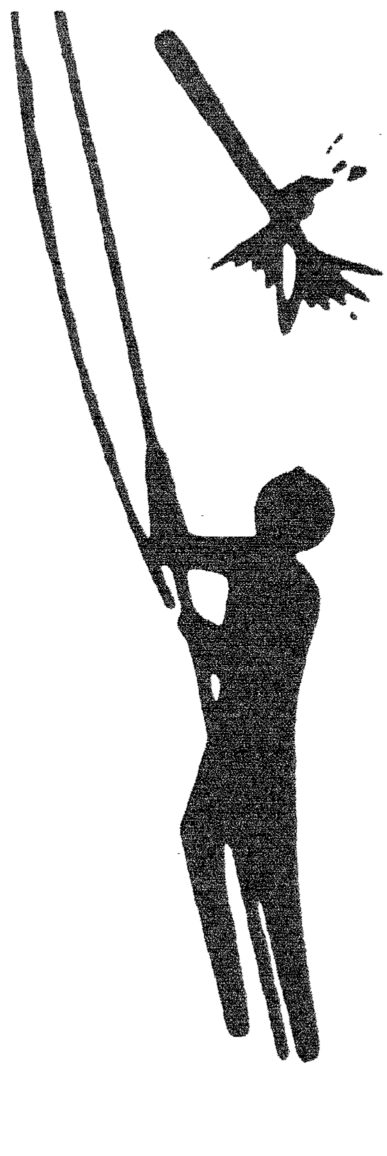
canusa
Canada
United States
Spruce Budworms
Program

Prepared by
United States
Department of
Agriculture
Forest Service
Northeastern
Station

General
Technical
Report NE-88
1984

Proceedings:

New and Improved Techniques for Monitoring and Evaluating Spruce Budworm Populations



PREFACE

The Canada/United States Spruce Budworms R&D Program (CANUSA) was created in 1977, when the United States Department of Agriculture and the Canadian Department of the Environment agreed to cooperate in an expanded and accelerated research and development effort. CANUSA was aimed specifically at the spruce budworm in the east and western spruce budworm in the west. The broad objective was to design and evaluate strategies for not only controlling budworms but also managing budworm infested forests, to help forest managers attain their objectives in an economically and environmentally acceptable manner.

Population monitoring and evaluation are basic to all insect pest control operations. These activities are routinely carried out by all agencies and departments concerned with forest protection. Furthermore, it is considered essential that, if "integrated pest management" techniques are ever to be fully and successfully applied to the protection of eastern spruce-fir forests, a more efficient method of monitoring low-level, between-outbreaks, populations of spruce budworm must be implemented. Endemic populations which are entering the outbreak phase must be recognized early, so that forest managers have more time to plan an appropriate course of action and make decisions to lessen the impacts of the impending outbreak.

Most forest insect pest survey techniques were developed more than 20 years ago, but there have been some important improvements in these methods during the last few years (the current outbreak). Techniques, such as monitoring spruce budworm populations with sex pheromone traps, have been developed in the last 5 years and have received considerable attention during the CANUSA program. Others, such as the L_2 survey procedures, are constantly undergoing modification and improvement as user experience suggests a better way.

The objective for this workshop was to present, for the benefit of all eastern forest pest control personnel and forest managers, the new or improved methods available for monitoring and evaluating spruce budworm populations. It also provided a forum for discussing ways of using that information to prepare for future outbreaks or mitigate the impacts of outbreaks as they occur. This was one of a series of workshops and symposia organized as part of the technology transfer effort of the CANUSA Program. We hope the information contained in the following papers will be of interest and use to forest protection people and forest managers everywhere.

DAVID G. GRIMBLE
DANIEL R. KUCERA
Co-chairmen and Workshop Coordinators

PROCEEDINGS

NEW AND IMPROVED TECHNIQUES FOR MONITORING AND EVALUATING SPRUCE BUDWORM POPULATIONS

Sponsored By

Vermont Department of Forests, Parks and Recreation

USDA Forest Service, State and Private Forestry

CANADA/United States Spruce Budworms R&D Program

September 13-15, 1983

Holiday Inn, Burlington, VT

February 1984

PROGRAM

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E. Bradford Walker, Director of Forests, Vermont

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W. Lloyd Sippell, Canadian Forestry Service, Sault Ste. Marie

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[1] No written paper submitted.

NEW AND IMPROVED TECHNIQUES FOR MONITORING AND EVALUATING SPRUCE BUDWORMS

Frank E. Webb

Forest Protection Ltd., P.O. Box 1030, Fredericton, N.B. Canada E3B 5C3

Because the spruce budworm is such an important forest problem in Canada, monitoring its outbreak behavior, forecasting and evaluating its impact, and probing the biological dynamics underlying its relationship with its hosts have been a preoccupation of Canadian forest entomology for half a century. Indeed the development of the federal forest entomological establishment in Canada owes its history in large part to this single insect.

The sequence of this development went like this. Studies of eastern outbreaks early in the present century by a few gifted observers made it clear to them that a recurrence of this extraordinary phenomenon only awaited the natural replacement of vulnerable host forests three or four decades down the road. They postulated that as the utilization practices of the day tended to encourage the succession of even more fir, the key problem species, the prospects were of major importance to the then-burgeoning wood-fibre industry. This advice provided convincing support for the establishment of the Canada-wide Forest Insect Survey in 1936 and a forest entomological research establishment of the late 1940s and 1950s that may never be surpassed in its strength and dedication to the fundamentals of forest insect population dynamics and to mitigating pest problems through natural control factors and applying biological controls. The work of this establishment found expression in a number of notable efforts - intensive field studies of the budworm's biology and impact in northwestern Ontario and Quebec, of its population dynamics by the Green River Project in New Brunswick and the establishment of the Insect Pathology Laboratory at Sault Ste. Marie. Outbreaks of the 1940s in Ontario and Quebec also encouraged cooperative trials with US Department of Agriculture of the first practical forest insecticide, DDT, and led to the establishment of the Chemical Control Research Institute in the 1950s, later to be amalgamated with the Insect Pathology Research Laboratory as the present Forest Pest Management Institute.

Thus spruce budworm monitoring and evaluation techniques originate from three basic needs in Canada: (1) those of the national Forest Insect Survey for very extensive annual surveys of population levels, natural controls and damage; (2) those of fundamental investigation of the budworm's biology, population dynamics and interaction with its hosts; and (3) to service the needs of insecticidal control projects.

Methodology for very extensive surveys is in many ways the least demanding. The product has important broad scale inter-provincial application and is basic to research of long-term outbreak and damage history. Much of prsent methodology still dates from the earliest survey days - observation reports, beating sheets, 45 cm branch tips, binocular examination of defoliation in tree crowns, aerial sketch mapping etc. Recent emphasis has been placed on evaluating impact, so far without particularly notable results. Except in Quebec, which provides this information to the national survey, this is almost entirely a federal responsibility of the Canadian Forestry Service with various degrees of field assistance provided by the provinces and industry.

The second need was the second to arise - that of intensive, fundamental field research usually at pin-point locations. It is exemplified best, perhaps, by the life-table methodologies developed by Morris and his colleagues of the Green River Project in New Brunswick in their analysis of the population dynamics of the insect and of its interaction with its hosts and environment. This narrower focus lends itself more readily to the development of scientifically verifiable data and statistical manipulation, but is time-consuming and expensive. For practical purposes it is a need primarily of fundamental research and therefore primarily of the CFS.

The third and most pressing recent need is that of the forest manager and the applied protection practitioner and lies between the first two in its demands for geographic coverage and statistical exactitude. It also features a number of other characteristics. It demands the ultimate in prompt reporting. In New Brunswick it has provided the driving component of the predictive simulations of budworm/forest/imposed protection interactions and budworm management modelling. It involves varying degrees of provincial self-reliance in carrying out the surveys depending upon their intensity and the importance of the problem in the separate provinces. Quebec's self reliance is virtually complete while New Brunswick's and Newfoundland's are largely so. In the remaining provinces, where the scale of applied protection remains relatively low, and the size of the job remains within the CFS capability, reliance has continued to be placed principally on federally-conducted surveys.

Methodologies for this third purpose lie somewhere between the first two in their scientific sophistication and amenability to statistical treatment. A major boost was provided to their development 30 years ago by Morris and Waters who almost simultaneously demonstrated the adaptability of sequential sampling for such middle-scale assessment needs. This method of anticipating defoliation from egg counts was combined with weighted assessments of three parameters of existing tree condition obtained by ocular estimation to develop the Webb et al hazard index introduced in New Brunswick in 1955. Surprisingly this model and its weighting remain, with mostly minor variations, the state of the art in forecasting hazard for planning protection throughout the Atlantic Provinces and Maine. Borrowed briefly in Quebec it was supplanted some years ago by one considered to be more sensitive to protection strategies and tactics there. The validity of the New Brunswick model, particularly in terms of measuring the ability of present-day trees and stands to withstand further stress is increasingly coming under overdue examination in New Brunswick and elsewhere. The washing technique and L_2 larval sampling techniques pioneered by Miller and Kettela in the early 1970s are believed to provide more sensitive forecasts of damage and have become a regular adjunct to conventional egg counting methods. Various attempts have been made to improve the sophistication of aerial surveys but these will probably remain essentially primitive in nature until remote sensing technology advances sufficiently to replace direct ocular estimation.

As I stand back and look at this history and the state of affairs in the windup years of CANUSA I am left with certain convictions, two or three of which I offer here.

First and foremost I find it difficult to recognize that the development of methodologies for monitoring and evaluating the budworm and the budworm problem over the past quarter century in Canada has been in any way commensurate with the need. Even allowing for what are termed "new and improved techniques" at this workshop, and the increasing swing of very recent years toward recognizing the problem as more of a forest management one than an entomological one, surveyors and assessors really have very little more or better methodology at their disposal then they did that long ago. Even with the equity that I have in some of that old stuff I cannot regard that as a satisfactory record.

There is a relationship, I suspect, between this and my second conviction. It is that on the Canadian side certainly, the CANUSA concept of a "user" community is confusing if not confused. For if one tracks the methodology "user" to his lair in most of Canada it usually turns out that he is from the very agency expected to develop that methodology; in short in more cases than not the CFS is playing the role of both developer and surrogate user. Except in Quebec, the design of by far most surveys and assessments for budworm management in Canada is left by forest managers to CFS advisors, the former often being only vaguely interested in the systems employed on their behalf.

This is not a criticism of the CFS. It is simply a statement of a situation that exists, and a partial explanation of my belief that there is really not much of a Canadian audience out there just now for the sort of Users' Manuals that CANUSA seems to have had in mind, unless it is to facilitate technology transfer within the federal establishment itself. Neither are my remarks intended to discourage state of the art and accomplishment reporting by CANUSA, but rather to discourage a misconceived approach to it. If I do have any criticism it is that the forest management agencies, i.e. the provinces, excepting Quebec, and the forest industry in Canada have shown too little interest in managing their budworm surveys and assessments themselves, of being too willing to accept a surrogate. Until this changes, it does not seem to me to be possible for them to demonstrate that they have their management responsibilities firmly in hand and that the accountability they have for that management can be properly provided.

Finally, if you will accept my argument that to a large extent the CFS is not only the principal producer of methodology in Canada but the main "user" as well, it might be appropriate to examine the effectiveness of producer/user interaction in that arena. To what extent, e.g. does the Forest Insect and Disease Survey get assistance in the development of better methodology from the more fundamental budworm research community? Evidently not a great deal in the past 30 years. The Green River project invented the branch surface-area unit for egg population expression, and a prototype egg-sampling table, but a CFS user-surrogate (in the person of myself in the 1950s) translated these into the subsequently-used tables and coupled this with tree condition to produce the long-lived empiricalhazard model referred to already. In fact, in New Brunswick almost every piece of monitoring and evaluating methodology that has stood the test of time for planning and evaluating spraying programs has originated from CFS user-surrogates. In recent years Forest Protection Limited and the New Brunswick Department of Natural Resources have begun to follow Quebec in developing methodologies for their special needs, notably computerized mapping of egg, hazard and vulnerability data.

In summing up I do not expect much argument that present methodologies are weak and short on definable statistical integrity. The concept of a producer/user breakdown for methodology use, as may be appropriate in the US, is at present largely illusory in the Canadian context, due in large part to insufficient assumption of the "user" role by the real resource managers except through a surrogate system. Finally, the institutional compartmentalization of the federal research/advisory service may be standing in the way of a sharp focus on methodological development for any of the three broad needs that I have identified. CANUSA might have stood a better chance of optimizing its effectiveness on the Canadian side had these realities come into clearer focus earlier.

For the sake of argument.

INTRODUCTION TO WORKSHOP ON "NEW AND IMPROVED TECHNIQUES FOR MONITORING AND EVALUATING SPRUCE BUDWORMS"

E. Bradford Walker

Director of Forests, Department of Forests, Parks and Recreation, Agency of Environmental Conservation, State Office Building, Montpelier, Vermont 05602

It is of considerable personal pleasure for me to have the Vermont Division of Forests cosponsor this workshop for the exchange of information on budworms, for I served on the CANUSA Joint Planning Unit for several of the early years of the program. I was, and remain, a vociferous (if not objectionable) proponent of making technology transfer a final integral phase of the CANUSA program.

Being a new home for the budworm, Vermont is the new kid on the block, so has a lot to learn about the idiosyncracies of the beastie. By the same token, however, we have the advantage of learning from the experience of other budworm battle veterans. Fortunately, much public interest in the spruce budworm problem has developed in northeastern Vermont on the part of private forest landowners, pulp cutters, consulting foresters, town officials, and legislators in the infested areas. Opposition to the use of chemical insecticides presents a difficult climate for carrying out direct control with anything but B.t., but this has proved helpful in gaining considerable support for a silvicultural approach to control through integrated pest management techniques. The last State Legislature appropriated (during hard economic times) special funds to initiate an integrated budworm management demonstration program supported by cooperative U.S. Forest Service funding. All we have to do now is make the budworm read our book and be manageable.

