE-095. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station; 63 p.

WOOD- AND BARK-BORING INSECTS

Safranyik, L.; Raske, A. G. 1970. Sequential sampling plan for larvae of *Monochamus* in lodgepole pine logs. Journal of Economic Entomology 63: 1903-1906.

Objective

To develop a sequential sampling plan for classifying the severity of damage from *M. notatus* on scattered and decked lodgepole pine, *Pinus contorta* Douglas var. *latifolia* Engelmann, logs.

Abstract

The northeastern sawyer, *Monochamus notatus* (Drury), breeds primarily in dead and dying eastern white pine, *Pinus strobus* L., balsam fir, *Abies balsamea* L., and red spruce, *Picea rubens* Sarg. Young larvae feed on the inner bark, cambium, and outer sapwood, while older larvae bore deep into the heartwood. Damage results in windthrow, and degradation of sawlogs and pulpwood stored improperly.

A sequential sampling plan is presented for classifying the severity of damage by larvae of *M. notatus* to decked and scattered lodgepole pine logs. Infestation classes are based on the number of borer holes per 929 cm^2 of bark surface and classified as light, medium, or heavy infestations. Sampling is confined to the infested outer portion of the decks and to the 10 o'clock and 2 o'clock positions of individual logs (12 o'clock being the top portion directly visible to the observer).

Sampling Procedure

Before the sampling plan is used, it should be determined whether the whole deck or just the top, outer, or exposed logs are infested. There is a tendency for decks with small diameter logs to be partially infested, while decks with large logs or logs stacked loosely to be infested throughout. Only *Monochamus* larval entrance holes are counted in the sample. Sampling is conducted in September when oviposition is completed and additional fresh attacks are unlikely.

Remove one sample of bark, 15.2 by 61 cm, with the long axis parallel to the grain from each log in the deck. The sample should be selected from the 10 o'clock or 2 o'clock position (i.e., 12 o'clock position being the top of the log directly visible to the observer). Count and record the number of entrance holes, reference the sequential sampling plan (Table 1), and continue sampling until a decision is met. Infestation severity will be classified into one of three categories: light ($\leq$ 0.5/929 cm^2), medium (1.0/929 cm^2 -1.5/929 cm^2), and heavy ($\geq$ 3.0 entrance holes/929 cm^2) (Table 1).

Note

The original paper contains information regarding economic losses that is no longer applicable in today's markets.

Table 1. Sequential sampling table for classifying the severity of *Monochamus* damage to lodgepole pine logs.

No. of sample units	Cumulative no. woodborer holes			
	Light (≤)	Medium (≥)	Medium (≤)	Heavy (≥)
1	—	—	—	12
2	—	—	—	14
3	—	—	—	16
4	—	—	—	18
5	—	—	—	20
6	—	—	—	23
7	—	—	—	25
8	0	—	—	27
9	1	—	—	29
10	1	—	—	31
11	2	13	13	33
12	3	14	15	35
13	3	15	17	37
14	4	15	19	40
15	5	16	22	42
16	5	17	24	44
17	6	18	26	46
18	7	18	28	48
19	8	19	30	50
20	8	20	31	52
21	9	20	34	54
22	10	21	36	56
23	10	22	38	59
24	11	23	41	61
25	12	23	43	63
26	13	24	45	65
27	13	25	47	67
28	14	25	49	69
29	14	26	51	71
30	15	27	53	73
31	16	27	55	75
32	17	28	57	77
33	17	29	59	80
34	18	30	62	82
35	19	30	64	84
36	19	31	66	86
37	20	32	68	88
38	21	33	70	90
39	22	33	72	92
40	22	34	74	94

Continue sampling

Continue sampling

Table reprinted with permission from the Journal of Economic Entomology, January 15, 2001.

Safranyik, L.; Raske, A. G. 1970. Sequential sampling plan for larvae of *Monochamus* in lodgepole pine logs. Journal of Economic Entomology 63: 1903-1906.

Objective

To develop a sequential sampling plan for classifying the severity of damage from *M. scutellatus oregonensis* on scattered and decked lodgepole pine, *Pinus contorta* Douglas var. *latifolia* Engelmann, logs.

Abstract

The Oregon fir sawyer, *Monochamus scutellatus oregonensis* (LeConte), breeds primarily in dead and dying fir, *Abies* spp., trees. Young larvae feed on the inner bark, cambium, and outer sapwood, while older larvae bore deep into the heartwood. Damage results in windthrow, and degradation of sawlogs and pulpwood stored improperly.

A sequential sampling plan is presented for classifying the severity of damage by larvae of *M. scutellatus oregonensis* to decked and scattered lodgepole pine logs. Infestation classes are based on the number of borer holes per 929 cm^2 of bark surface and classified as light, medium, or heavy infestations. Sampling is confined to the infested outer portion of the decks and to the 10 o'clock and 2 o'clock positions of individual logs (12 o'clock being the top portion directly visible to the observer).

Sampling Procedure

Before the sampling plan is used, it should be determined whether the whole deck is infested or just the top, outer, or exposed logs. There is a tendency for decks with small diameter logs to be partially infested, while decks with large logs or logs stacked loosely being infested throughout. Only *Monochamus* larval entrance holes are counted in the sample. Sampling is conducted in September when oviposition is completed and additional fresh attacks are unlikely.

Remove one sample of bark, 15.2 by 61 cm, with the long axis parallel to the grain from each log in the deck. The sample should be selected from the 10 o'clock or 2 o'clock position (i.e., 12 o'clock position being the top of the log directly visible to the observer). Count and record the number of entrance holes, reference the sequential sampling plan (Table 1), and continue sampling until a decision is met. Infestation severity will be classified into one of three categories: light ($\leq$ 0.5/929 cm^2), medium (1.0/929 cm^2 -1.5/929 cm^2), and heavy ($\geq$ 3.0 entrance holes/929 cm^2) (Table 1; refer to p. 216).

Note

The original paper also contains information regarding economic losses that are no longer applicable in today's markets.

Dudley, C.O. 1971. A sampling design for the egg and first instar larval populations of the western pine beetle, *Dendroctonus brevicomis* (Coleoptera: Scolytidae). Canadian Entomologist 103: 1291-1313.

Objective

To develop a sampling method for the egg and larval stages of *D. brevicomis.*

Abstract

The western pine beetle, *Dendroctonus brevicomis* LeConte, is primarily a pest of ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., in the western USA. Outbreaks are associated with factors that contribute to a lack of tree vigor such as crowding, mechanical damage, pathogens, or drought. The insect is capable of killing sections, strips, or patches of the cambium without causing tree death. Severe infestations cause growth loss and extensive tree mortality.

This study was conducted in the central Sierra foothills of California in a mixed conifer cover type with a predominance of ponderosa pine. The distributions of attack, gallery lengths, eggs, and first instar larvae of an endemic population of *D. brevicomis* were described. Mean gallery length (GL) and mean larval densities (L) of mature populations are correlated significantly with mean attack density (A), and can be described by the simple linear regressions GL = 20.76 + 24.50A and L = 20.52 + 33.34A, respectively. The ratios of E/GL and L/GL are stable over a wide range of gallery length densities, and consequently egg-gallery length (E = - 2.63 + 1.64 GL) and larval-gallery length (L = - 5.59 + 1.32 GL) correlations are highly significant.

An 88-cm^2 sampling unit was satisfactory for estimating egg or first instar populations. Taking four paired samples, evenly spaced along the infested bole of each of four trees per *D. brevicomis* generation, provided a sampling precision of 85%. Increasing the number of paired samples to 10 and the number of trees sampled per generation to 9 improved the precision to 90%. If trees are sampled before oviposition is complete, then the number of trees sampled per generation should be increased by one for each level of precision (i.e., 1%).

Sampling Procedure

Cut two circular 88-cm^2 sample bark cores at 1.5 m intervals along the infested bole. Extract samples by cutting through the bark with a portable circular saw. Carefully remove the cores, label and place them in a refrigerator prior to examination.

To sample eggs, remove cores with a 2 cm thick sapwood backing attached to prevent desiccation. For most trees, collect 2 sets of egg samples 1 week apart. To sample larval gallery mines, cores are taken 6-8 weeks after the initial attack when all viable eggs have hatched. These samples are taken

adjacent to the earlier egg samples. Remove the sapwood backing and frass, and record the number of attacks, parent gallery length, and eggs and larval mines. Dissect all samples under 10 power magnification.