Either way, all of the subjects on the agenda of this workshop are especially timely for us here in Vermont because the sampling schemes are tailored to our needs in facing a new fast-developing epidemic evolving from a long-standing, historically endemic situation. Incidentally, any of you researchers who have money and will travel, Vermont presents an ideal opportunity to study the insect in the initial stages of problem development.

Indeed, not only we in Vermont, but all who battle the budworm, can benefit from new and improved techniques for monitoring and evaluating spruce budworms on an ongoing basis, not simply to prepare for future outbreaks, but to better understand and manage budworm populations on an integrated pest management basis. Forest managers need to gain "a working knowledge of natural numerical regulation . . . and particularly the identification of existing limiting density factors." With such knowledge, "treatments should no longer be applied blindly according to type procedures inherited from the past or other disciplines but be made to conform objectively with the forest ecosystem, local circumstances, and the future. Suppression of intolerable populations (whatever the criterion) is the ultimate consequence of comprehensive husbandry based on sound ecological fact and theory. The integrated control concept is the embodiment of this philosophy." I wish I could take credit for these thoughts, but Geier and Clark beat me to it back in 1960 in "An Ecological Approach to Pest Control"; and Ron Stark reiterated them at the Third Annual Northeastern Forest Insect Work Conference in 1970. Stark summarized his paper on "Integrated Control, Pest Management, or Protective Population Management?" by saying: "Although great creative effort will be necessary, [this approach] should prove to be less costly, invoke less social and ecological repercussions, and be of more lasting benefit than the continued use of present-day methods which ignore the ecological realities of pest regulation."

Ron concluded his talk with
"Let us take heed!"

With this workshop, it appears we are on track. Continuing low-, medium-, and high-level monitoring on an ongoing basis using new and improved techniques, should provide the basic information needed to formulate and conduct a long-overdue, truly integrated, pest management program for spruce budworms--
and, at long last, we are indeed taking heed.

WHY SHOULD WE MONITOR SPRUCE BUDWORM POPULATION TRENDS?

Robert P. Ford

Entomologist, USDA Forest Service, Northeastern Area State and Private Forestry, 1992 Folwell Avenue, St. Paul, MN 55108

The three reasons why we should monitor spruce budworm population trends are to 1) provide information for further research, 2) manage spruce budworm, and 3) record historical data.

There are three basic reasons why we should monitor spruce budworm population trends. They are: to provide information for further research, to manage the biological and economic values of the fir-spruce resource, and to record budworm related history.

Research scientists use information to solve problems. Tools, references, and equipment that they employ to gather such information are an essential part of research. At this workshop we will be discussing some of the tools used in monitoring spruce budworm population trends. Research scientists may use the information to solve a number of problems and answer several questions posed by pest managers. As budworm population levels rise, can we expect insect behavior to change? Will dispersal patterns, feeding behavior, or mating vary with population levels? If so, how, and what are the implications for budworm management?

If we monitor spruce budworm population trends, we can learn something about population trends of associated plants and animals. For example, research investigations into budworm parasites and preditors, insects feeding concurrently with budworm, and seed production depend upon information about budworm population trends and numbers.

Budworm population trend data are also needed for researching correlation of weather impacts on spruce budworms and host trees. Short term trends between life stages and long term trends between outbreaks are of value in addition to trends from year to year.

Monitoring of spruce budworm population trends is essential to the economic aspect of pest management. Decisions on what action to take, if any, are based primarily on budworm population levels expected in the near future. Being able to predict budworm population levels could save us considerable time and expense, but we need to know trends.

When spray operations are conducted to suppress damaging budworm populations, we need to know project efficacy. This knowledge applies to the current year and to the several years following an operation. Phermone traps may be able to better evaluate spray project results in the future.

Many people, dollars, and pieces of equipment need to be sent to the right place at the right time if we are to economically manage budworm. If we monitor the trend of budworm populations at all levels of infestation, pest managers can allocate resources for maximum benefit.

The proper timing of treatments depends upon knowledge of budworm population levels. The earlier in an outbreak we can suppress a population, the less costly control will be in the long run. By knowing the trend of a population, we will know when to act. Stable, extremely low populations have a way of rapidly building to destructive levels. Relying on aerial surveys to detect defoliation by budworm puts us at least one year behind in planning and suppression.

Changes in budworm populations may indicate that a different kind of sampling unit, a different life stage, or other adjustments in our management surveys should be used. Economics, time-frames, available assistance, or type of facilities may all be involved in deciding which sampling units and techniques we use.

Trend data collected during an outbreak may help pest managers predict a crash or collapse of a budworm population. Once the event occurs, follow-up monitoring would be needed to locate relic budworm populations that provide spawn for future outbreaks. These small relics would be relatively inexpensive to eradicate. Budworm populations have different trends in our numerous small stands in the Lake States. Therefore, monitoring is needed to delineate the areas of immediate concern and those where further work can be delayed.

A third reason for monitoring spruce budworm population trends is to provide a historical record. Short term trends of several populations could be used to predict region-wide trends. The prediction in turn could aid forest managers and others in formulating forest plans.

Trend data over the years can be used to advise political leaders of impending budworm problems. History of budworm outbreaks and reliable predictions lead to better political handling of the budworm problem. Budworm outbreaks are just one of many factors in the conduct of political operations and trend data can put the budworm situation in perspective.

Investigators in biological sciences need to know the history of budworm population changes so they can study other life forms associated with the spruce-fir type. We can save considerable amounts of time and money in the public sector by having trend data available for use by others.

The uses of budworm trend data are many. New uses are still to be found. New tools and methods will help us standardize our units of measure and make reliable trend predictions. Why should we monitor spruce budworm population trends?--so that forest managers, pest managers, researchers and political leaders have the best information on which to make decisions.

STANDARDIZATION OF MONITORING AND EVALUATION TECHNIQUES: WHY?

Louis Dorais

Quebec Department of Energy and Resources, 175 Rue St-Jean, Quebec, Quebec, Canada G1R 1W4

A case study of 3 year's effort for standardization of entomological techniques used on large scale forest spraying programs against the spruce budworm, Choristoneura fumiferana (Clem.), in northeast America (Ontario, Quebec, New Brunswick, Maine, Newfoundland and Nova Scotia) is presented. Differences between techniques used are discussed and approaches promoting standardization are recommended when comparable techniques are suitable.

Introduction

Standardization of entomological techniques is like "Virtue", nobody could be against it but it is difficult to practice it.

The literature regarding techniques is scant; only a few publications deal with detailed descriptions, or techniques will be summarized in a brief chapter being part of the scientific approach, but not the essence of the communication, and I think this is right. It is important to describe the method used, but why elaborate on a technique that will be repeated 2 to 3 times?

Meanwhile, the problem is quite different with spruce budworm requiring each year a tremendous amount of information directly affecting costly decisions for different jurisdictions. Techniques then appear to be more important.

The problem of entomological techniques standardization was presented to the Eastern Spruce Budworm Council, who mandated their entomologists to standardize techniques used on large scale spraying programs. The idea was that, even if provinces or states react differently to the budworm problem, the techniques used to make decisions should be similar, or at least comparable, from one jurisdiction to the next (Dorais and Kettela, 1982).

Scope and Objectives

As a first step, the entomologists listed sampling techniques that were routinely used in the decision making process for recommendation of spraying. The list was as follows:

I. Infestation Surveys

A. Population surveys

1. egg mass surveys
2. overwintering larvae surveys

B. Damage surveys

1. aerial defoliation surveys
2. ground evaluations of defoliation
3. tree mortality surveys

C. Risk rating

II. Spray Program Evaluations

1. insect and host development
2. larval mortality
3. assessment of foliage protection
4. overwintering larval mortality

The entomologists also agreed that essential to any standardization was a systematic description of techniques used, in order to be able to compare and to point out at what level differences appeared. The points compared were:

1. objectives
2. references in literature
3. area covered and intensity
4. timing
5. field procedure
6. data collection
7. cost
8. interpretation and use of data

Comparison of Techniques

1. Objectives

Comparison of objectives showed a general consensus; entomological techniques are used to evaluate population levels, damage to tree foliage, or treatment efficacy, in order to facilitate spray decisions. In this perspective, techniques selected are those which give the answers wanted; techniques seem to be inadequate when used for any other purpose than the initial objective of spray recommendation. For example, when areas of tree mortaility are reported by an aerial defoliation survey and the information is used to plan a salvage cut, then sampling precision is often criticized as inadequate.

2. References in Literature

Techniques used operationally are essentially the same in each province or state and are derived from an original reference in the literature. Good examples are the egg mass survey described by Morris, and the caustic soda larval survey described by Miller and Kettela.

Over time, these have been improved locally for more accuracy or adapted to suit local conditions. These modifications are minor, however, and do not alter significantly the original technique. Standardization of techniques which did not take into account the improvements would be unacceptable and could even be considered as a step backward.

This brings up the point that the first step in standardization must be an accurate, detailed description in a scientific publication; some modifications could then be introduced but at least they would be oriented in the same direction. The absence of careful documentation in the literature is an invitation to very different approaches and the widest variety of data collection methods (example-tree mortality evaluations).

A carefully described survey technique, however, provides the forest manager a tool (guide) that is sufficiently precise to conduct his entomological survey, even though such activities are not the main part of his occupation.

3. Area Covered and Intensity

Some surveys are done for specific needs (example - caustic soda larval survey) but for many surveys all of the spruce - fir forests under management must be considered (example - aerial defoliation survey). Faced with the situation of very large territory to cover and limited funds available, all provinces and states end up with very intensive (expensive) methods for experimental blocks, intensive surveys for high priority areas and extensive surveys where a general evaluation of the infestation is sufficient.

In low priority areas, the intensity of surveys will vary as a function of accessibility; large areas often can not be covered adequately and get minimal coverage by way of a few very expensive plots (helicopter plots).

The intention is to get enough pieces on the puzzle to get the general picture of the situation, but everybody understands that on such a basis the local resolution of the evaluation is poor. Because no spraying is usually anticipated in these areas, the information always seems to be sufficient.

For intensive surveys, the intensity will be a direct result of needs and the precision required vs time and money available. On a statistical basis, intensity itself is hard to standardize while fluctuating with the stage of development of the outbreak.

Example - patchy situation of early and late stages of the infestation needs more samples than the homogeneous pattern of a wall-to-wall infestation.

Meanwhile, the information required to guide spray decisions is an index of population magnitude plus a standard deviation. The standard deviation of the mean, at that time, more than sampling intensity itself, would be the thing to standardize to get more uniformity on precision of evaluations. Sampling precision is now determined by the money available, allowing for an acceptable minimum based on experience. ($\sigma_{\bar{\mu}}$ = 15%)

The reliability of data collected for large scale spraying programs is considered as acceptable by jurisdictions to make good decisions for spraying, but is definitely not sufficient to explain each result at the stand level, such as experimental blocks with special requirements for very good statistical precision. ($\sigma_{\bar{\mu}}$ = 10%) Higher precision is always possible, but that will not improve the actual result. Standardization of precision is not recommended as long as the minimum acceptable is adequate to meet needs.

Intensity of sampling in insect development plots in another story and varies with the tree phenology and stand composition of the area. Highly homogeneous areas won't need as many plots as mountainous ones and the intimate knowledge of the area by the field technician will result in cost and time savings. The same thing could be said for stand composition, where insect development varies between host species; a pure fir stand won't need as many samples to time spray operations as a mixed fir - white spruce stand. Standardization then has to be subordinated to the judgement of field personnel which appears to be the key factor for timing of sampling development plots. The practice of dividing the total territory into smaller areas, with each smaller area re-evaluated by the same person, provides a lot of advantages and seems to be more and more popular in the different jurisdictions.

To standardize intensity of sampling appears to be sometimes not desirable and sometimes unrealistic. The precision of sampling in large scale spray programs must be considered acceptable based on a minimum of information required to make good decisions regarding spraying. No standardization is recommended as long as the minimum acceptable precision is attained to meet needs.

Example - Aerial defoliation surveys in New Brunswick are flown along lines 3-5 km apart, covering all the province. This is not done in Ontario or Northern Quebec which present a more patchy pattern of host type than in New Brunswick.

4. Timing and Field Procedures

Usually, evaluations are timed according to development of the insect or phenology of the host tree, except for tree mortality evaluations, which could be done at anytime during the year but preferably not during the "browning" period.

Field procedures are similar from one province or state to another, except for the ground surveys (defoliation and egg masses) where the long-standing controversy of field vs lab examination arises. Evaluations could be done in the field or in the lab, depending on approaches taken and the facilities available, without that much difference, but a central laboratory seems to be favored when a massive project is required. The lab then allows for better control and uniformity of results.

5. Data Collection and Cost

Activities such as this meeting, having people involved in sampling described and rationalize their routine operational exercises, is, per se, very constructive and helps to standardize data collection.

Example - Branch measurement for egg masses survey could be done in various ways when not described in detail.

Pictures and color slides shared among evaluators doing the same job in different jurisdictions have been found to be a very good tool to help standardize data collection, especially when the information required is not quantitative.

Example - Bud index, L_2 larvae on filter paper, and insects other than budworm encountered on sample branches.

Having techniques well described and illustrated will improve uniformity, especially when examinations of sample branches each year are done with inexperienced workers. In such a situation, the experienced lab technician will be able to present things in easily understood language.

Uniformity of data collection between jurisdictions can not be complete without considering representativeness; that is, field techniques could present an objective local evaluation or a large-scale subjective evaluation.

Example - Fettes method vs field-glasses evaluation of annual defoliation.

Both techniques are used, but which one is the best? Each of these techniques has its place, depending upon the goal for the spruce budworm evaluation. The first one (Fettes) is directly associated with larval mortality and is needed to complete the treatment efficacy picture in terms of branch defoliation, while the latter method (field-glasses) allows for wider coverage and is used to validate the aerial evaluation of defoliation.

The degree of conformity between these two different evaluations will be directly related to the homogeneity of the area studied and to the skill of the field technician in finding trees which are really representative of the area evaluated. Once again, it seems that standardization must be subordinated to the judgement of the experienced field technician, who afer must assist the entomologist with only a minimum of resources.

Survey costs, reported per plot or per km^2 are in the same way related to facilities available. As always, cost per plot is reduced when large numbers of plots are examined. (Example - L_2 caustic soda larval survey).

6. Interpretation and Use of Data

Comparison of techniques shows that results are presented using the same categories or same sample units in all jurisdictions.

Example - Light, moderate and severe defoliation categories. Number of larvae per 45 cm branch tip.

Still, some differences exist in defining limits of the categories, where the interpretation, per se, in terms of impact on the tree is not documented precisely enough to clearly specify the border lines.

Example - Defoliation is considered moderate when between 35-70% in Quebec and between 26-65% in New Brunswick.

On the other hand, the risk rating map, derived from a summation of all data collected, is based on four categories essentially identical everywhere and spray recommendations based on those categories are the same as well: no spray recommended for the low category, but spray considered for the others. The only grey area that persists at this time is the cut-off point at which time a forest is considered already too damaged to be sprayed.

Conclusion

We can't expect to have things done (budworm) sampling) exactly the same way all over northeast America, but up to a certain degree the approaches and techniques used are already standard from one province or state to another. Differences pointed out are minor and were made to improve the original technique or to suit local conditions; further standardization would not be acceptable if those minor improvements were not retained.

Techniques now in use seem to meet the original goal for which they were developed. The intensity of sampling sometimes differs, but seems to meet the needs, considering the money available and variations in forest composition or geography. Once again, standardization is sometimes unacceptable and sometimes must be subordinated to judgement of experienced personnel in the field.

In the long run though, frequent contacts between people involved in sampling and discussions of problems encountered appears to be the ideal way for movement toward standardization of techniques, which has to be considered, as "Virtue", the long term goal.

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USING TRAP CATCH TRENDS TO WARN OF FUTURE DAMAGE

Gary A. Simmons and Norman C. Elliott

Associate Professor and Graduate Student, respectively, Department of Entomology, Michigan State University, East Lansing, MI 48824-1115

Predicting the timing and occurrence of forest insect infestations and outbreaks has long been a goal of many forest entomologists. Analyses of yearly light trap catch totals from Maine showed that population upsurges of budworm were indicated four to seven years before defoliation was first observed. In this paper we discuss how such trend information can help predict infestations or outbreaks of spruce budworm.

The Idea Behind Trend Information

Spruce budworm populations persist at low densities until the forest ages sufficiently to support higher populations. These fluctuations occur at irregular intervals, ranging from 20 to 90 years in individual stands. Three possible conditions can "release" the population to high densities: (a) weather conditions favoring budworm populations but not favoring natural enemies of the budworm, (b) migrating budworm moths laying eggs in numbers such that natural control factors cannot keep the budworm at low numbers, and (c) a combination of the above. Regardless of the cause, the population fluctuation for budworm over time follows an "S-shaped" curve (Fig. 1).

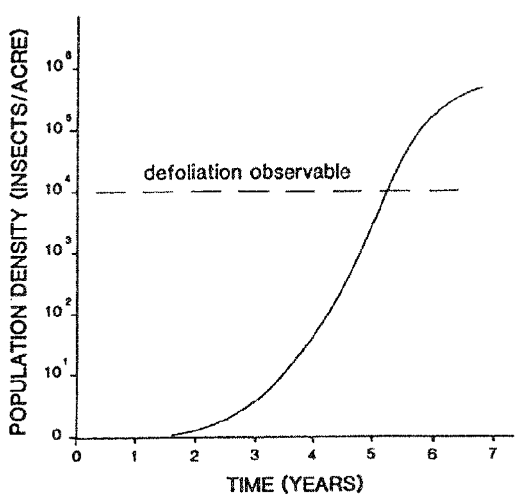

Figure 1. Fluctuation in the density of a hypothetical spruce budworm population over time.

The point on the graph where the curve turns upward from low density is when the "population release" occurs. From this point on budworm populations will continue to rise to a high level. Theoretically, this "population release" point occurs several years before budworm populations are high enough to cause noticeable damage.

By using light traps or pheromone traps (Simmons 1980), which measure budworm populations, this population release can be detected. To do this, place a trap at the same location over several years; plot catch totals on a graph. The graph should pinpoint "population release" for that location.

Analyzing Actual Trap Catch Trends

A plot of yearly light trap catch data, taken at Eustis, Maine, from 1962 to 1974, is shown in Figure 2. From 1962 through 1966, no moths were caught--establishing a trend of very low (undetected) populations. In 1967, three moths were caught, and in 1968, nine moths were caught. The 1967-68 period is the first upward trend in the plot--the "population release" point. From 1968 onward, all captures exceeded ten moths per year indicating a rising trend to a high population. Noticeable defoliation was recorded for the first time in 1974. If 1968 is the first year of the rising trend, there were six years before defoliation was first observed at Eustis.

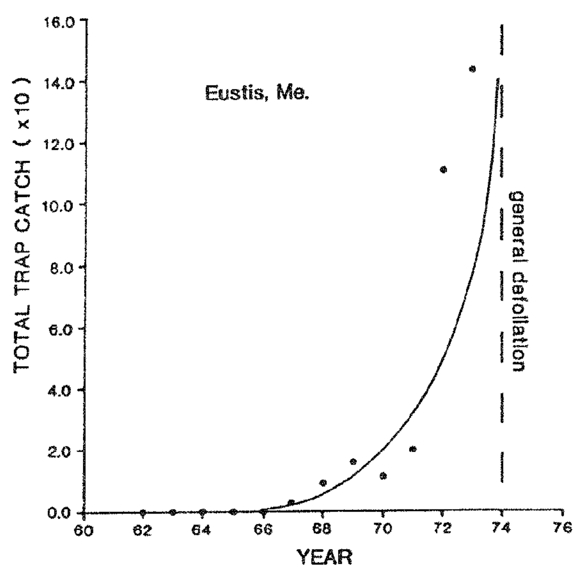

Figure 2. Yearly light trap catch totals, taken at Eustis, Maine, from 1962 to 1974.

Operational Use of Traps

Actual trap catch information, such as that just described can be used in regular forest management operations. One of the first steps would be to organize the forest area of concern into smaller management units. In the Lakes States Region, these units are often termed "compartments." These are parcels of forest land from 1,000 to 3,000 acres. Within the compartments are usually several timber types, sometimes including a few to several individual stands of spruce-fir.

The next step is to determine which compartments have stands of spruce-fir worth managing. Those compartments containing stands of sufficient value to be of concern should be located and noted. Compartments containing no spruce-fir would not be considered.

Within each compartment containing spruce-fir of value, stands should be rated (hazard rating) for their potential to sustain damage from spruce budworm if an infestation or outbreak should occur. Compartments containing high hazard stands would be the target of trapping to help predict damaging populations of the spruce budworm.

Two approaches to monitoring low spruce budworm populations could be employed: (a) a "lower precision" approach that monitors only the compartments of concern and (b) a "higher precision" approach that monitors every stand of value at risk within every compartment of concern. The "lower precision" approach would use one trap in one high hazard stand in each compartment of concern, providing a general monitoring station for the entire compartment. The "higher precision" approach would use one trap in each high hazard stand within every compartment of interest, thus providing multiple monitoring stations within a compartment (unless only one stand was considered high hazard).

The advantage of the lower precision approach is that fewer traps are required per compartment, thus reducing the cost of monitoring. The disadvantage is only one stand is monitored and that information might not represent what is happening in every high hazard stand in the compartment. An alternative is to use one trap in homogeneous compartments while deploying multiple traps in more heterogeneous compartments.

When Is This Approach Appropriate?

In areas where budworm is "always a problem" or in areas that have been repeatedly sprayed for budworm control the methods described herein will not give four to seven years of lead time before tree damage occurs. There may be some lead time, but damage could also occur within a year or two. This approach works best when populations of the spruce budworm are usually low and unnoticeable for many years, erupt to outbreak for a few years, then return to low and unnoticeable for many years.

What's Best to Use: Light Traps or Pheromone Traps?

When we conducted our studies, the only long-term data sets available were from light trap catches. Assuming that pheromone traps are at least as sensitive as light traps in detecting population change, pheromone traps are probably a better tool than light traps. They cost less individually, are easier to transport and deploy, and most importantly, are selective in attracting spruce budworm moths. Light traps attract all kinds of insects, requiring the catches to be sorted by entomologists and necessitating the traps being tended every few days. Pheromone traps can be left for the entire moth flight season, then retrieved, with the counting done by non-entomologists.

Our suggestion--use pheromone traps!

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APPLICATION OF PHEROMONE TRAPS TO EFFECTIVELY MONITOR SPRUCE BUDWORM POPULATIONS

Lawrence P. Abrahamson, Douglas C. Allen and Gerald N. Lanier

State University of New York, College of Environmental Science and Forestry, Syracuse, NY 13210

Non-saturating traps baited with synthetic sex pheromone can effectively monitor spruce budworm populations. Presently available traps, and possibly the lure, need further improvements in order to provide a commercially available combination in which field personnel will have confidence. A standardized protocol will be essential for implementing a pheromone trapping system.

Preliminary results from extensive field trials in Canada and the United States during the past three years indicate that a non-saturating trap baited with synthetic sex pheromone offers forest managers and pest survey specialists a relatively inexpensive and reliable way to monitor populations of spruce budworm (Choristoneura fumiferana (Clemens)). The sex pheromone used was a 97:3 to 95:5 blend of E- and Z-11 retradecenal (Sanders and Weatherston 1976, Ramaswamy and Carde 1982). The E:Z ratio varies among commercially available lures. Ample evidence was accumulated during the last five years to demonstrate that traps baited with synthetic sex pheromone catch male moths in numbers that can be related to budworm larval density. Research in Michigan (Ramaswamy and Carde 1982, Carde 1983), Canada (Sanders 1978, 1981; Sanders et al. 1983) and the CANUSA-East field trials in Quebec, Newfoundland, Maine, New Hampshire, Vermont, New York and Michigan, produced meaningful trap catch correlations (r^2) of 0.76 to 0.95 with 3rd (3L) and 4th (4L) instar larval counts of the same generation and with 2nd (2L) instar larval counts of the next generation in sparse to moderate populations. Very promising results have also been obtained at higher population levels.

If the results of the 1983 CANUSA-East field trials corroborate earlier work, we may be able to utilize pheromone traps operationally in the near future. It is anticipated that a properly deployed trapping system will provide an early warning of impending outbreaks in low population areas where other forms of sampling are expensive, time consuming, or logistically unreasonable. Hopefully we may even be able to supplement other sampling procedures rountinely used in high populations such as egg mass or overwintering (L2) larval surveys.

The covered-funnel trap (CFT), a non-saturating model developed by Ramaswamy and carde (1982) and slightly modified by us (Fig. 1) is presently our standard trap. A recent trap design by Sanders (Sanders et al. 1983), called the double funnel trap (DFT), also performed to the same degree as the CFT trap. Additionally, a commercially available plastic canister gypsy moth trap, modified for use in the CANUSA trials, also appears promising. However, as you will hear tomorrow, additional improvements will be necessary before we have a "standardized commercial trap" that we can recommend with confidence.

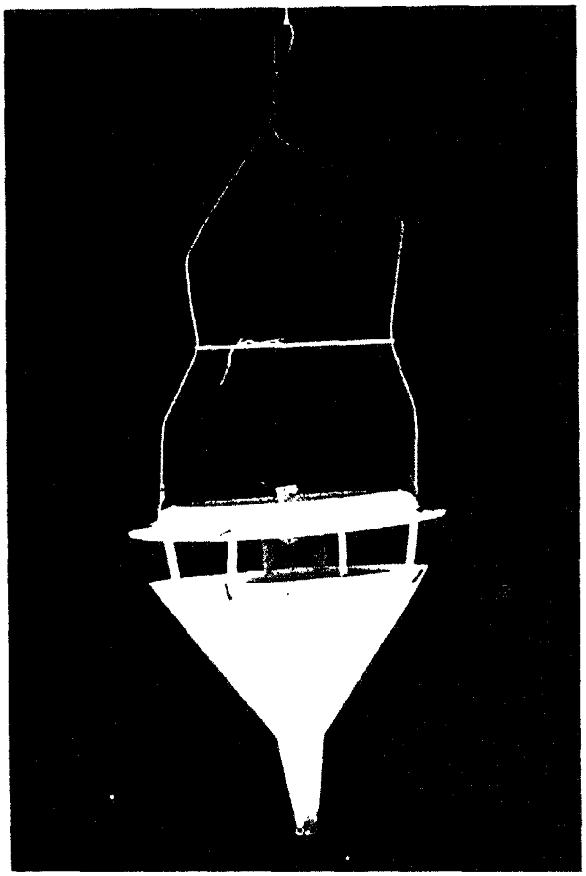

Figure 1. Covered-funnel trap (CFT), the standard non-saturating trap used in CANUSA-East field trials.

The CANUSA project used two commercial lures; the Hercon® (Health-Chem) Luretrap®, a 1/2" square plastic laminated sandwich impregnated with a 95:5 blend of E- and Z-11-tetradecenal and the Conrel® (Albany International), a white celcon hollow fiber containing a 94:6 blend of E- and Z-11-tetradecenal. Both gave good results in the 1982 CANUSA field tests and in Sanders'[1] 1982 lure evaluations. However, until our 1983 results are analyzed and compared to those from Canada, we cannot recommend either one. Our intent is to obtain a consistent pheromone release rate and develop a trapping system that reliably correlates moth catch with larval budworm density.