Egg sampling requires more effort than larval sampling to estimate density with similar precision (Table VIII). A practical sampling method should provide population estimates with the highest precision pertinent to the objective of the investigation. For example, at least 10 samples (20 cores) would be required to estimate egg populations at a precision level of 90% (Table VIII). If time and cost considerations are important, and a lower precision is acceptable (i.e., 85%), a minimum of 4-5 samples (8-10 cores) can be taken from just the lower half of the bole. Only nine samples (18 cores) would be required to estimate larval densities with a precision level of 90% (Table VIII).

Table

Table VIII. The number of sample trees needed to estimate mean density of *D. brevicomis* eggs, larvae, and gallery length per dm^2 at selected sampling intensities (N_s) and precision levels. Blodgett Research Forest, Georgetown, California 1967 (Modified from Dudley, 1971).

		N_s		
Variable	Precision (%)	4	8	20
Eggs	95	52	44	40
	90	13	11	10
	85	6	5	4-5
Larvae	95	42	38	36
	90	10-11	9-10	9
	85	5	4	4
Gallery length	95	41	37	35
	90	10	9	9
	85	4-5	4	4

Table VIII reprinted with permission from the Canadian Entomologist, January 15, 2001.

Southern Pine Beetle

Dendroctonus frontalis Zimmermann
Coleoptera: Scolytidae

Billings, R. F. 1988. Forecasting southern pine beetle infestation trends with pheromone traps. In Payne, T. L.; Saarenmaa, H., editors. Integrated control of Scolytid bark beetles: proceedings of IUFRO Working Party and International Congress of Entomology Symposium; 1988 July 4; Vancouver, BC, Canada; 295-306.

Objective

To develop an operational monitoring system for predicting the severity of regionally based *D. frontalis* infestation trends.

Abstract

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, is the most damaging bark beetle in the southeastern USA. All species of indigenous pines are susceptible to attack except longleaf pine, *Pinus palustris* Mill., presumably due to its high resin flow. Mature, over-stocked stands of loblolly, *P. taeda* L., and shortleaf, *P. echinata* Mill, pines on poorly drained sites are most susceptible to infestation. During beetle epidemics, groups of host trees are typically killed, and termed "spots" to delineate from other infestations in close proximity.

A method of forecasting infestation trends of *D. frontalis* was developed in Texas and tested in 28 locations throughout the southern USA. Multiple-funnel traps, baited with frontalin and turpentine, were deployed during the early spring to sample *D. frontalis* populations and its major clerid predator, *Thanasimus dubius* (F.). The proportions of *D. frontalis* to *T. dubius*, as well as mean numbers of *D. frontalis* trapped per day, were correlated with county- and state-wide infestation trends that occurred the same year. A risk rating system was developed by plotting the mean number of *D. frontalis* trapped per day against the mean percentage of *D. frontalis* for each location (Fig. 1). Four levels of infestation severity were suggested: low (<6.0 *D. frontalis*/trap/d); declining (trap catches averaged <40 *D. frontalis* regardless of the number per day); increasing or high (trap catches averaged >35 *D. frontalis*/trap/d with *D. frontalis* >40%); and moderate or static (6-35 *D. frontalis*/trap/day with *D. frontalis* >40%).

Severe outbreaks should be expected when early season trap catches exceed 75 *D. frontalis* per trap per day and contain 75% *D. frontalis*. A simple key was provided to forecast infestation levels from trap catch data (Table 3).

Sampling Procedure

Sample flying *D. frontalis* and *T. dubius* with multiple–funnel traps and the aggregation pheromone frontalin (Phero Tech Inc., Delta, BC). Bait each trap with two Eppendorf capsules of frontalin and a rapid-release rate (about 3.6 g/trap/d) of steam distilled turpentine (W. M. Barr Co., Memphis, TN) from loblolly pine. Dispense the turpentine in 250 ml amber bottles with an 18 cm long cotton wick (Fisher Scientific Intl., Springfield, NJ).

Place two multiple-funnel traps in each of 3 separate pine stands located greater than 3.2 km apart within the area of concern in March or April. Collect insects weekly for 4 weeks. Calculate the mean percent *D. frontalis*, (*D. frontalis* / (*D. frontalis* + *T. dubius*) x 100), and the number of *D. frontalis*/ trap/day for all traps and sampling dates within each area of concern. Refer to Table 3 to forecast infestation trends based on this data.

Figure and Table

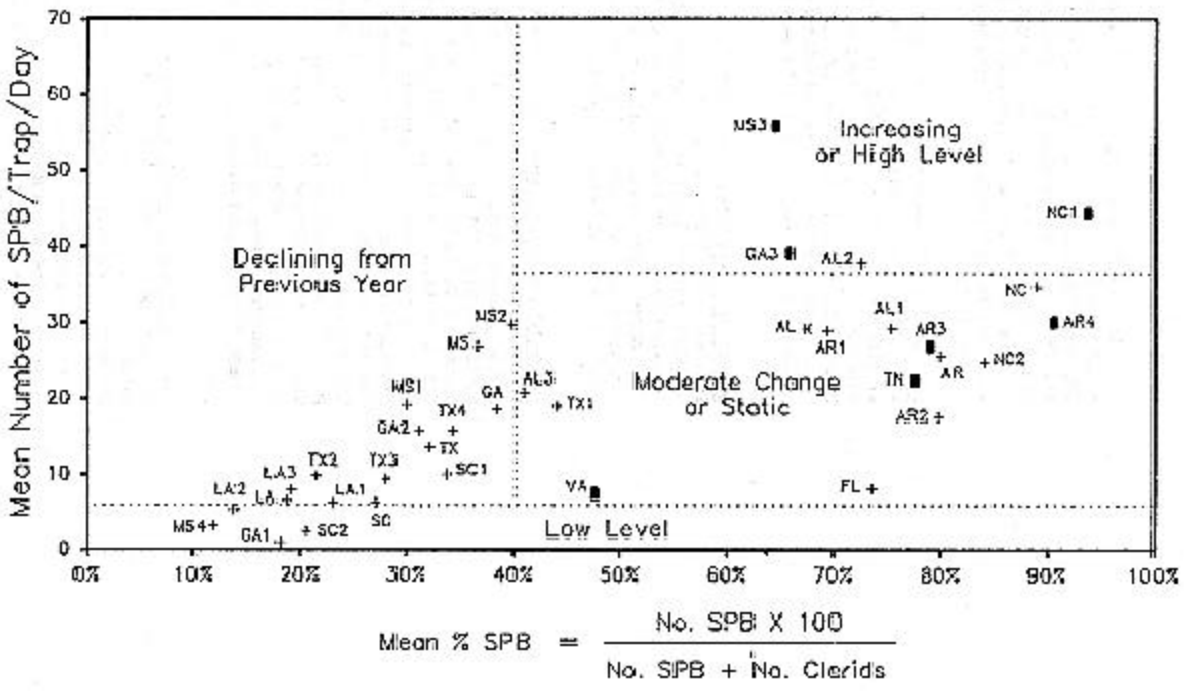

Fig. 1. Mean values of SPB/trap/day and percent SPB for 28 localities within 11 southern states derived form early season pheromone surveys in 1987. State averages are indicated by state symbols without numbers, while specific localities are according to codes given in table 2. Data points in form of (+) indicate localities in which SPB infestation levels declined in 1987; (●) indicates those with increasing SPB levels while those marked with (✱) remained static, compared to 1986.

Table 3. Guide for forecasting southern pine beetle infestation trends based on early season pheromone trap data.

Required information:	(a) Average percent SPB from spring survey, where percent SPB = $\frac{\text{total number of SPB}}{\text{total number of SPB + clerids}} \times 100$ (b) Average number of SPB/trap/day from spring survey
Optional Information:	Average number of SPB/trap/day in last year's spring survey from same general locality.

Answer the following questions to determine SPB infestation trend for the current year.

1. Is SPB/trap/day less than 6?	If yes, go to 7 If no, go to 2
2. Is percent SPB less than 40?	If yes, go to 8 If no, go to 3
3. Is percent SPB greater than 75 and number of SPB/trap/day greater than 75?	If yes to both, go to 12 If no to either, go to 4
4. Is number of SPB/trap/day greater than 35?	If yes, go to 10 If no, go to 5
5. Is number of SPB/trap/day known for the previous year from the locality?	If yes, go to 6 If no, go to 11
6. Compute ratio: $\frac{\text{\# SPB/trap/day for current year}}{\text{\# SPB/trap/day for previous year}}$	
Is the ratio less than 0.75?	If yes, go to 8
Is the ratio between 0.75 and 1.25?	If yes, go to 9
Is the ratio greater than 1.25?	If yes, go to 10
7. The SPB infestation level is predicted to be low.	
8. The SPB infestation level is predicted to decline from last year's level.	
9. The SPB infestation level is predicted to remain similar to last year.	
10. The SPB infestation level is predicted to increase from last year's level.	
11. The SPB infestation level is subject to moderate change from last year's level, but the trend (increasing or declining) is unpredictable.	
12. The SPB infestation is expected to increase to severe outbreak level.	