The present trap, and possibly the lure, need further improvements in order to provide a commercially available combination in which field personnel will have confidence.

Results of the 1983 CANUSA-East field trials will tell us if we are ready to start the development of regional budworm monitoring systems using pheromone-baited traps. Recommendations for a pheromone trap monitoring system will be presented tomorrow. One of the most important aspects of monitoring with pheromone traps is standardization of not only the trap and lure, but also a protocol to implement the system. Without standardization the system will provide limited opportunity to apply results and improve the technique. Careful organization and planning during the early stages of development will increase the opportunity to produce a monitoring system that is applied in a standard fashion by all agencies.

The three years of CANUSA-East field trials with pheromone traps have shown that data inconsistency was due, in part, to the fact that field crews did not follow standard protocol. This lack of conformity resulted from inadequate clarification and demonstration of methods. Part of the problem can also be attributed to a propensity for field personnel to "do their own thing." Following is a basic framework from which we can develop a standard procedure for application of pheromone traps within regional pheromone monitoring systems.

TRAP: A standard non-saturating trap should be approved by all participants in a monitoring system. The trap must be commercially available, durable, and easy to assemble. It must retain numbers of moths that consistently reflect changes in population density.

LURE: A reliable commercial lure that releases pheromone for a specified time at a desired rate is essential. The lure must be positioned within the traps in such a manner that pheromone release is not obstructed (Fig. 2). Lures must be stored in a freezer within their original wrapping until taken to the field. Lures are placed in the traps when traps are deployed, approximately one week before flight begins. "Aging" is necessary to avoid field exposure to the adults during the initial burst of chemical that is characteristically released when a bait is taken out of storage.

TRAP PLACEMENT: Traps should be suspended approximately 1.5 m above the ground and attached to a branch on a host tree (if possible) (Fig. 3), or a non-host if the latter is more convenient. A trap should not be closer than 0.3 to 0.5 m to the trunk of the tree. When placed immediately adjacent to the trunk (Fig. 4), air flow is obstructed and traps may become wind battered. Foliage and branches must be removed from the vicinity of the trap (0.5 m clearance) so

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[1] Personal communication, C.J. Sanders, Canadian Forestry Service, Sault Ste. Marie, Ontario.

Figure 2. A commercial lure properly positioned within the CFT trap.

Figure 3. A properly placed plastic canister gypsy moth trap, modified for use in the CANUSA-East trials, correctly suspended to a host tree branch.

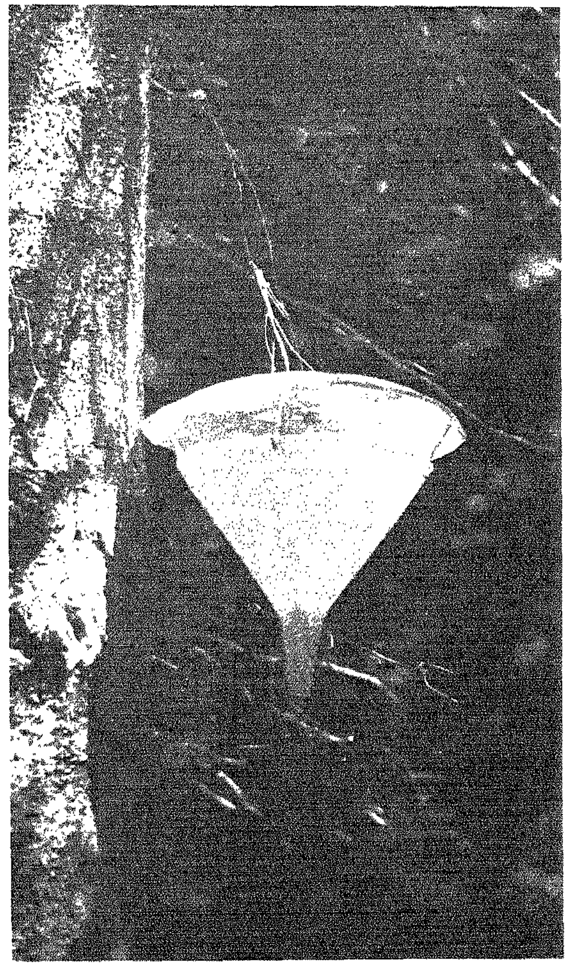

Figure 4. A CFT trap placed too close to the tree trunk where air flow is obstructed and the trap could be damaged by the wind.

that moth flight will not be hindered. Traps placed along road corridors should be positioned so that the traps are at least 5 m into the host type.

TRAP PLOTS: A plot consists of one five-trap cluster, however, a three-trap cluster is adequate in locations where interference from bears or people is not a problem. Traps should be placed 40 m apart, one in each cardinal direction around a center trap (Fig. 5). The three-trap cluster can be placed in any triangular configuration as long as a minimum of 40 m is maintained between traps. Baited traps should be placed in the field 5-7 days before moth flight begins and remain in the field until adult activity ceases. The total duration of the field exposure of traps is 5 to 6 weeks.

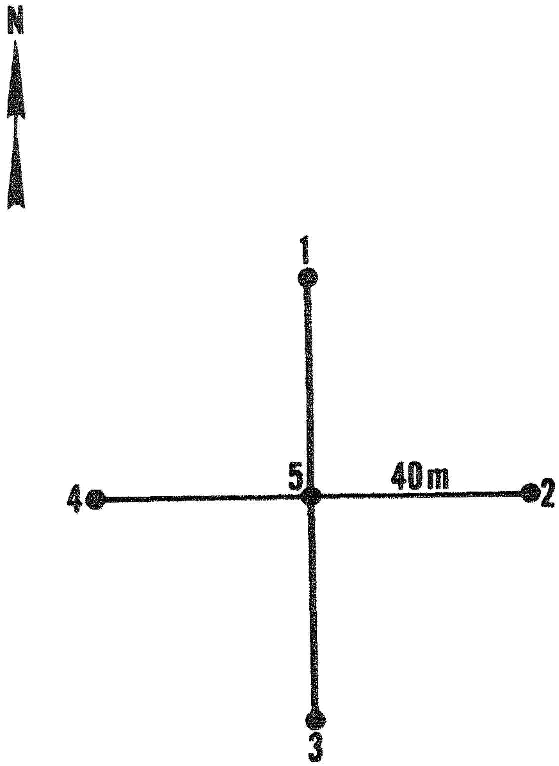

Figure 5. The five-trap cluster used as a plot design in the CANUSA-East trials.

DATA COLLECTION: Male moths should be counted soon after the traps are collected. Small numbers (less than 50) can be counted by hand while larger quantities will be estimated by a weighing procedure that we are developing this year in cooperation with Luc Jobin, Canadian Forestry Service, Quebec. Moth numbers should be recorded on standard forms and data sent to centralized collection centers for regional reporting and statistical analysis.

These are some of the more important aspects of our standardized protocol that must be considered when pheromone traps are used for regional surveys of spruce budworm. We must also recognize that these pheromone traps are not a panacea, but they will provide a valuable monitoring and survey tool within an integrated pest management approach.

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SEX PHEROMONE TRAPS AND LURES FOR MONITORING SPRUCE BUDWORM POPULATIONS--THE ONTARIO EXPERIENCE.

C.J. Sanders

Research Scientist, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, Canada, P6A 5M7.

Sex pheromone traps for spruce budworm were originally envisioned as tools for providing an 'early warning' of outbreaks. While there is no doubt they will be effective in this role, the advent of practical, low-cost, "high capacity" traps raises the possibility that pheromone traps could replace more costly sampling techniques, such as egg sampling. A 'home-made' double-funnel trap design has given correlations between trap catches and larval densities with r^2 up to 77%. Limited trials with commercial trap-designs indicate that several designs may be suitable for operational use, but more testing is required before a long-term program using a standardised trap design is begun. Similarly, while several types of lure are adequate for the purpose, further testing is required to determine which is the 'best'.

Introduction

Sex pheromones are chemicals released by one sex to attract the other sex of the same species for the purpose of mating. In the case of the spruce budworm, as with most other Lepidoptera, it is the female which releases the pheromone, the male which responds. When ready to mate, the female spruce budworm everts a special gland at the tip of the abdomen which secretes the pheromone. The pheromone plume is wafted downwind, and a receptive male on perceiving the pheromone, flies upwind towards the source. On arrival he searches for the female and mating takes place.

Most, if not all, sex pheromones of the Lepidoptera are blends of several chemicals. In the right combinations and at the right concentrations, these blends are extremely species-specific as indeed they must be to prevent female moths from attracting the wrong males. This is one of their advantages as a sampling tool--only the target species is involved. Pheromones are also extremely potent; while it is probable that the effective range of the pheromone is less than 100 m, only a few milligrams are necessary to attract males for weeks, and this is a second advantage--they are extremely efficient.

The main component of the spruce budworm pheromone was identified in 1971 (Weatherston et al. 1971), but early trapping results were disappointing and it was subsequently found that a minor component was missing (Sanders and Weatherston 1976). With the addition of this it is now possible to produce lures which attract more males than a virgin female moth can (Sanders 1981). The synthetic pheromone is now readily available commercially for a few dollars per gram. This may sound expensive, but when it is remembered that only a few milligrams are necessary to bait a trap, the cost per trap is negligible.

Now that we have virtually unlimited supplies of the synthetic pheromone, what can we do with it? First, it can be used to disrupt the natural sequences of mating behavior to preventing successful mating, thus regulating populations. This has turned out to be a tricky research problem, but is not of concern here. Second, the pheromone can be used to lure the male moths to traps, where they can be captured and counted.

In some ways sex pheromone traps are similar to light traps, they efficiently attract and capture individuals of the target species so that they can be easily counted. The great advantage of sex pheromone traps over light traps is that they are species-specific, inexpensive and simple to operate--no power source is required.

But, before proceeding any further, it is very important to be quite clear of the objectives of trapping the spruce budworm, since traps have been used for a variety of purposes with other insects and the optimum trap design varies with the purpose.

a) Mass Trapping

Traps can be used to catch and remove males from the population. If the baits are potent enough and there are enough traps, sufficient males can be removed to reduce the mating success of the females. Although this has been demonstrated as a practical proposition for some agricultural insects it is not practical for such a numerous, widespread insect as the spruce budworm.

b) Timing of Control Operations

Since pheromone traps are very efficient, they can be used to find out when the first moths fly, and, again in some agricultural situations, this can be used to determine when insecticides should first be applied. Also, for some agricultural pests, notably in orchards, pheromone traps have been used to indicate when it is necessary to spray--when a certain threshold number is reached, the pest has reached economically serious levels.

c) Detection

For migratory pests, or introduced pests which are extending their range, such as the gypsy moth, pheromone traps are an efficient method of establishing if the pest is present, indicating whether or not more intensive sampling is necessary.

d) Monitoring Population Changes

Finally, we come to the primary purpose for which traps are being used for spruce budworm, to monitor annual changes in population density to provide an "early warning" of impending outbreaks.

For mass trapping, timing of treatment, and detection, highly potent baits are required. For mass trapping, traps must be of large capacity, and their efficiency is measured by the number of insects caught. For detection and timing, efficiency is measured by the ability of the traps to capture the first moths to appear; for detection numerous low cost traps are required, for timing of treatments fewer traps are required, so they can be more elaborate and costly.

For monitoring population fluctuations high efficiency of capture is not necessary and may even be a disadvantage--too many insects in a trap take too long to count. The chief attributes required for monitoring spruce budworm populations are:

i) Catch correlated with population density,
ii) Durability over 6-week period,
iii) Convenience,
iv) Cost,
v) Constant capture rate,
 a) for 6-week period,
 b) from year-to-year.

These attributes are affected by both the trap design and by the formulation of the lure.

Let us first consider the trap design.

Trap Design

a) Early Tests

When development of the spruce budworm sex attractant for monitoring population changes began in the mid-seventies, the traps available were mostly of a sticky variety. The non-sticky traps which used an insecticide to kill the moths were generally too bulky and too expensive.

Comparative tests of the sticky traps available at this time led to the conclusion that the Pherocon 1CP (Fig. 1) was most appropriate (Sanders 1978). Its design kept the accidental capture of non-target insects to a minimum, and it proved to be durable enough to remain effective 12 months. It was recognized early on that there is a problem of 'saturation'--the sticky surface becomes so covered in moths and scales that incoming moths escape--but, it was hoped that this could be overcome by reducing the potency of the lure. Early trials with the 1CP traps did in fact give reasonable correlations between moth catches and larval densities. Then, in 1980, the Michigan State University group designed a non-sticky trap (Fig. 2) which was no larger and no more expensive than the sticky traps (Ramaswamy and Cardé 1982).

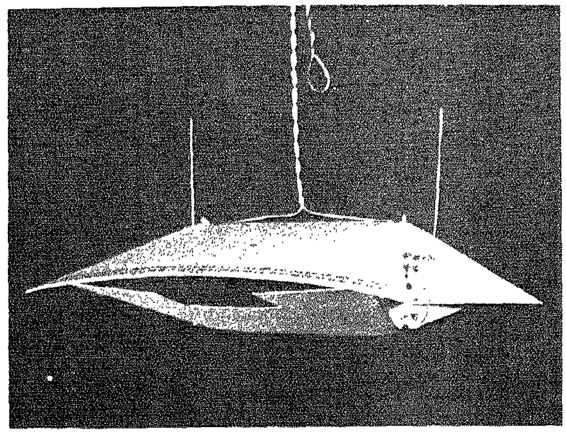

Fig. 1. Pherocon 1CP sticky trap. Only the inside of the lower half is coated in sticky material.

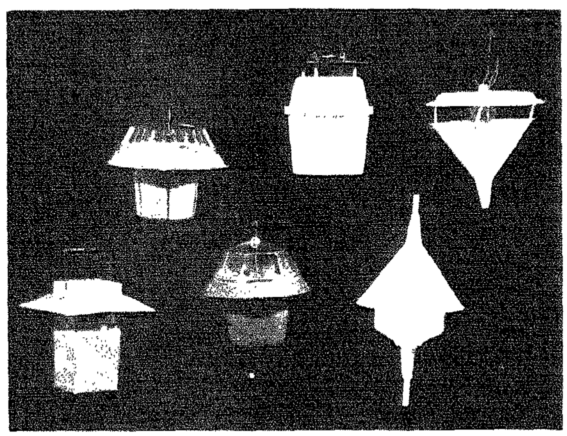

Fig. 2. Different designs of 'non-saturating' traps in which moths are killed by insecticide vapor. Top, l. to r. Health-Chem gypsy moth canister trap; International Pheromones Ltd. Uni-trap; Covered-funnel trap. Bottom, l. to r. Health-Chem gypsy moth 'milk carton' trap; Baker Chemicals "Bag-a-Bug"; Double-funnel trap.

b) 1981 Tests

Tests in 1981 in Ontario, as well as elsewhere, demonstrated that these traps gave a good range of catches over a wide range of population densities. However, we found the traps inconvenient to assemble and store. Also, water entered the traps causing the captured moths to rot making counting nearly impossible.

c) 1982 Tests

This led to a new design which we have called the double-funnel trap (Fig. 2) and in 1982 we carried out a test to compare the effectiveness of the Pherocon 1CP, the MSU covered-funnel trap (CFT) and the double-funnel trap (DFT). Twenty-three plots were established in northern Ontario, selected to provide a wide range of spruce budworm densities.

Pherocon 1CP traps were baited with 3 different potencies of lure. At the 2 highest all the traps were saturated At the lowest also, many of the traps were saturated, but at densities below 2.5 larvae/branch tip the correlation between catch and population density was reasonable with an $r^2 = 61.5\%$ and maximum catches of 36 moths/trap (Fig. 3).

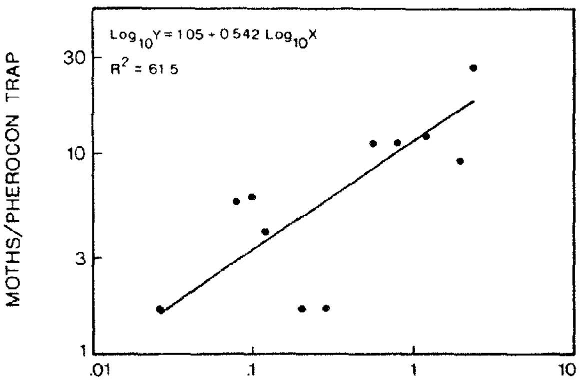

Fig. 3. Relationship between catches in Pherocon 1CP traps baited with low-potency lures and larval density (Ontario, 1982).

Neither the CFT of DFT traps showed signs of saturation, even at the highest population density. For the CFT, $r^2 = 59.0\%$ with catches ranging from 2.6 to 244/trap, for the DFT $r^2 = 76.6\%$ with catches ranging from 18.2 to 670/trap (Fig. 4). In 16% of the CFT traps accurate counting was impossible because the moths had rotted due to the accumulation of moisture which occurred in spite of the modification aimed at preventing this. No such problem occurred with the DFTs.

d) 1983 Tests

In 1983 we again tested the DFT traps for correlations with larval densities. This time we tested clusters of 5 traps and clusters of 3. Correlation between trap catch and larval density gave $r^2 = 51\%$ and 49% respectively, poorer than in 1982, but still highly significant. Correlation between the average catch in the 5 trap cluster and the 3 trap cluster was excellent (Fig. 5) $r^2 = 93\%$, implying that a 3 trap cluster is quite adequate. We also tested the correlation between the 1982 moth catches and the 1983 larval density, i.e., the ability of the moth catches to predict larval density the following year, and obtained an r^2 of 61% which is quite encouraging (Fig. 6).

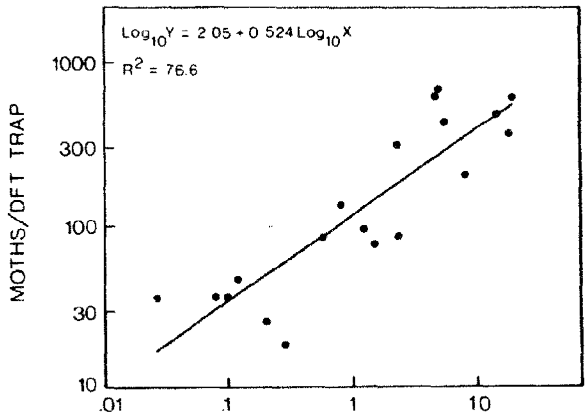

Fig. 4. Relationship between catches in double-funnel traps and larval density (Ontario, 1982).

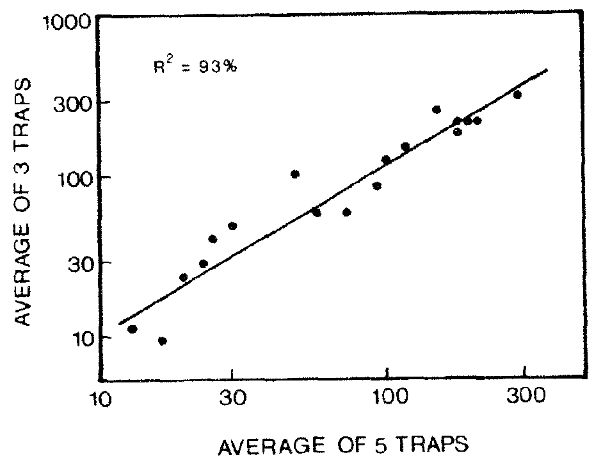

Fig. 5. Relationship between average catch per trap in clusters of 3 traps and clusters of 5 (Ontario, 1983).

e) New Trap Designs

In 1983 we carried out some comparative tests of other commercial trap designs. these were the International Pheromone Limited, Unitrap (IPL), Baker Chemical 'Bag-a-Bug' and 2 Health-Chem products, the gypsy moth carton and gypsy moth canisters (Fig. 2). The last 2 were modified by enlarging the openings to make them conform to other designs.

These traps, along with the DFT and CFT were placed out in 2 areas, one of relatively low density (< 2 larvae/branch tip) and the other high (ca. 10 larvae/branch tip). At the higher densities, all designs except the Health-Chem carton captured reasonable numbers (Table 1). However, at the lower densities the Bag-a-Bug and both Health-Chem designs gave very low catches, low enough to make it questionable if they would be of value for monitoring low density populations, although higher potency lures might increase catches sufficiently.

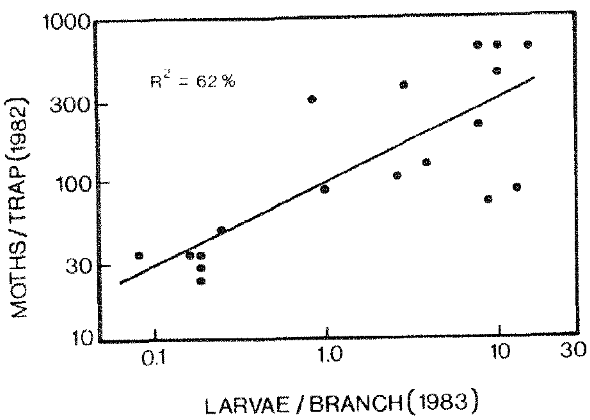

Fig. 6. Relationship between moth catches in 1982 and larval densities in 1983.

Table 1. Average catches in 6 different trap designs left out for 1 week during peak flight period in high and low population densities. The right-hand column provides an indication of the variation among catches in the low density population (each trap replicated 8 times).

	Population Density		Coefficient of
	High	Low	Variance
International Pheromones Ltd.	135	78	.24
Health-Chem "milk carton"	96	3	.44
Health-Chem plastic canister	21	7	.36
"Bag-a-Bug" canister	112	8	.36
Covered funnel	78	26	.40
Double funnel	139	39	.20

An important attribute of the catch is the variability among traps. This can be measured by the coefficients of variance which are shown for the 6 trap designs also in Table 1. The lowest values, indicating the least variation among traps was attained by the DFT and IPL traps.

Where then does this leave us? The traps have four attributes of concern--an adequate catch, convenience, cost, and durability. The six designs are rated for these 4 attributes in Table 2. Since adequacy of catch is of paramount importance the 2 Health-Chem designs and the 'Bag-a-Bug' are inadequate unless catches can be increased by higher potency lures. This is unfortunate, because their design is certainly the most convenient for assembly and storage. Of the remaining 3; the covered-funnel can be excluded on the grounds that it allows moisture to enter, and that it is too inconvenient to assemble and store. The IPL trap is superior in all attributes except cost.

Table 2. Subjective evaluation of 4 attributes of pheromone traps. ++ = best, -- = worst.

	Catch	Convenience	Cost	Durability
Int. Phero. Ltd.	+	+	-	++
Health-Chem Carton	- -	-	+	-
Health-Chem Canister	-	++	+	+
Bag-a Bug	-	++	+	+
Covered funnel	+	- -	+	+
Double funnel	+	-	-	++

Therefore, none of the designs can be considered the 'perfect solution'. My recommendation is that since the DFT has proven itself now for 2 years, it should be used as the operational trap in 1984, pending testing of other designs and modifications to existing designs. A change over from one design to another need present no serious problems. Provided each new design is in its turn, correlated with larval population densities, then a continuous integrated monitoring system can be maintained.

Already we have simpler more convenient and cheaper designs in mind. Also, modifications of the Health-Chem canister and Bag-a-Bug will be tried to determine if differet configurations of entrances, and different colors would improve their catches in low density populations.

Trap Layout

The 1983 results showed that a cluster of 3 traps, 40 m apart in a triangle, gave the same results as 5, 40 m apart in a star-shaped layout. Therefore it can be argued that 3 traps are sufficient. However, there is always the danger that 1 or 2 traps may be destroyed or lost. Therefore, we recommend the 5-trap layout, with the reassurance that if 1 or 2 traps are lost, the remaining catches are still meaningful.

Distribution of Plots

The question of how far apart the plots should be to obtain an adequate picture of population change is difficult to answer. Certainly the answer must depend upon topography and size of forest stands. In homogeneous stand types few plots may be needed. In more broken country plots will need to be closer.

For seven years ICP traps were placed out annually in 30 locations in northwestern Ontario. The plots were located at intervals along a triangular route approximately 400 km long encompassing an area of about 6500 km^2. Catches throughout the entire area showed a very good correspondence (Fig. 7), implying that one plot could have been used to represent the entire 6500 km^2. In areas such as northwestern Ontario where climate and forest type are relatively homogeneous, 1 plot every few thousand km^2 may be adequate. But, in other areas plots should be located by stratifying the forest by stand type and climate.

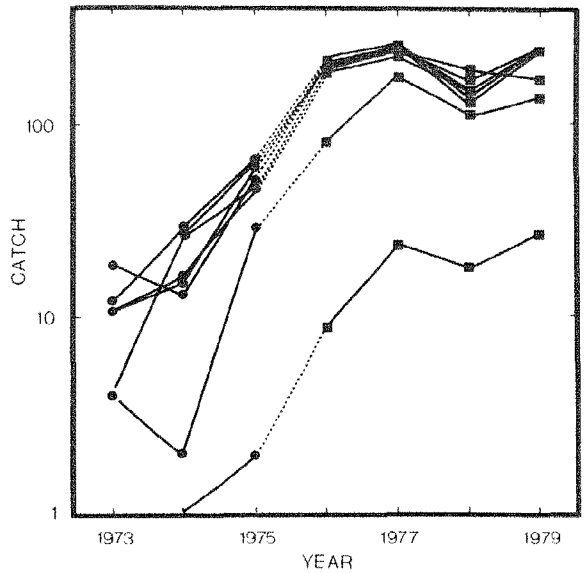

Fig. 7. Trends in moth catches (sum of 5 traps) in 8 plots in an area of 6000 km^2 in northwestern Ontario, 1973-1979. Solid circles "Sector I" traps, squares Pherocon ICP traps. (Note similarity of trends even in lowest line which is for traps placed in centre of 6000 ha area burned in 1968.)

Lures

The second component of the trapping system which influences trap catches and their comparability from year-to-year is the lure.

The attributes of a good lure are:

i) stability of the pheromone,
ii) a release rate of 10-20 ng/hr,
iii) a constant release rate for 6 weeks,
iv) a comparable release rate from year-to-year.

The major components of the spruce budworm pheromone are unsaturated aldehydes. Such compounds are notoriously unstable. Fortunately, the fact that they are in the trap provides considerable protection from the elements, but the lure formulation must ensure protection from chemical and photo-degradation.

The release rate of 10-20 ng/ha is purely arbitrary. Female moths release the pheromone at approximately this rate, therefore, it is appropriate on biological grounds. Furthermore, this rate has been used for many years and has produced a good range of catches over a wide spectrum of population densities. Fortunately, there appears to be a fairly wide tolerance to male response, and rates can vary ± 100% without affecting capture rate significantly.

Release rates must be as constant as possible so that the capture rate is constant. A 6-week figure has been chosen since this allows time for the traps to be placed out before the moth flight, and collected up after.

Finally, to ensure that catches are comparable from year-to-year release rates must be constant from year-to-year, which implies that each batch of lures must be identical.

We have assayed 4 formulations of lure over the past few years: Hercon plastic laminated flakes; Albany International (Conrel) hollow microfibres; Bend plastic capsules, and polyvinyl chloride (PVC) pellets. The first 3 of these are commercial products, the last is a formulation made in our own laboratory which we have been using since 1973.