Figure 1 and Table 3 reprinted with permission from Virginia Polytechnic Institute and State University, Blacksburg, January 15, 2001.

Lih, M. P.; Stephen, F. M. 1987. Arkansas SPBMODEL – a computer simulation model. Protection Report R8-PR 5. Atlanta: U. S. Department of Agriculture, Forest Service, Southern Research Station; 2 p.

Objective

To provide a model useful at predicting *D. frontalis* spot growth for either research or management purposes.

Abstract

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, is the most damaging bark beetle in the southeastern USA. All species of indigenous pines are susceptible to attack except longleaf pine, *Pinus palustris* Mill., presumably due to its high resin flow. Mature, over-stocked stands of loblolly, *P. taeda* L., and shortleaf, *P. echinata* Mill, pines on poorly drained sites are most susceptible to infestation. During beetle epidemics, groups of host trees are typically killed, and termed "spots" to delineate from other infestations in close proximity.

The Arkansas SPBMODEL predicts *D. frontalis* spot growth in currently infested stands over a three month period. This model estimates the number of infested trees, the cumulative number of dead trees, and the associated timber volume and dollar losses, in loblolly and shortleaf pine stands. The model uses data collected from 70 infested stands in Arkansas, Georgia, Louisiana and Mississippi, and had a mean absolute error of 13.3% for predicting the number of dead trees over a 92-d period.

Sampling Procedure

Required inputs:

1. Spot identification (for user's future reference)
2. State in which infestation is located
3. Date ground checked
4. Desired number of days of prediction
5. Percentage of shortleaf and loblolly pines in stand
6. Mean d.b.h. of stand
7. Mean pine and hardwood basal areas (BA)
8. Number of trees currently infested with SPB
9. Number of trees previously infested with SPB
10. Data measurement units (standard or metric)

Optional inputs:

1. General d.b.h. distribution of the stand
2. Predominant SPB lifestages (attacking beetles, eggs, larvae, pupae, and brood adults) present in trees at breast height
3. Mean age of all pines
4. Average radial tree growth over the last 5 years
5. Desired temperature modification (°F)
6. Local stumpage prices for salvaged pine sawtimber and pulpwood.

The program predicts daily and weekly spot growth for the requested period of time including confidence intervals on the number of currently infested trees and cumulative number of dead trees. Options also allow the user to estimate volume and economic losses for the period of simulation based on the diameter distribution of infested trees.

Notes

The model assumes that spots will continue to grow. A personal computer (PC) version runs on any IBM-compatible computer (>286 with math coprocessor) with a minimum of 256K of memory, and MS-DOS 2.0. The model may also be accessed through the USDA Forest Service Data General computing system. Diskettes for the PC version and copies of the User's Guide are available from the USDA Forest Service, Forest Pest Management, 2500 Shreveport Hwy., Pineville, LA 71360. A newer version of this model is being developed.

Linit, M. J.; Stephen, F. M. 1978. Comparisons of methods for estimation of attacking adult populations of *Dendroctonus frontalis*. Journal of Economic Entomology 71: 732-735.

Objective

To determine the reliability of three methods used to estimate attacking densities of *D. frontalis*.

Abstract

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, is the most damaging bark beetle in the southeastern USA. All species of indigenous pines are susceptible to attack except longleaf pine, *Pinus palustris* Mill., presumably due to its high resin flow. Mature, over-stocked stands of loblolly, *P. taeda* L., and shortleaf, *P. echinata* Mill, pines on poorly drained sites are most susceptible to infestation. During beetle epidemics, groups of host trees are typically killed, and termed "spots" to delineate from other infestations in close proximity.

Attacking adult densities of *D. frontalis* in loblolly pine were estimated by three procedures: X-ray analysis (XRAY), bark dissection to locate attacking adults (ADULT-DISS), and bark dissection to locate the entry point of attacks (ATK-SITE). Estimates of mean attacking density via ADULT-DISS and ATK-SITE methods were in close agreement. Analysis of XRAY estimates by one worker resulted in consistently lower estimates than either the ATK-SITE or ADULT-DISS method. Analysis of XRAY estimates by the second worker was variable and could not be attributed to inexperience on the part of that analyst.

Each of the three methods provided reliable estimates of attacking density. The authors suggested the XRAY method would not differ from other methods if the analysts were more experience and consistent in their observations. Both the ADULT-DISS and XRAY methods required precise timing in regard to the stage of adult colonization. Samples must be taken after attacks are complete and prior to reemergence. Since all three methods yielded reliable estimates, the authors suggested the choice of which method to use should depend on the level of personnel training and their objectives.

Sampling Procedure

To collect samples, fell each tree and remove a log from the central portion of the infested bole prior to adult emergence. Cut 36 100-cm^2 circular samples, and remove them from each log with the sapwood attached to prevent beetles from falling out of the galleries prior to analysis. Store samples in a refrigerator when not being processed.

X-ray determination of attacking adults (XRAY): X-ray each bark sample immediately following removal using a Faxitron 43805® or similar X-ray system. Two workers are needed to examine the X-rays. Count and record the number of attacking adults on each sample separately.

Dissection for attacking adults (ADULT-DISS): Remove the sapwood from the bark sample with a chisel and count all *D. frontalis* adults. Remove frass and resin from egg galleries by using forceps and a stiff brush. Egg galleries are searched extensively for the presence of attacking adults as are all holes and crevices on the bark surface. Count the total number of adults and record their sex.

Attack site determination (ATK-SITE): Locate attack sites on each bark sample by using a binocular microscope and the criteria of Stephen and Taha (1976). If the criteria are met, then count the suspected attacked site and multiply by two to account for monogamous pairs.

Notes

In this study, samples were collected during mid-July from three loblolly pines 37-yr-old and 35-cm d.b.h. The sex ratio of attacking adults did not differ significantly from unity, supporting the premise that one male and one female are associated with each attack site. This assumption is necessary for the validity of the ATK-SITE method.

Reference

*Stephen, F. M.; Taha, H. A. 1976. Optimization of sampling effort for with-in tree populations of southern pine beetle and its natural enemies. Environmental Entomology 5: 1001-1007.

Stephen, F. M.; Taha, H. A. 1976. Optimization of sampling effort for within-tree populations of southern pine beetle and its natural enemies. Environmental Entomology 5: 1001-1007.

Objective

To optimize sampling effort required for estimating within-tree populations of *D. frontalis.*

Abstract

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, is the most damaging bark beetle in the southeastern USA. All species of indigenous pines are susceptible to attack except longleaf pine, *Pinus palustris* Mill., presumably due to its high resin flow. Mature, over-stocked stands of loblolly, *P. taeda* L., and shortleaf, *P. echinata* Mill, pines on poorly drained sites are most susceptible to infestation. During beetle epidemics, groups of host trees are typically killed, and termed "spots" to delineate from other infestations in close proximity.

Areas in southern Arkansas were surveyed to determine optimum sample sizes as a function of attack density, egg gallery length, and total brood size. A series of permanent 2,000-cm^2 X-ray maps were made. They depicted *D. frontalis* life stages occurring at varying heights in trees of different sizes. The map data were stored as addressable grid cell values in a computer, and programs were written for randomly selecting a series of defined experimental units. From these observations, the relationship of sample number to sample unit size was determined, and a procedure was outlined for estimating *D. frontalis* density.

Sampling Procedure

Select 10 trees in each spot in either the pupal or callow (teneral) adult stage. Cut three logs containing approximately 2,000 cm^2 of bark surface area from each tree (n=30), taking one log each from the upper, middle and lower bole. Count and record the number of pupae and callow adults.

Measure each log to determine bark area, and identify sections to be placed on X-ray film for radiography. Count the number of attacks and any brood (live larvae, pupae or callow adults). Mark their locations with colored china markers to produce a map. Identify *D. frontalis* galleries on the original bark samples, and by cross-comparison between the samples and map, draw the galleries on the map. Measure the gallery lengths. Following identification and marking, a transparent grid with 2.5 cm squares on each side is placed over the entire map and all variables and their locations are measured and recorded.

The values for each variable are stored on a computer by coordinates of each unit grid square (6.25 cm^2) on the maps. The computer program represents the map as a cylinder and then generates the random samples to be taken.

Procedure:

1. Depending on the variables to be measured, use equations in Table 2 of the original publication to calculate desired sample sizes.
2. Survey the infested area where population measurements are desired in order to estimate the number of infested spots.
3. Depending on the number of samples determined from Step 1, allocate a proportionate number to each spot depending on the number of infested trees in suitable stages of brood development.
4. Samples should be collected from a minimum of three heights, which are divided evenly along the infested portion of the tree bole.

Example: The average number of samples required to estimate attacking density was 107 100-cm^2 samples, 20 500-cm^2 samples or 10 1,000-cm^2 samples (Table 3). Assume that 100-cm^2 samples are used, there are three infested spots, and that the number of trees suitable for sampling in each spot is 10, 20 and 2. Therefore, the 107 samples would be divided according to the proportion 5:10:1 (i.e., 33, 67 and 7 samples, respectively).

Table

Table 3. Calculated number of samples needed to estimate density of the given variables within 10% of the mean for 100 cm^2, 500 cm^2, and 1,000 cm^2 sample unit areas. Number of samples needed at the lower and upper 90% confidence intervals are also given.

		No. of Samples		
Sample unit area	Variable	Lower	Average	Upper
100 cm^2	Attacks	72	107	158
	Gallery Length	11	17	25
	Total Brood	49	95	178
	Parasites	212	385	675
	Predators	429	650	971
500 cm^2	Attacks	13	20	32
	Gallery Length	4	6	9
	Total Brood	12	26	56
	Parasites	55	112	220
	Predators	104	170	276
1000 cm^2	Attacks	6	10	16
	Gallery Length	2	4	6
	Total Brood	7	15	34
	Parasites	31	66	136
	Predators	56	96	160

Stephen, F. M.; Taha, H. A. 1979. Area-wide estimation of southern pine beetle populations. Environmental Entomology 8: 850-855.

Objective

To expand existing techniques (Stephen and Taha 1976) to permit estimation of the absolute density of *D. frontalis* within a defined forest stand.

Abstract

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, is the most damaging bark beetle in the southeastern USA. All species of indigenous pines are susceptible to attack except longleaf pine, *Pinus palustris* Mill., presumably due to its high resin flow. Mature, over-stocked stands of loblolly, *P. taeda* L., and shortleaf, *P. echinata* Mill, pines on poorly drained sites are most susceptible to infestation. During beetle epidemics, groups of host trees are typically killed, and termed "spots" to delineate from other infestations in close proximity.

This study was conducted in 800 ha of over-mature pine-hardwood dominated by loblolly and shortleaf pines in Arkansas. Aerial and ground survey methods were combined with within-tree sampling procedures for the purpose of estimating absolute numbers of *D. frontalis* over a discrete forest stand containing a series of spots. Using this survey and sampling technique, a procedure for determining the total area of infested bark within the stand was developed. Trees were selected from actively infested spots and sampled intensively to obtain density estimates of *D. frontalis* stages per unit area of infested bark. On average, the following numbers of 100-cm^2 samples were sufficient to produce an estimate with 90% precision for measuring the number of attacks (107) and mature brood (95), and determining gallery length (17). The mean and variance per 100 cm^2 were calculated from all bark disks. The product of these estimates multiplied by the number of infested trees within the stand provided an estimate of the total number of *D. frontalis* for the stand.

Sampling Procedure

Aerial survey: A helicopter is used to detect *D. frontalis* spots (Thatcher and others 1982) that were subsequently ground checked.

Ground survey: Record host tree species, d.b.h., stage of beetle development at breast height, and crown color for each tree sampled in the spot. Also, determine the average height, average height of the infested portion of the bole, and pine and hardwood basal areas. If necessary, measure radial growth or tree age depending on your objectives. Flag each tree with a particular color specific to that survey trip.

The date on infested bole lengths are necessary for calculation of infested bark area. Selected trees must be climbed or felled in order to obtain this information accurately.

Population sampling: Trees are selected from actively infested spots and sampled intensively to obtain density estimates of *D. frontalis* stages per unit area of infested bark (Stephen and Taha 1976). On average, the following numbers of 100-cm^2 samples were sufficient to produce an estimate within 10% of the mean 90% of the time for measuring the number of attacks (107), mature brood (95), and determining gallery length (17).

Climb trees to minimize disturbance to the surrounding stand. Remove samples (3 per infested bole length), and process in the laboratory. Record the data for each variable and express that value per unit of infested bark area.

Mathematical model for area-wide estimation of *D. frontalis* populations: To estimate total *D. frontalis* numbers, calculate the mean and variance per 100 cm^2 from all of the bark disks collected. In addition, calculate the mean and variance of the infested bark area for each infested sample tree. The product of the means of these two estimates times the total number of infested trees in the stand provides an estimate of the total number of *D. frontalis* in the stand.

Determination of infested bark area: Procedures for estimating the average infested phloem area (bark area) of a tree are provided by Coulson and others (1976) and Foltz and others (1976).

Notes

The techniques presented here violate some statistical assumptions necessary in obtaining a completely random sample. Sample trees must be large enough to climb and the authors' selection of three sample heights per tree evenly spaced along the infested bole is not random. The techniques are standardized and reproducible, which suggests that any bias introduced into these estimates is relatively constant.

References

Coulson, R. N.; Pulley, P. E.; Foltz, J. L.; Martin, W. C. 1976. Procedural guide for quantitatively sampling within-tree populations of *Dendroctonus frontalis*. Miscellaneous Publication 1267. College Station: Texas Agricultural Experiment Station. 26 p.

Foltz, J. L.; Mayyasi, A. M.; Pulley, P. E.; Coulson, R. N.; Martin, W. C. 1976. Host tree geometric models for use in southern pine beetle population studies. Environmental Entomology 5: 714-719.

* Stephen, F. M.; Taha, H. A. 1976. Optimization of sampling effort for within-tree populations of southern pine beetle and its natural enemies. Environmental Entomology 5: 1001-1007.

* Thatcher, R. C.; Mason, G. N.; Hertel, G. D.; Searcy, J. L. 1982. Detecting and controlling the southern pine beetle. Southern Journal of Applied Forestry 6: 153-159.

Thatcher, R. C.; Mason, G. N.; Hertel, G. D.; Searcy, J. L. 1982. Detecting and controlling the southern pine beetle. Southern Journal of Applied Forestry 6: 153-159.

Objective

To summarize new and improved techniques for locating, evaluating, and treating *D. frontalis* infestations.

Abstract

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, is the most damaging bark beetle in the southeastern USA. All species of indigenous pines are susceptible to attack except longleaf pine, *Pinus palustris* Mill., presumably due to its high resin flow. Mature, over-stocked stands of loblolly, *P. taeda* L., and shortleaf, *P. echinata* Mill, pines on poorly drained sites are most susceptible to infestation. During beetle epidemics, groups of host trees are typically killed, and termed "spots" to delineate from other infestations in close proximity.

Four USDA handbooks dealing with detection, evaluation, suppression and prevention of *D. frontalis* infestations are summarized here. Topics include aerial detection and evaluation of spots (Billings and Doggett 1980), ground checking (Billings and Pace 1979), and methods for assigning control priorities. Aerial surveys are used to locate infestations. Each infestation is assigned a low, medium or high priority based on the color of infested tree foliage, the number of infested trees, and the threat to surrounding forests (Table 1). At each spot, a ground crew checks to determine if *D. frontalis* is the mortality agent. Following correct diagnosis, trees are catalogued according to the stage of beetle attack (Table 2). This information is then used to assign control priorities based on stand hazard ratings (Table 3).

Sampling Procedure

Locate *D. frontalis* infestations by conducting an aerial survey via small fixed-wing aircraft or helicopter. These areas will appear as pockets of dead or dying pines commonly referred to as spots. Spots expand in late spring and early summer as adult beetles emerge from brood trees and attack adjacent pines at the leading edge of the infestation. An expanding spot viewed from the air appears most often as a group of red- and yellow-crowned trees. Trees of different crown colors (from red to yellow) indicate the direction of spread. Most red–crowned trees no longer contain viable brood. Yellow-crowned trees have been attacked more recently and often contain brood. Freshly attacked trees at the leading edge of the spot appear green and healthy. Therefore, you cannot distinguish uninfested from fresh-attacked trees without conducting a ground check.

Spots with 10 or more red- and yellow-crowned trees are assigned ground check priorities. Assign each spot a low, medium or high priority based on the color of infested tree foliage, the number and

volume of infested trees, and the threat to surrounding forests (Table 1). Provide ground crews with a map indicating spot locations, sizes, and priorities for ground checking.

At each spot, a ground check crew determines if *D. frontalis* is the mortality agent by removal of bark sections from yellow-crowned trees and examining for the presence of *S*-shaped galleries. External symptoms such as the presence of pitch tubes on the bole, and reddish boring dust at the base of tree are also useful indicators of *D. frontalis* infestations. Following correct diagnosis, trees are catalogued according to the stage of beetle attack (Table 2).