In 1982 and 1983, samples of each formulation were 'pre-aged' by placing them in a fumehood for various lengths of time. Lures of different 'age' were then placed out simultaneously to compare their rates of capture.

a) 1982 Results

The PVC pellets had a release rate estimated by New Brunswick Research and Productivity Council (RPC) at 10 ng/hr after 10 days, the Conrel fibres and Hercon flakes were designed by their manufacturers to have release rates between 10 and 20 ng/hr. The Bend capsules which were added to the experiment at the last moment had a far higher release rate, close to 2 μg/hr. Lures were 'aged' from 1-6 weeks and results are shown in Figure 8. As anticipated from the release rates, catches with the Bend formulation far exceeded the others. Catches with the Hercon flakes were far lower than with either the Conrel or PVC although release rates were supposed to be similar. The Bend, Hercon and Conrel showed little variation in rate of catch with age (a desirable feature), but the PVC lures did.

b) 1983 Results

Catches with all 4 formulations were more comparable in 1983 than in 1982 (Fig. 9), indicating that release rates were closer, though by no means equal. The Bend was considerably less potent than in 1982, while the PVC and Hercon, relative to the Conrel were lower. As in 1982, the PVC lures showed a decrease in catches with age, the Conrel fibres were rather variable, while the Hercon flakes showed higher catches during the first week of age, all undesirable features. Only the Bend showed a relatively constant release rate, and so it must be considered the best of the 4 types of lure.

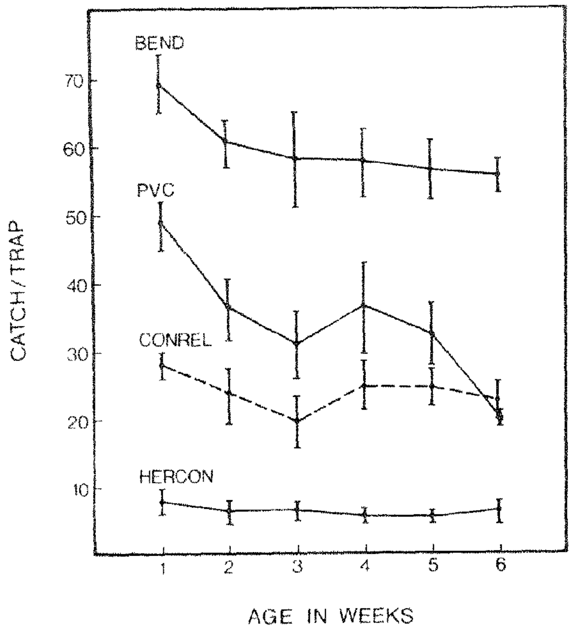

Fig. 8. Comparative catches in Pherocon 1CP traps baited with 4 types of lure aged for different lengths of time (all deployed at same time) (Ontario, 1982).

Recommendations

Results up to this point in time (September 1983) demonstrate that non-sticky, non-saturating traps baited with synthetic pheromone of the spruce budworm are capable of monitoring fluctuations in low density spruce budworm populations, therefore of providing early warning of impending outbreaks. It is also apparent that they can be used to predict larval population densities, from one year to the next with reasonable accuracy, and may be suitable for replacing egg sampling.

However, it is important to remember that such a monitoring system must be standardised throughout the areas where the spruce budworm is a problem, and second, that to provide information for predicting year-to-year changes, the trap and lure must not be changed from year to year. Therefore, it is crucial to be sure that the operational system will stand the test of time. The current 'best' trap is not suitable for mass production, while the 'best' lure has not been adequately evaluated yet to be sure of its performance.

Therefore, it is recommended that there be a further year of testing, in which the following tests are carried out:

a) Modified commercial traps are evaluated, using the DFT as a standard.
b) Bend lures are tested over a wide range of population densities.

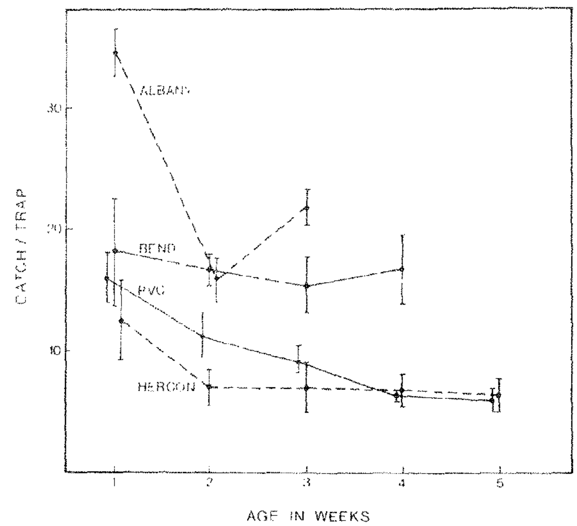

Fig. 9. As for Figure 8, but 1983 data.

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MONITORING SPRUCE BUDWORM POPULATIONS WITH PHEROMONE-BAITED TRAPS

Douglas C. Allen, Lawrence P. Abrahamson and Gerald N. Lanier

Professor, Senior Research Associate and Professor, State University of New York College of Environmental Science and Forestry, Syracuse, NY 13210

Pheromone-baited traps are a promising new tool for monitoring spruce budworm populations. Further field trials of improved traps and lures and acquisition of time series data are necessary to improve methods and interpretation of trap catch. Preliminary results from recent field tests suggest that pheromone traps can be used to detect and delineate large-scale moth dispersal, predict population trend and predict population density or damage.

At present, it is not possible to unequivocally define specifications of a pheromone-oriented monitoring system for spruce budworm. Further refinements in trap design, lure characteristics and interpretation of trap catch data require additional field testing. Preliminary results from extensive field trials in Canada and the United States during the past three years, however, indicate that a monitoring system can be implemented in the near future.

We hope that this assessment and those preceding, will stimulate panel discussion on techniques and tools for monitoring spruce budworm. Those of us who have been involved with the field trials recognize the importance of dialogue between researchers and practitioners in order to maximize efficiency and ensure acceptance and implementation of a pheromone-oriented monitoring system.

Results of the 1983 CANUSA-East field trials will permit an analysis of the relationship of trap catches to a number of forest and budworm-related variables. These data represent 110 forest stands that occur in five states and four provinces. Cooperative field trials during the previous two years were beleaguered with logistical problems or inadequate traps and lures. Improvements were made during 1983, but additional work is necessary to assure that lures consistently provide suitable pheromone release rates and that trap catch will reliably reflect desired budworm variables.

Need for Time Series Data

A major concern that emerged from the 1981-1983 trials was the influence that local variations in budworm density, weather and stand conditions had on trapping results. Though it would be nice to develop a single model to predict spruce budworm population trend or density in widely separated geographical locations, this may be an unreasonable goal. Preliminary data from the CANUSA trials and work with spruce budworm in Michigan (Ramaswamy et al. 1983) and Ontario (Sanders 1983) indicate that a family of regional models, as opposed to a single model, may be necessary to provide reasonable confidence limits for predictions. Long term intra-regional (state or province) trapping surveys that follow a standard protocol and utilize a system of permanent plots are necessary to develop and test this hypothesis.

We believe that time series information from pheromone-baited traps will be at least as revealing as long term light trap data (Simmons 1980), without the cost or time consuming logistical problems characteristic of the latter. Also, the relatively low cost of a pheromone trapping system and its applicability at low budworm densities are advantages over the standard egg mass or overwintering larval (L2) surveys.

Assuming that average trap catch will provide a consistently reliable measure of budworm populations or expected damage, cost becomes a decisive factor when comparing the advantages of a pheromone system to other types of surveys. A major portion of the cost of any survey is travel to and between plot locations. Placement and recovery of pheromone-baited traps requires less time and equipment than other sampling methods. This will allow forest managers or survey specialists to implement the system while doing other types of field work. In other words, the major expense of travel can be minimized by combining the travel needs of a survey that uses pheromone traps with other field activities.

Management of a Pheromone Monitoring System

Maximum effectiveness of a permanent, large-scale survey will be attained only if survey responsibilities are centralized. Future application of a standard protocol should be closely supervised and augmented by annual training/review sessions. Experiences during the past three years demonstrated the value of organized review sessions to obtain input from practitioners. These interactive critiques, followed by on-site inspections, are necessary to assure uniformity of trapping procedures. Because we expect the system to change with experience and technical improvements, continuation of some degree of control is especially important. Similarly, centralized data management, that includes analysis, collation of results and dissemination of summary information should enhance opportunities for all agencies to obtain maximum value from future monitoring efforts with pheromone-baited traps.

Survey Procedures

The appropriate number of plots (one three- or five-trap cluster = one plot) must be determined by the agencies responsible for forest management activities or pest surveys. Survey intensity will be determined largely by the significance placed on spruce budworm defoliation (i.e., hazard potential, resource value) and funds available. A few trapping locations may adequately indicate population trends over large areas (Sanders 1981).

In order to continually verify or "calibrate" the system, especially when alterations are made in the survey tool (e.g., trap design, lure characteristics), it is important to establish a minimum of 20 intensive plots in stands where another budworm life stage is annually measured. We envision multiple sets of these intensive plots. The plots included in each set must be selected according to similarity of stand conditions, climate and other factors. Clustering of relatively homogeneous plots will help to minimize statistical variation and provide more reliable models. Combining plots into regional sets for analytical purposes can be accomplished by survey management with help from forest managers, irrespective of political boundaries. Additional satellite plots can be established whenever users wish to extend survey coverage. These satellite plots follow the regular trapping protocol, but collection of supplementary budworm or forest stand data will be minimized. In order to insure future interpretability of satellite plot trapping data, base line information on stand composition, defoliation history and current defoliation is essential. Most of this information should be available from existing forest management records. The more extensive the coverage (plots per unit area of forest), the better forest managers and survey specialists will be able to monitor budworm. The benefits derived from additional plots must be weighed against their costs.

Application of Trapping Results

Mean trap catch can be quite useful within a decision support system for spruce-fir management. Absence of data limits interpretation of the relationship of catches in traps to long term trends, but preliminary efforts at short term predictions are encouraging.

Pheromone-baited traps can detect large-scale moth dispersal that may precipitate many outbreaks. This would be especially useful in remote areas where people are unlikely to observe flight activity. Trap catch would serve as a "pest alert" that provides lead time for a concerned forest manager to make traditional measures of budworm abundance, such as an overwintering larval survey. In addition to documenting the presence or absence of unusual dispersal activity, a network of trap-clusters will help to delineate the geographic area that has been invaded. Knowledge of rapid invasion is especially critical in high value forests, such as plantations, previously thinned stands or deer yards, where prompt action may be required to protect investments or sensitive areas.

Intra- and inter-stand time series data from permanently established plots is an inexpensive way to document and map budworm population trend. Comparison of trend between stands and years may also be used to identify areas that warrant additional evaluation or require immediate silvicultural attention. Similarly, pheromone-baited traps can be used to detect significant population shifts in stands that have historically served as epicenters. The major contribution of this application is that reliable time series information will allow forest managers to anticipate problems several years in advance of significant defoliation. This advance notice provides lead time necessary to alter cutting schedules and plan control activities.

The most sophisticated use of information obtained from pheromone-baited traps is to predict population intensity (i.e., number of larvae or egg-masses/unit of food supply) or expected damage. Initially, interpretation of trap catch data may be used to describe population classes or categories (e.g., expected density low, medium, or high), or to identify a threshold above which significant damage may occur. For some forest managers, this information may be an adequate basis for making management decisions. As this survey system is refined, we anticipate being able to place confidence limits on predictions and, ultimately, to use pheromone-baited traps in place of other, more costly survey methods.

Average trap catch may also be applied in other ways to facilitate short term decision making by forest managers of pest control specialists. For example, adult population monitoring could serve as an index of spray efficacy or a means of timing other survey activities.

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FOREST PEST MANAGEMENT EXPERIENCES WITH SPRUCE BUDWORM PHEROMONE TRAPPING

Dennis J. Souto

Entomologist, USDA Forest Service, Northeastern Area State & Private Forestry, Forest Pest Management, P.O. Box 640, Durham, NH 03824

In 1982, the USDA Forest Service began a special project to correlate trap catches with other predictions of budworm population levels and defoliation in outbreak areas. The 1982 trap catches were much lower than expected because the lure/trap combination did not work well and/or spraying reduced populations drastically. The 1983 trap catch did correlate with defoliation patterns in sprayed areas, and indicated that a mass flight occurred in western Maine. FPM impressions about pheromone trapping are discussed.

Our involvement with spruce budworm pheromone trapping began in 1982 when the Durham Field Office, Forest Pest Management, received special project funding. Also, both the Passamaquoddy and Penobscot Indians were conducting suppression projects in 1982. This activity gave us a location to work in.

Our project focused on demonstrating pheromone trapping in high population areas. Our objective was to correlate trap catches with egg mass, overwintering larval, large larval and defoliation estimates. We provided Doug Allen with our data to use in the CANUSA pheromone project analysis. But our project differed from the CANUSA project in two respects. First, we were looking to work in high population areas. Second, we had aerial Bt applications in many of our clusters.

In each five trap cluster we used covered funnel traps and Hercon laminated lures in both years. Five clusters are located in northern Washington County on Passamaquoddy land. This area consists of spruce and hemlock with about 7% balsam fir. The balsam fir has completely gone by with only live balsam fir regeneration. Tree condition for spruce and hemlock is fair to poor with top kill common in hemlock.

Let's look at the 1982 and 1983 data. In 1982, populations averaged 13 large larvae/18" branch. Although this survey was timed for prespray counts, it coincided with third and fourth instar larvae. These clusters were sprayed with Bt and our moth catch averaged 23 moths/trap. In 1983, populations averaged 8 large larvae/18" branch. The clusters were sprayed again with Bt, and moth catch averaged 20 moths/trap.

I considered the moth catch very low in both years. In fact, the biggest concern I had before the project began was trap saturation. Why hadn't we caught more moths? I thought of two possible explanations. First, our lure/trap combination does not efficiently capture moths that visit traps. Second, our spray projects were so successful that only a fraction of male moths were available to trap.