This information is used to assign control priorities based on the proportion of stage 1 and 2 trees, stand density (basal area) and average d.b.h. (inches) (Table 3). For example, stands with stage 1 and 2 trees, high stand densities and large average diameters are assigned highest priority for control.

References

Billings, R. F; Pase, H. A. III. 1979. A field guide for ground checking southern pine beetle spots. Agric. Handb. 558. Washington, DC: U. S. Department of Agriculture, Forest Service; 19 p.

Billings, R. F.; Doggett, C. 1980. An aerial observer's guide to recognizing and reporting southern pine beetle spots. Agric. Handb. 560. Washington, DC: U. S. Department of Agriculture, Forest Service; 12 p.

Table

Table 1. Example of a table for setting southern pine beetle ground check priorities from the air, May through October. Choose the spot classification which best describes the spot. (From Agric. Handb. 560).

Priority for ground check	Spot classification
Priority 1 (high)	More yellow- than red-crowned trees. In dense natural pine stand or in area with past history of SPB outbreaks. Easy access or high salvageable volume. In plantation or other high value area.
Priority 2 (breakout)	Yellow-crowned trees in spot previously reported controlled or inactive.
Priority 3 (medium)	More red- than yellow-crowned trees. Poor access or moderate salvageable volume.
Priority 4 (low)	Few yellow-crowned trees. Infested pines surrounded by hardwoods or open land. Difficult to locate on ground because of small size or inaccessibility. In unmerchantable timber or with low salvageable volume.

Table 2. Symptoms associated with southern pine beetle-attacked trees in various stages of deterioration. (From Agric. Handb. 575).

Symptom	Stage 1 Trees with fresh SPB attacks	Stage 2 Trees with developing SPB broods	Stage 3 Vacated trees
Foliage color	Green	Green yellow trees with larvae; fade to yellow before brood emerges	Red, needles falling
Pitch tubes	Soft, white or light pink	Hardened, white	Hard, yellow, crumbles easily
Checkered beetles	Red, white, and black adults crawling on bark	Pink or red larvae ½ in long in SPB galleries	Larvae and pupae are purple; occur in pockets in the outer bark
Bark	Tight, hard to remove	Loose, peels easily	Very loose, easily removed
Color of wood surface	White, except close to new adult galleries	Light brown with blue or black sections	Dark brown to black
Exit holes	None	Few, associated with attacking adult reemergence	Numerous
Ambrosia beetle dust	None	White, localized areas around base of trees	Abundant around base of trees

Table 3. Guide to southern pine beetle spot growth and control priorities (May through October). (From Agric. Handb. 558)

Key to spot growth	Your spot's classification	Risk-rating points
A. Stage 1 trees	Absent	0
	Present	30
B. Stage 1 and 2 trees	1-10	0
	11-20	10
	21-50	20
	More than 50	40
C. Pine basal area (ft^2/ac) (or stand density) at active head or heads or spot	Less than 80 (low density)	0
	80-120 (medium density)	10
	More than 120 (high density)	20
D. Stand class by average d.b.h. (in inches)	Pulpwood (9 in or less)	0
	Sawtimber (more than 9 in)	10
	Total[1]	

[1] *If total is 70-100, control priority is high. If total is 40-60, control priority is medium. If total is 0-30, control priority is low.*

Mountain Pine Beetle

Dendroctonus ponderosae Hopkins
Coleoptera: Scolytidae

Carlson, R. W.; Cole, W. E. 1965. A technique for sampling populations of the mountain pine beetle. Res. Pap. INT-20. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 13 p.

Objective

To determine the most appropriate sample size and location for estimating *D. ponderosae* densities within a tree.

Abstract

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is the most destructive western bark beetle species in the USA and Canada. Lodgepole pine, *Pinus contorta* Dougl. ex Loud, is the primary host, although ponderosa, *Pinus ponderosa* Dougl. ex Laws., sugar, *P. lambertiana* Dougl., and western white, *Pinus monitcola* Dougl. ex D. Don, pines are also attacked. During epidemics, tree mortality is often extensive.

This study was conducted to develop suitable sampling techniques for estimating densities of *D. ponderosae* in lodgepole pine in Utah and Wyoming. The experimental design tested for variation between sample sizes, locations on the tree, and trunk diameters. Six sample units were superimposed in a nested fashion at each point sample, and included: 92.9-cm^2, 232.3-cm^2 and 464.5-cm^2 rectangular; and 92.9-cm^2 and 232.2-cm^2 circular. The 92.9-cm^2 and 232.3-cm^2 rectangular samples were recommended.

Sampling Procedure

Remove one bark sample either 92.9 or 232.2 cm^2 from the north and south aspect of the bole of an infested lodgepole pine 30.5 cm above and 30.5 cm below breast height. If more precision is required, then you should collect similar samples at all four aspects. Measure the density of successful attacks, length of egg galleries, and density of larvae, pupae or callow adults. The number of samples (trees) needed for a 20% standard error of the mean (SEM) at the 2/3 probability level was computed for each sample size and variable at breast height (Table 8). If the 92.9-cm^2 sample is used, the zone can be divided into 6 levels of 10 cm each; three above and three below breast-height producing 24 sample locations (units). If the 232.2-cm^2 sample is used, the zone can be divided into 4 levels of 15.2 cm each, producing 16 sample locations (units).

Notes

Results contained in this paper may only be applicable to areas that are bioclimatically similar. This sampling plan was developed on trees greater than 15 cm in diameter.

Table

Table 8. The number of trees required to be sampled for a 20 percent SME at 2/3 probability level based upon summed north and south bottom samples (rectangular samples only).

Density	Plot	Sample size			
		1/10 sq. ft.	¼ sq. ft.	½ sq. ft.	Proportional
Attack density	Teton	9.13	3.36	2.42	3.13
	Wassatch	7.76	4.22	3.63	3.08
Gallery density	Teton	6.40	5.71	5.56	4.67
	Wassatch	2.46	2.63	2.20	2.12
Brood density	Teton	8.19	9.93	6.16	7.56
	Wassatch	54.06	66.94	67.84	55.36

Mountain Pine Beetle

Dendroctonus ponderosae Hopkins
Coleoptera: Scolytidae

Knight, F. B. 1960. Sequential sampling of Black Hills beetle populations. Res. Note RM-48. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 8 p.

Objective

To develop a sequential plan for predicting trends in *D. ponderosae* populations.

Abstract

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is the most destructive western bark beetle species in the USA and Canada. Lodgepole pine, *Pinus contorta* Dougl. ex Loud, is the primary host, although ponderosa, *Pinus ponderosa* Dougl. ex Laws., sugar, *P. lambertiana* Dougl., and western white, *Pinus monitcola* Dougl. ex D. Don, pines are also attacked. During epidemics, tree mortality is often extensive.

A procedure for sampling *D. ponderosae* in ponderosa pine was developed to predict infestation trends using a fixed sample size. The method required counting the number of live beetles in early July in 20 15.4 by 15.4 cm bark samples removed from the tree 1.5-2.1 m above ground. One sample taken from the north and south aspect of 10 trees produced accurate estimates. The sequential sampling plan was referenced and sampling was continued until a decision was met. Infestations were classified as increasing, decreasing, or static. Accurate estimates are obtained with minimal effort using this procedure. However, in some infestations as many as 80 samples were required. If no decision was reached after 80 samples, infestations were classified as the greater of the two classes.

Sampling Procedure

Remove one 15.4 by 15.4 cm bark sample from the north and south aspect of the bole of an infested ponderosa pine 1.5 to 2.1 m above ground. After a minimum of 10 trees, reference the sequential sampling plan (Fig. 1), and continue sampling until a decision is met. If no decision is reached after 80 samples, consider the population to be the higher of the two levels. Populations are classified as: increasing (emerging beetles will kill more trees than infested currently; $\geq$9 beetles/sample), static (emerging beetles will kill a similar number of trees as infested currently; 5-8 beetles/sample), or decreasing (emerging beetles will kill less trees than infested currently; $\leq$4 beetles/sample).

Two sequential plans are available. One with a precision of 90% (Fig. 1) and the other with a lesser precision of 80% (Fig. 2). The sequential plan with lower precision may be useful in situations where a higher risk of error can be accepted.

Notes

Sampling must be done in early July before beetle flight commences. Trees are easy to find at that time because the foliage on all infested trees is discolored. Borderline cases should always be placed in the higher classifications when sampling is complete.