After our first trapping season, I called Doug Allen and told him about the poor catch. He thought the lures may not have worked well in 1982, but he felt that a correlation with low moth catch was still possible and maybe a blessing in disguise.

The 1983 trap catches were correlated with spray efficacy observations. In the northern spray block, foliage protection seemed poor (aerial observations) and traps averaged 30-35 moths/trap. In the southern spray block where foliage protection was good, traps averaged about 7-8 moths/trap. These results indicate that trap cathes and foliage protection (or defoliation?) are correlated. This relationship deserves more attention, but these traps did have water in them. So, I wonder if these results are reproducible.

Fifteen clusters are located in western Maine on Penobscot land near Alder Stream. This more mountainous area consists of spruce and fir with much less hemlock and a large hardwood component. Budworm defoliated spruce and fir several years ago, but current tree condition is fair to good.

In 1982, populations averaged 3 large larvae/18" branch indiçating a lower population than in Washington County. Nine clusters were sprayed with Bt in 1982. Traps within sprayed areas caught 3 moths/trap compared to 10 moths/trap in unsprayed areas. This difference indicates that spraying does affect trap catches.

In 1983, populations averaged only 0.7 large larvae/18" branch and this area was not sprayed. Trap catch increased sharply to 49 moths/trap - the largest average catch for both years. I thought of three possible explanations why the catch increased so sharply. First, these clusters were not sprayed in 1983. 1982 trap catch in this area does indicate that spraying affects trap catch. However, the very low spring larval population level suggests a mass flight occurred. A third possibility is that the lures performed more consistently than in 1982. Lures did work more consistently in 1983 because trap catch variation between traps in the same cluster was noticeably decreased.

Let me summarize my impressions of budworm pheromone trapping after two years experience:

1. Are low trap catches in high population areas a problem? Is our lure/trap combination effective?

2. 1982 gave a very poor correlation between trap catch and egg mass, overwintering larval and defoliation counts in 1982.

3. The ideal trap will prevent water from entering traps. Water retention can be a major problem.

4. Pheromone trapping is easy to execute compared to egg mass and overwintering larval surveys.

5. Not only lures, but insecticide strips, need to be carefully standardized.

6. Leaving trap hangars in the woods after trapping is completed is a safety hazard. I cut my ear on one.

Although we have not reached our goal of an operational pheromone monitoring system, we have made great progress. Don't throw away your pole pruners yet, as pheromone monitoring for budworm is on the way, and, it will be a valuable addition to our surveying and monitoring tools.

SPRUCE BUDWORM PHEROMONE TRAPPING - VERMONT

EXPERIENCES AND PROBLEMS

Ronald S. Kelley

Forestry Protection Specialist
Vermont Department of Forests, Parks and Recreation, Agency of Environmental Conservation
RD 1, Box 2300, Morrisville, VT 05661

Of the four different types of traps tested during the past three years, the covered funnel trap (CFT) was the most efficient at catching moths but some problems with water intake and retention remain despite annual modifications. Of the two gypsy moth traps tested in 1983, the canister trap produced the best results.

Introduction

Ideally the field testing of a pheromone trap as a survey tool should begin with a single trouble-free trap and lure combination that could be evaluated for several consecutive years. Unfortunately, problems with trap design and lure reliability have meant that we have had to work with four different traps and three different lures during the three years that Vermont has participated in the spruce budworm pheromone project. The one trap that was used each of the three years was modified in each successive year. These factors make it difficult to evaluate the results from one year to another. Specific observations and problems will be discussed by type of trap.

The Perocon 1CP Trap

These "sticky" traps were tested with the PVC pellet lure during 1981 and 1982. They are light and easy to use but most ended up with moth counts at or near the saturation point for the trap. A lure with a slower release rate might work well with these traps but with the lures tested, traps even in very lightly infested stands became saturated so that moth counts did not vary much between stands.

The Covered Funnel Trap (CFT)

The covered funnel trap (CFT) was the primary trap used in the project. It was used with the PVC pellet lures in 1980 and with both the Hercon and Albany International lures in 1981 and 82. This is a non-saturating trap that has been the most efficient trap at catching spruce budworm moths. It has the advantage of being easily constructed out of materials that can be purchased locally but the disadvantage of being time-consuming to assemble and bulky to deploy and retrieve.

Most of the problems encountered with this trap relate to water intake and retention. The moths congregate in the bottom of the funnel and any water retention leads to partial decomposition of moths and attracts undesirable insects such as carrion beetles. Holes drilled through the bottom of the funnel just above the cork did not allow sufficient water drainage during the initial 1981 trials once moths were caught and began to congregate at the bottom of the funnel.

In 1982 corks were replaced by a wire screen plug placed inside the bottom of the funnel. This provided better drainage but it appeared that the air outlet may have reduced the effectiveness of the Vapona strip. This, along with release-rate problems with both commercial lures used, may have been responsible for erratic moth catch numbers within plots in 1982.

In 1983, the plastic cover plate was replaced by one of larger diameter to provide more overhang to shed water. The cork of 1981 was again used, with the addition of the wire screen plug above the drain holes. In making these modifications, we had to drill our own holes through the funnels and above the corks of traps first used in 1982. When traps were collected, it was discovered that if these holes were not flush or just below the top of the cork, water retention remained a problem. And in some plots with large moth counts (i.e. 100+), even correctly modified traps continued to have some moth decomposition problems because large numbers of moths congregated in the bottom of the wire plug and impeded water drainage.

The Gypsy Moth Canister Trap

The gypsy moth canister trap was compared to the CFT trap and the gypsy moth milk carton trap in 5 stands in Vermont in 1983 - four lightly infested stands and one that had become moderate. The trap is light, easy to use, and retains moths in a dry condition. It has the added advantage in that one is able to see if it is catching moths by looking up through the translucent bottom or down through the transparent top. It caught moths as early in the flight season as did the CFT trap. Height of lure suspension varied slightly from one trap to another because everyone bent their own lure-holding wires, but this did not noticeably affect the results. Generally, moth counts were much lower than with the CFT traps except for the moderately infested stand where the canister traps caught more moths. This trap caught more than four times as many moths in the moderately infested stand than in any other stand compared to about a two-fold difference with the CFT and gypsy moth milk carton traps. If this relationship holds true for other locations, this could be an advantage of this particular trap.

The Gypsy Moth Milk Carton Trap

The gypsy moth milk carton trap was tested in 1982 in the same stands where the gypsy moth canister traps were placed. It is the lightest and simplest trap yet tested and also retains moths in a dry condition. It generally caught fewer moths than the canister trap and was not as efficient at catching moths early in the flight season as the canister trap. Even though these traps are made of wax-coated cardboard, they do absorb moisture over time. A couple of them were found hanging by only one wire at the end of the season because the sides became spongy and bent inward, slipping loose from the holding wire on one side. Bending the ends of the wires upward slightly would probably alleviate this problem.

General Observations and Discussion

Both commercial lures worked well in 1983 without the erratic within-cluster results from one trap to another that occurred in 1982. The Albany International lure consistently caught more moths in 1983 than the Hercon lure except when the two were compared in a moderately infested stand. The Hercon lure resulted in a noticeable difference in trap catch between the moderate and light stands that was not apparent with the Albany International lure. If this difference is significant and remains consistent in other locations and other years, it could be an advantage of the Hercon lure.

Northern and central Vermont received a mass flight of spruce budworm moths in July, 1983. It is not known to what degree this influenced moth trap results but it could make it difficult to correlate trap results backwards with data such as numbers of third and fourth instar larvae.

Any trap is subject to windfall damage and animal attacks. In 1983, one CFT trap was downed by a windblown tree early in the season and two gypsy moth milk carton traps were attacked by bears - one of these was completely demolished, and the funnel end of one CFT trap was chewed off by a squirrel. In 1981, one Pherocon trap caught a bird which reduced the numbers of moths that could be collected in that trap. A cluster of traps should be maintained for future monitoring so that data can be obtained even if 1 or 2 traps in a stand is lost. Whether the number of traps per cluster can be reduced depends upon the variability of the trap-catch data, but it is almost as easy and fast to use a five-trap cluster as it would be to use a smaller cluster.

Of the traps used in Vermont, the gypsy moth canister trap tested in 1983 was preferred by field personnel. It is light, easy to use, keeps the moths dry, and appears durable enough to last for several seasons. More testing of this trap with both commercial lures is recommended. The method of lure placement with this trap should be standardized, possibly by providing all users with pre-bent wires that would ensure that all lures are suspended at the height of the trap openings. It might be desirable to modify the lure suspension system so that it resembles that used in the CFT traps. But for consistency of results, it is suggested that any modifications be used in conjunction with a five-trap cluster and Hercon lures as used in 1983.

FOREST PEST MANAGEMENT CONCEPTS OF A GOOD SPRUCE BUDWORM PHEROMONE TRAP

Daniel R. Kucera

Methods Application Coordinator
Forest Pest Management, USDA Forest Service
Northeastern Area, 370 Reed Road, Broomall,
PA 19008

Many agencies and organizations in both State and Federal governments have experienced recent budget and personnel cuts. Consequently, many of us have had to restrict or limit our budworm monitoring activities. The pheromone trap has the potential of replacing more labor intensive spruce budworm surveys. More important, however, the pheromone trap is an additional tool to supplement existing survey techniques.

The characteristics of a good trap are that it should be weather proof, lightweight, portable, easy to construct, commercially available, and consistent in trapping performance. Pest Managers want a trap that is species specific to spruce budworm, a trap that acts as an attractant and not a confusant. They prefer a simple protocol or a simple set of instructions which covers systematic trap placement and allows for uniformity in data collection and compilation. Instructions should be presented in such a manner that data can be compared from province to province or state to state.

The sample design should be one that will allow trap placement in a minimum number of points or sites to get a representative readout on moth activity and potential defoliation for the coming year. Later, after eggs have been laid, more intensive larval sampling points can be set out for fine-tuning population levels. These two augmentative survey tools can then serve as basic data when evaluating the need for intervention or silvicultural management.

Pheromone traps will be useful in establishing baseline data during light infestations. Data collected from previous years will indicate whether or not a population is building.

Traps will also serve to identify pockets of heavy infestation for additional surveys and to provide a more concise analysis. As the population reaches epidemic proportions, other survey techniques will come into play. Their most efficient use will be in determining light to building populations.

Now that EPA has exempted pheromone attractants from FIFRA requirements (August 24, Federal Register), the door has been opened for much quicker implementation of new, more efficient trapping systems. This new ruling covers not only pheromones, but also synthetic compounds substantially similar to those actually produced by an arthropod.

EXPERIENCE AND PROBLEMS WITH PHEROMONE TRAPS

Jerry R. Williams

Coordinator, Spruce Budworm Silviculture,
International Paper Company, Northeast Region,
9 Green Street, Augusta, ME 04330

A pheromone monitoring system of spruce budworm moth activity may be useful to identify areas where more costly and labor intensive monitoring is justified. The system needs to be simple, non-labor intensive, and provide a volumetric classification. More research is needed to predict future outbreaks.

Early detection of changes in population levels of damaging insects is an essential element of forest management. As land managers, we have utilized the light traps to monitor moth activity and egg mass of L-II surveys to predict the next year's feeding, or population levels. Each of these three activities have unique points; both good and bad. Because other speakers are addressing the alternative activities to pheromone use at this workshop, I will skip lightly over them. However, I will attempt to briefly classify how I perceive these to be useful in our Company's program.

1. Light Traps. Incur a moderate monitoring cost, but require specific artificial energy sources to provide illumination. This activity is generally limited to low intensity sampling when used in wildlands or remote areas. Trap catches can indicate the possible severity of next year's insect activity and possibly identify a future change from endemic to epidemic populations.

2. Egg Mass and L-II Surveys. Require a highly labor intensive sampling and processing activity, with resultant high cost per sample unit. These provide valuable predictive levels for the severity of expected defoliation and insect activity. During epidemics or periods of known high infestations, the cost of the sampling is justifiable. In areas of endemic levels, it is very difficult to justify the high costs for monitoring individual stands.

What is needed is a moth activity monitoring program that is not labor intensive, does not require outside energy source, and does not require expensive processing or analysis. Use of such a system would be twofold:

1. To identify sampled stands that experience a level of moth activity that justifies more costly intensive sampling or some other management activity.

2. To identify changes in historic levels of moth activity that would provide an early warning of a future outbreak. This early warning would allow managers to adjust forest management plans accordingly.

It has been assumed by many that pheromone traps may provide such a monitoring tool and research has been conducted as part of the CANUSA program.

My experience using pheromone traps is minimal and limited to participation as a cooperator in the CANUSA project led by Doctor Douglas Allen, S.U.N.Y. CESF, Syracuse. Indications are that pheromones will be useful in monitoring the high value or sensitive areas, but not necessarily the total forest. I believe that the traps will identify those specific locations where additional sampling is necessary and will result in a less costly monitor system overall than is currently in place.

The traps are easy to handle and distribute, and could be established and picked up (with the catch) by foresters, technicians, road crews, or temporary labor when they are working in or passing through the area. The catch should be in some sort of holding unit that allows classification on a volumetric basis. Absolute numbers I do not believe are meaningful or necessary if we are to use this method to simply identify areas where moth activity is substantial enough to conduct more intensive surveys. Furthermore, there is potential for pheromone trap catches to be used in identifying changes in trend and predict timing of future outbreaks which possibly may require a more specific count, but additional research is needed for this objective. I doubt that field personnel will extensively utilize pheromone traps for general surveys if the catches need to be hand counted.

The experimental traps have been easy to use and I expect that commercial gypsy moth traps of similar size, construction, and material to those used in the 1983 CANUSA test should be acceptable. The traps should be available for purchase through outside suppliers and be durable enough for several years use. The pheromone bait and the valpona strips should be readily available and easy to install.