Figures

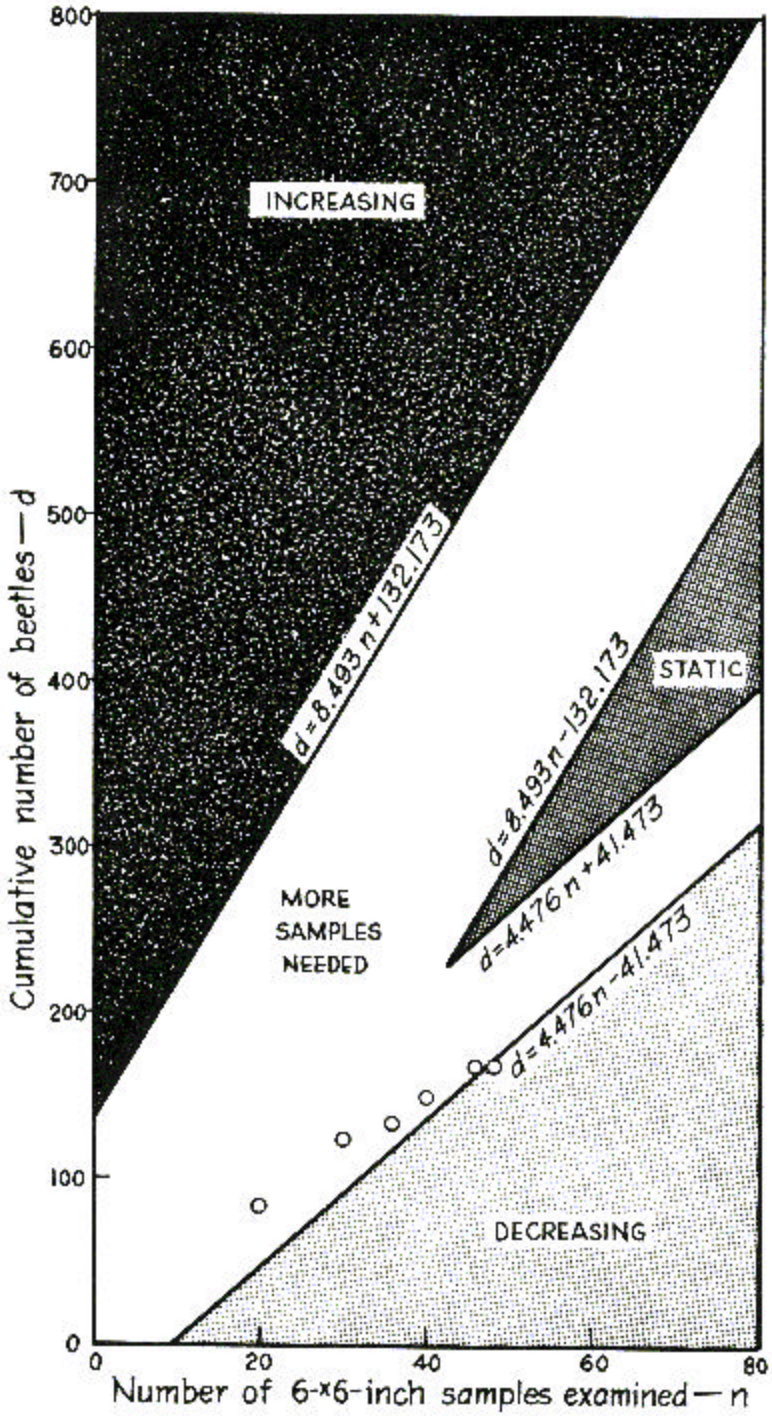

Figure 1. Sequential graph for sampling Black Hills beetle populations in 6" x 6" bark samples (90% confidence level). The small o's represent cumulative counts in a hypothetical sampling situation. The 48th sample is below the decision line for decreasing; the infestation prediction is decreasing.

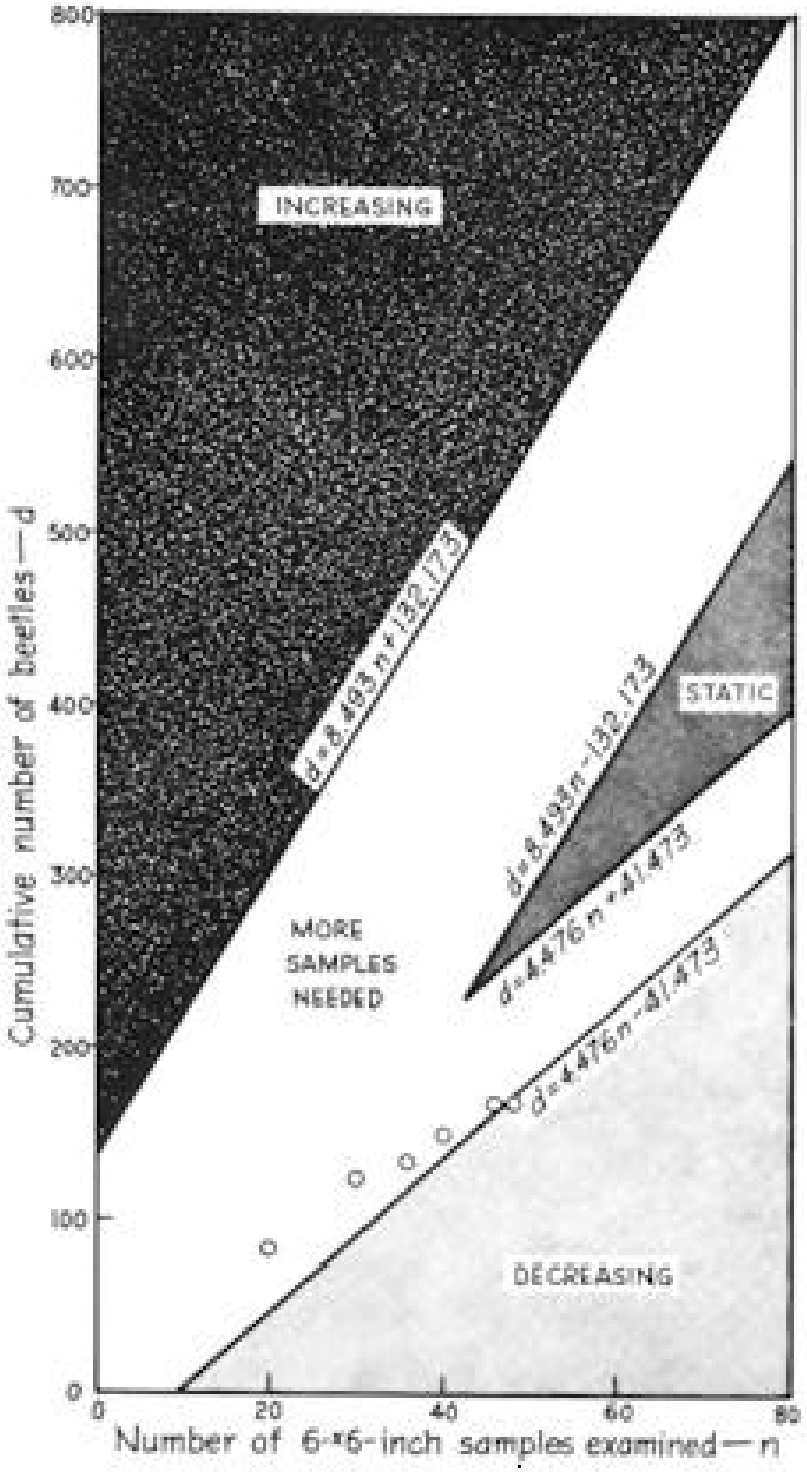

Figure 2. Sequential graph for sampling Black Hills beetle populations in 6” x 6” bark samples (80% confidence level). By the use of the same hypothetical situation as as in fig.1, the decision can be made after recording 36 sample counts.

Knight, F. B. 1960. Sequential sampling of Engelmann spruce beetle infestations in standing trees. Res. Note RM-47. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 4 p.

Objective

To develop a sequential sampling procedure for estimating *D. rufipennis* populations and deciding if control is warranted.

Abstract

The spruce beetle, *Dendroctonus rufipennis* Kirby, is the most destructive pest of Engelmann, *Picea engelmannii* Parry ex. Engelm, sitka, *Picea sitchensis* (Bong.) Carr., and white, *Picea glauca* (Moench) Voss, spruce in western North America. Typically, outbreaks have been associated with windthrow, or large accumulations of slash. Recently, a large-scale outbreak has resulted from the Routt Divide Blowdown in Colorado in 1997. Severe infestations cause growth loss and tree mortality.

A sequential sampling plan was developed to estimate *D. rufipennis* populations and classify infestation levels. An early season procedure enables resource managers to make decisions about treatment in the current year. A late season procedure provides information for predicting infestation severity the following year. A 15.2 by 15.2-cm bark sample was removed from the north and south aspect of each of 20 trees. The number of living *D. rufipennis* was counted and recorded, and the sequential sampling plan was referenced. Late season populations were predicted to increase, decrease, or remain static the following year.

Sampling Procedure

General procedures: Remove one 15.2 by 15.2-cm bark sample from the north and south aspect of each of 20 trees. Bark samples are removed from the bole 1.2-2.1 m above ground. Count and record the number of living *D. rufipennis.*

Early sample: This sequential plan will help determine if immediate control is necessary. Sample at least 20 trees, adding the number of beetles found in each sample. Reference the sequential sampling plan (Table 1), and continue sampling until a decision is met. Infestations will be classified as requiring or not requiring control. If no decision is made after 80 samples, classify the infestation as requiring control. The limits for these classes are $\leq$4 beetles per sample for decreasing populations, and $\geq$5 beetles for static or increasing populations that warrant control operations.

Late sample: This sequential plan will help predict the severity of infestations the following year. Sample at least 20 trees, reference the sequential sampling plan (Table 2), and continue sampling until a decision is met. Populations are classified as: increasing (emerging beetles will kill more trees

than infested currently; ≥4.5 beetles/sample), static (emerging beetles will kill a similar number of trees as infested currently; 2.5-3.5 beetles/sample), or decreasing (emerging beetles will kill less trees than infested currently; ≤1.5 beetles/sample).

Notes

Data are collected from standing trees and do not consider the beetles that may occur in windthrown trees, which may be a significant portion of the population. The data follow a negative binomial distribution (for calculations, see Waters 1955).

Reference

Waters, W. E. 1955. Sequential sampling in forest insect surveys. Forest Science 1: 68-79.

Tables

Table 1. Sequential sampling plan for Engelmann spruce beetle infestations in standing trees for determining treatability (June counts).

No. of samples examined	Cumulative no. of beetles		No. of samples examined	Cumulative no. of beetles	
	Not treatable	Treatable		Not treatable	Treatable
20	27	151	52	170	294
22	36	160	54	179	303
24	45	169	56	188	312
26	54	178	58	197	321
28	63	187	60	205	330
30	71	196	62	214	339
32	80	205	64	223	348
34	89	214	66	232	357
36	98	223	68	241	366
38	107	232	70	250	374
40	116	241	72	259	383
42	125	250	74	268	392
44	134	259	76	277	401
46	143	268	78	286	410
48	152	277	80	294	419
50	161	285			

Table 2. Sequential sample plan for Engelmann spruce beetle infestations in standing trees for predicting infestation trend (August-September counts).

Number of samples examined	Cumulative number of beetles		
	Decreasing	Static	Increasing
20	22	---	137
22	26	---	145
24	30	---	153
26	34	---	161
28	38	---	169
30	42	---	177
32	46	---	185
34	50	---	193
36	54	---	201
38	58	89-91	209
40	61	93-99	217
42	65	97-107	225
44	69	101-115	233
46	73	105-123	241
48	77	109-131	249
50	80	112-139	256
52	84	116-147	264
54	88	120-155	272
56	92	124-163	280
58	96	128-171	288
60	99	132-179	296
62	103	136-187	304
64	107	140-195	312
66	111	144-203	320
68	115	148-211	328
70	119	151-219	335
72	123	155-227	343
74	127	159-235	351
76	131	163-243	359
78	135	167-251	367
80	138	170-258	375

Fir Engraver

Scolytus ventralis LeConte
Coleoptera: Scolytidae

Berryman, A. A. 1968. Development of sampling techniques and life tables for the fir engraver, *Scolytus ventralis* (Coleoptera: Scolytidae). Canadian Entomologist 100: 1138-1147.

Objective

To develop sampling methods for a detailed, scientific study of *S. ventralis* inhabiting individual trees; and to describe methods for detecting *S. ventralis* populations occupying large areas.

Abstract

The fir engraver, *Scolytus ventralis* LeConte, is an important pest of true firs, *Abies* spp., in western North America. Outbreaks are associated with stressed trees caused by drought, windthrow, or competition in combination with favorable weather conditions for insect development. *Scolytus ventralis* is capable of killing sections, strips or patches of cambium and phloem without causing tree death. Severe infestations cause growth loss and tree mortality.

A method was presented for sampling and constructing life tables for *S. ventralis* inhabiting individual trees. A bark area of 464.5 cm^2 was determined to be an effective sample unit. The collection of two sample units from two vertical strata along the infested portion of the bole reduced within-tree variation. Trees were felled, and samples taken serially throughout the year. A sampling design was presented for increasing the precision of life tables, and for determining optimal sample sizes.

Sampling Procedure

The optimum sample unit was determined from the number of attacks on the tree bole according to Berryman (1968). Fell each sample tree. Cut a 30.5 cm long bolt from the infested portion of the tree at two strata. In the laboratory, remove a 464.5-cm^2 vertical strip of bark from the bolt, and count and record the number of attacks, total gallery length, eggs, larvae (by instar), pupae and adults. Larval instars are identified by their size, and their distance from the parent gallery (Ashraf 1968).

Serial sampling involves the removal of a set of samples from a single tree at several points during development of *S. ventralis*. Sample once every three weeks during active periods (summer and spring) and once during the overwintering period. It is estimated that 10 sample sets would be required during the one year life cycle of *S. ventralis.* For each subsequent sample, cut 15 cm above or below the previous sample. Refer to Fig. 3 to determine the number of samples required to estimate *S. ventralis* density with known precision.

Note

This paper includes detailed descriptions on estimating survivability of different life stages of *S. ventralis*.

Reference

Ashraf, M. 1968. Biological studies of *Scolytus ventralis* LeConte (Coleoptera: Scolytidae) with particular reference to the nematode parasite, *Sulphuretylenchus elongatus* (Massey). Pullman: Washington State University; Ph.D. dissertation. 81 p.

Berryman, A. A. 1968. Distributions of *Scolytus ventralis* attacks, emergence, and parasites in grand fir. Canadian Entomologist 100: 57-68.

Figure

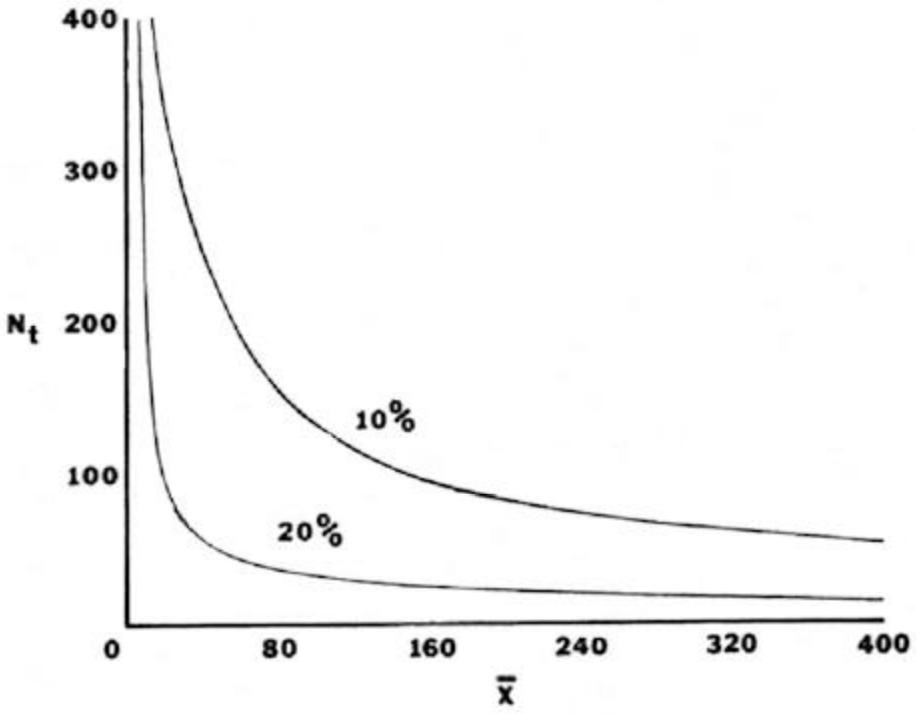

Fig. 3. The number of trees (N) required to estimate the mean density of *S. ventralis* at two levels of precision (SE = 10% and 20% of mean) and at various mean densities per mean square foot.

Figure 3 reprinted with permission from the Canadian Entomologist, January 15, 2001.

Striped Ambrosia Beetle

Trypodendron lineatum (Olivier)
Coleoptera: Scolytidae

Lindgren, B. S.; Borden, J. H. 1983. Survey and mass trapping of ambrosia beetles (Coleoptera: Scolytidae) in timber processing areas on Vancouver Island. Canadian Journal of Forest Research 13: 481-493.

Objectives

To develop a method of sampling and estimating overwintering populations of *T. lineatum*; to determine the spatial and temporal distribution of *T. lineatum* using pheromone-baited traps; and to determine the prevalence of *T. lineatum* that has been imported onto the site via infested host material.

Abstract

The striped ambrosia beetle, *Trypodendron lineatum* (Olivier), is a serious pest in timber yards of the Pacific Northwest. Losses result from degradation of lumber and plywood veneer, which are attacked on dryland log sorts. The distribution and population density of overwintering *T. lineatum* were determined by sampling beetles in the duff at four dryland log sorts in British Columbia, Canada. Significantly fewer beetles overwintered at the base of trees directly facing the sort than in any other quadrant (Fig. 1). Therefore, samples should be collected on the far side of the tree relative to the sort.

The temporal and spatial distributions of flying *T. lineatum* were determined by catches in pheromone-baited traps. The heavy flight of *T. lineatum* in May and early June accounted for 79% of the total trap catch. At one dryland sort, the data from duff sampling and trapping were used to establish optimal trap placement for the subsequent year, and trapping effort was expanded into a mass trapping program. A reduction in damage as a result of removing *T. lineatum* was not evident.

Sampling Procedure

Overwintering samples: Collect duff samples of 20 by 20 cm and 2-4 cm deep from at least 10 points 15-20 m inside the forest margin. At each sample point, take a sample from the base of each designated tree in quadrant 3, which is always placed directly away from the sort (Fig. 1). Return samples to the lab and place them in 2 L milk cartons with an emergence jar attached. Collect and record the number of emergent beetles by sex for the first week, and every other day during the second week.

Estimating overwintering populations of *T. lineatum:* Factors influencing the distribution of overwintering *T. lineatum* have been investigated thoroughly (Dyer and Kinghorn 1961). Based on data from that study, an equation for estimating the total population (*N*) of overwintering beetles was derived (see Fig. 1). To estimate the total overwintering area (*TOA*), three beetle densities from transect samples (*DT*) are calculated by dividing the total number of beetles by sample area. *DT*s were then compared with the mean density of overwintering beetles from the permanent overwintering samples (*DP*) from that year, and the equation that yielded a value of *DT* closest to *DP*, but still smaller, was chosen. The 60 m distance used to calculate *TOA* was the maximum included in the total sample area for that equation.

All duff samples are taken as close to trees as possible, and the mean number of beetles per square meter at each sort is considered the maximum density (*X*) at that sort. A high (*Nh*) and low (*Nl*) estimate is made by varying the area (*A*) within which the population density was *X*. For *Nh*, it is assumed that the density *X* extended to 0.9 m (i.e., where highest densities are encountered) from each tree within *TOA* and for *Nl* to 0.45 m. To calculate the actual *A*, the mean basal area (*BA*) multiplied by the total number of stems (*S*) within *TOA* is deducted from the area of *S* circles with the radius 1 m + mean radius of the trees for *Ah* and 0.5 m + mean radius of trees for *Al*. The total number of beetles within *A* is then (*Al* x *X*) for *Nl* and (*Ah* x *X*) for *Nh*.

The density of *T. lineatum* in overwintering bark was about 60% of the density in the adjacent duff, and therefore density was $Y = 0.6X$. The mean area of 1 m of stem is calculated, and multiplied by *S* for the total stem area (*SA*) with beetle density *Y*. The total number of beetles overwintering in bark is then calculated as (*SA* x *Y*).

No direct information is available on the relative density of *T. lineatum* in duff greater than 0.9 m from trees. It is assumed that the density of overwintering beetles in the area *Oal* or *Oah*, outside the perimeter of *Al* and *Ah*, is ($Z = 0.15\ X$). *Oal* and *Oah* are calculated by deducting the area of *S* circles with the radius 0.5 m + mean radius of trees and 1 m + mean radius of trees, respectively, from *TOA*. The total number of beetles within *Oal* is calculated as (*Oal* x *Z*) and within *Oah* as (*Oah* x *Z*). To obtain a low (*Nl*) and high estimate (*Nh*) of the population use the following equations:

$$Nl = (Al \times X) + (SA \times Y) + (OAl \times Z)$$
$$Nh = (Ah \times X) + (SA \times Y) + (OAh \times Z)$$

Survey for temporal and spatial distribution: Setup 12 cylindrical sticky traps (Browne 1978) around the margin of dryland ports at each of four locations from early spring through fall. Bait one trap with lineatin, one with (±) – sulcatol, and one with *s*-(*x*)-sulcatol. The latter two are also baited with ethanol and a-pinene (Lindgren and others 1982). Placing traps near or inside stands of red alder, *Alnus rubra* (Bong.), reduces the number destroyed by bears, *Ursus americanus* Pallas, but also decreases trap efficiency. Placement should depend on the level of bear interference. Check traps weekly and replace baits as needed. Count and record the number of *T. lineatum*.

Log sampling: Sample incoming logs regularly as they are placed on log decks. Cut a 20 by 20 cm area of bark out with a chainsaw, remove with a chisel, and count and record the number of *T. lineatum* attacks. Sampled logs should be marked and resampled at the sawmill. Managers can use this information to define problem areas in the forest or improperly handled logs in order to take appropriate control measures.

Note

Overwintering estimates were less reliable in areas with ill-defined forest margins. These methods have largely been replaced by the use of multiple-funnel traps which are much less labor intensive to use.

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Figure

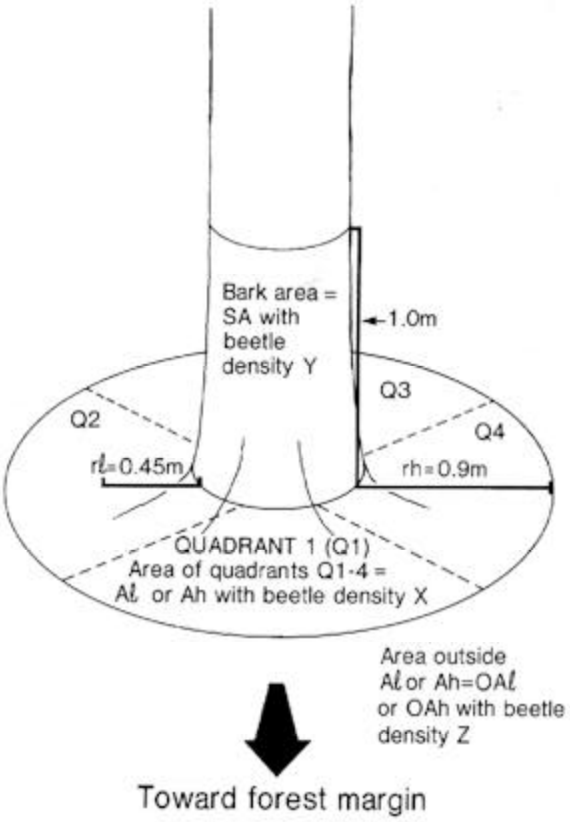

Fig. 1. Diagram illustrating areas used for estimating overwintering populations of *T. lineatum* at four dryland sorts on Vancouver Island. See text for explanation of symbols.

Figure 1 reprinted with permission from the Canadian Journal of Forest Research, January 15, 2001.

GLOSSARY

basal area (BA)	The cross-sectional area of a tree at 1.37 m above ground level; usually accumulated on a per acre basis for all trees and used as an indicator of stand density.
BAF	Basal area factor; dependent on the sighting angle arbitrarily selected for a prism used in point sampling; e.g., in the eastern United States a sighting angle of 104.18 min or BAF 10 is commonly used. Any tree tallied within the plot represents 10 ft^2 of basal area per acre.
codominant	A tree with crown forming part of the general canopy level; receiving full sunlight from above and little from the sides.
d.b.h.	Diameter at breast height; the diameter of a tree at 1.37 m above ground level on the uphill side.
dominant	A tree with crown extending above the general canopy level formed by codominants; receiving full sunlight from above and partly from the sides.
frass	Solid larval excrement exuded from the anus.
fundatrix (pl., fundatrices)	In aphids, the wingless, parthenogenetic female that emerges in spring from overwintering eggs.
gallicola (pl., gallicolae)	Gall-forming stages (insects).
instar	The period or stage between molts during the larval stage; usually numbered to designate the various periods (typically five or six); e.g., the first instar occurs between egg hatch (eclosion) and the first molt.
integrated pest management (IPM) programs	The use of multiple techniques that are effective, economically-viable, and ecologically compatible for maintaining populations below a certain threshold.
intermediate	A tree with crown extending into the general canopy level; receiving little direct sunlight from above and none from the side.
oviposition	The act of laying eggs.

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