One possible weak point in relying on pheromone trap catches to identify problem areas is the potential of fall or spring invasion of L-II larvae by wind drift. This weakness also exists for areas sampled in early fall by egg mass or L-II survey.

In summary, while my experiences with pheromone traps is minimal, I believe the outlook is good that a pheromone monitoring system of spruce budworm moth activity may be developed into a useful low cost tool to monitor high value stands and identify where additional more costly monitoring is justified. The sampling method should not be labor intensive. Traps should be left in place four to five weeks during the moth activity period and then collected along with the catch by designated workers. The catch will be volumetrically classified by a management forester, technician, or entomologist at the office or lab following collection.

Finally, before pheromone traps can be used operationally in spruce budworm monitoring to identify potential outbreaks while in endemic situations, more research data and effort is necessary to signify the importance of trap catches.

Thank you.

Response to Program Discussion

1. In Maine, the Maine Forest Service conducts the general statewide monitoring system. Our use of pheromone traps would be to supplement the State's program. The selection of stands to be monitored by us would not necessarily be part of a State monitoring system but would be restricted to those high value or sensitive stands where prompt protection or other action is warranted; this would concur with the objective referred to by Doug Allen as a "pest alert system."

2. Implementation - We would expect to use this tool in low population areas of the current epidemic, but primarily we see this being most useful following the full collapse of the present epidemic, in sampling low populations prior to the next outbreak. We must remember that during the period following the collapse of this epidemic, foresters and those involved with daily field work may not have had field experience during high population levels of spruce budworm and most of their knowledge about the spruce budworm will be through the literature only. History has indicated that when populations are low and insects are not a problem, the overall concern for monitoring diminishes as well as the funds available to conduct monitoring. Thus, I believe a low cost pheromone monitoring system not requiring high labor costs or highly technical labor involvement will be more readily acceptable as an operational tool.

3. A comment was made that it may be necessary for two special field trips to place and remove the traps and that this cost may result in pheromone systems being more expensive to operate than the L-II or egg mass programs which require only one field trip. Our intentions are to possibly use pheromones where personnel are travelling in the area on other assignments and the establishment or collection of traps would incur only minimal costs and effort. However, if we found it necessary to make special trips, we would consider the use of other alternatives, selecting the most efficient and cost-effective.

4. In response to the question of how useful a pheromone trapping system would be without having absolute counts, again I state that our primary use of this monitoring system would be as a pest alert where absolute numbers are not necessary but an index would be the output. The index could indicate areas of no concern, areas where additional surveys should be conducted before fall, or perhaps where levels of activity is such that some treatment activity should definitely be considered and supplemented with an L-III or L-IV verification prior to implementation of the treatment.

5. Dennis Suoto's presentation included the objective to evaluate spray treatments. Yes, I assume one could use this to supplement the post treatment surveys and determination of efficacy. We often find larvae present after the spray treatment and at times we find that these larvae do not complete their development to the adult stage. Thus, efficacy surveys of treatment areas might include measured mortality plus reduced moth activity as compared to unsprayed areas.

WAYS TO REDUCE ERRORS AND IMPROVE EGG

MASS SURVEYS

Gary A. Simmons, Gary W. Fowler and Norman C. Elliot

Associate Profesor, Dept. of Entomology, Michigan State University, E. Lansing, MI 48824-1115; Professor, School of Natural Resources, University of Michigan, Ann Arbor, MI 48109; and Graduate Student, Dept. of Entomology, Michigan State University, E. Lansing, MI 48824-1115.

When estimating egg mas density, two kinds of errors usually occur: those from random chance and those from human sampling and counting errors. Random chance errors cannot be avoided, but human-caused errors can be decreased by taking certain precautions. This paper offers guidelines to minimize human-caused errors.

Egg mass surveys are commonly used to gain a fix on spruce budworm populations and expected damage. Errors, however, can creep into these surveys and possibly influence reliability. To begin with, egg mass density estimates are highly variable, often deviating from "true" populations densities by 100% or more. These deviations result from the small samples we take compared to all the branches that could be sampled in a forest. The resulting "random" estimating errors are unknown to us and cannot be controlled by what we do.

Other errors occur from the way we sample and count. These usually occur when we

a) sample one host species in stands containing multiple host species,
b) sample too low or too high in the tree crown,
c) use small branches as the sample unit,
d) make rough estimates of surface area when calculating egg density,
e) assume egg masses do not vary in size from one generation to the next.
f) do not distinguish between new and old egg masses when examining foliage, and
g) make counting errors when searching for egg masses,

In the following, we discuss each source of potential error and provide guidelines for taking precautions to minimize such error.

One Tree Species in a Stand of Mixed Host Species

Surveys often concentrate on sampling balsam fir even though white and red spruce may also comprise stands. Our studies show that in white spruce/balsam fir stands, egg densities are 2 to 4 times higher on white spruce than on balsam fir. Restricting sampling to fir trees could result in underestimates. To counter this error, include fir and spruce in rough proportion to basal areas of each in a stand.

Branch Location

Branches selected from the upper third of the live crown of a tree tend to overestimate populations, and estimates tend to be highly variable. Branches selected from the lower third of the live crown tend to underestimate populations, and again estimates are highly variable. Sample branches taken from the middle third of the live crown tend to slightly overestimate population densities, but the variability is much less than the other areas of the crown. To minimize error, sample from the middle third of the live crown.

Branch Size

Egg mass sampling schemes have used 15-inch branches, 18-inch branches and full-length branches. Our studies show that when using full-length branches estimates vary the least compared to all other branch lengths.

Surface Area Measures

Egg mass surveys sometimes report number of egg masses per unit surface area (10 ft^2 or m^2 or 1000 cm^2). Ways to estimate surface areas include (a) measuring the length of the branch and multiplying by the width at the midpoint, and (b) cutting up the branch into small segments and placing on a grid. We have found the grid method is the most consistent measure of surface area.

Old and New Egg Masses

A small percentage of egg masses are retained on foliage for more than one year. Consequently, densities may be overestimated because both old and new are counted. Here are some guidelines that may help distinguish between old and new egg masses.

(a) If egg masses are found on current year's foliage, they are definitely new egg masses.
(b) Color, shape, and condition of egg masses can be of some help; the tendency is as follows:
New: bright white, bulgy, intact
Old: brownish-gray, flat, deteriorated

Size of Egg Masses

Egg mass densities are usually reported as "number of egg masses per square ft of foliage." This implies that the number of eggs in a mass is the same from mass to mass and year to year. Our studies have illustrated that the average number of eggs per egg mass varies from year to year and locality to locality. We suggest taking a sample of egg masses and determining average egg mass size each year to correct for these differences.

Egg Mass Searching

While all counters will underestimate egg mass numbers, the extent to which individuals overlook egg masses varies widely. In addition, counting accuracy for a given individual may vary with time, egg mass density (low, medium, or high), or tree species being examined.

We have developed a simple method for adjusting egg mass density estimates for accurate counts and therefore more accurate conclusions based on the resulting data (Fowler and Simmons 1980). Four steps are involved in applying a bias adjustment to counts obtained by examining tree foliage for egg masses:

(a) determine the range of egg mass densities expected in the survey,
(b) check the accuracy of each individual involved in counting,
(c) calculate the average counter accuracies for each examiner, and
(d) use the accuracy estimates to adjust counts for each examiner.

The accuracy of each counter on the crew can be determined by carefully checking individual branch samples that already have been counted by a member of the crew. The supervisor or the most experienced counters should conduct the checking process. Fifty or more branches per counter for each density class should be checked (Fowler and Simmons 1980). Checking should be done periodically and without the counter knowing when a branch is going to be checked.

Once the checker has re-examined the branches for egg masses, the average counter accuracy can be determined. Estimates of accuracy should be determined for each counter for each egg mas density level encountered during the survey. If time and resources permit, other factors can be considered when determining accuracy estimates for each counter.

Once accuracy estimates have been determined they can be used to develop more accurate (less biased) estimates of egg mass density. Readers interested in the details of this bias adjustment technique should consult Simmons and Fowler (1982). For a more in depth understanding of the derivation of the techniques see Fowler and Simmons (1980).

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AUTOMATED EGG MASS COUNTER

Daniel T. Jennings

Research Entomologist, USDA Forest Service
Northeastern Forest Experiment Station
USDA Building, University of Maine
Orono, ME 04469

Loren F. DeLand

Electrical Engineer, USDA Forest Service
Missoula Equipment Development Center
Fort Missoula
Missoula, MT 59801

Reviews the design and development of an automated egg mass counter. The counter scans foliage samples, detects egg masses based on their characteristic fluorescence, and counts the egg masses electronically.

Egg masses of the jack pine budworm (Choristoneura pinus pinus Freeman), the spruce budworm (C. fumiferana (Clem.)), and the western spruce budworm (C. occidentalis Freeman) fluoresce when excited by longwave ultraviolet (UV) light. The excitation wavelength extends from 300 to 400 nm. Early tests demonstrated that both accuracy and efficiency of egg-mass examinations can be increased by inspection of foliage illuminated with UV light (Jennings 1968; Acciavatti and Jennings 1976).

A study was initiated at the University of Maine, Departments of Physics and Electrical Engineering, in collaboration with the Northeastern Forest Experiment Station and the Department of Entomology, to determine: 1) the fluorescence properties of spruce budworm egg masses; 2) the fluorescence properties of associated components on balsam fir foliage; and 3) the feasibility of using these properties to scan foliage, detect egg masses, and count the egg masses electronically.

Spectral analyses indicated that egg masses of the spruce budworm have a characteristic violet and green fluorescence that is distinguishable from most other fluorescing components on balsam-fir foliage (Carniglia et al. 1977). Egg mass fluroescence is predominately violet light, but the ratio of green to violet fluorescence is also important. By measuring fluorescence levels together with ratios of green to violet fluorescence, egg masses of the spruce budworm can be distinguished from most other fluorescing objects on host tree foliage.

A Prototype I egg mass counter was designed and built at the University of Maine. Basic components of the counter include: an electro-optical scanner, beam splitter, photomultiplier tubes, and electronic signal discriminator. Preliminary tests of Prototype I vs. manual counts indicated that, when calibrated, manual counts can be predicted ($R^2 = 0.97$, $\alpha = 0.01$) from electronic counts (Turner et al. 1980). Electronic counting showed a highly significant reduction in processing time; electronic $\bar{X} = 8.6$ min./branch vs. manual $\bar{X} = 29.5$ min./branch, n = 477 branches.

A Prototype II egg mass counter is being designed and developed at the USDA, Forest Service, Missoula Equipment Development Center, Fort Missoula, MT. New design features include: a variable optical scanning system to detect egg mass fluorescence of both spruce budworm and western spruce budworm egg masses on 5 host tree species (balsam fir, spruce, Douglas-fir, white fir, and grand fir); a stepper motor-variable belt drive system; and a programmable computer (microprocessor) with terminal for operation and maintenance. The new Prototype II includes an "egg hunt" routine for scanning foliage until an egg mass is found, stopping, and then allowing the operator to look at what the counter "sees".

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L_2 SURVEYS - SODA WASH

FOR "NEW AND IMPROVED TECHNIQUES FOR MONITORING AND EVALUATING SPRUCE BUDWORMS

Henry Trial, Jr.

Director, Survey and Assessment
Maine Bureau of Forestry, Department of Conservation
P. O. Box 415
Old Town, ME 04468

Introduction

This paper is a discussion of work done in the winter of 1982-83 by the Maine Forest Service (MFS) to evaluate and improve the over-wintering larval sampling method (L-2 method). The MFS has used the caustic soda larval extraction method developed by Miller et al (1971) since the mid 70's as a supplement to the egg mass population prediction survey. This paper will also include a brief discussion of evaluations conducted from 1978 to 1983 designed to test the predictive power of the L-2 method.

The desire to evaluate and improve the over-wintering larval extraction method in Maine was motivated by two factors. First, egg mass sampling conducted in the late 70's proved to be erratic and resulted in several erroneous predictions. Egg assessments both overestimated and under-estimated populations in those years. Second, the L-2 method seemed to present an excellent opportunity to reduce survey costs by reducing the time required for laboratory assessment. Even when relatively crude methods were employed in the late 70's, 2 or 3 laboratory workers using the L-2 method could evaluate as many samples per week as an 8 person egg mass laboratory. When spruce is included in the survey method, the L-2 method has an even greater laboratory advantage.

Much of the work summarized here is ongoing, but was used in the 1983 Maine population prediction survey. It has not been published, but two publications are expected. One publication will deal with the predictability of the L-2 method and the second with L-2 laboratory and field procedures.

Funding for this work has been provided by the Maine Forest Service and Maine forest land-owners through the Maine budworm excise tax. Several useful suggestions on method development have been provided by the Eastern Spruce Budworm Council, Committee for the Standardization of Survey and Assessment Techniques.

Methods

To contrast the new techniques discussed, the method used by the MFS through the 70's will be described.

The original technique employed was that of Miller et al (1971) and involved collecting 4, three foot fir branches from a collection site, cutting each branch into 3-4 inch sections, bagging the foliage from each branch separately and transporting it to the laboratory for processing.

The foliage from each branch was placed in a pail, approximately 1/3 cup of lye (NaOH) added, and the bucket filled with hot tap water from a garden hose. Water temperatures varied from 120° to 180°F. These buckets were set on the floor, manually stirred every 15-20 minutes, and the foliage allowed to soak for 4 to 6 hours.

Following soaking, the foliage and contents of each bucket were poured and washed through progressively smaller sieves and the remaining substrate collected on filter paper for larval counting. Larval counts were extrapolated to 100 square feet of foliage.

In the early years of the survey, few samples were processed annually. Admittedly, the original laboratory techniques and the laboratory facilities were quite primitive. As the size and importance of the survey grew, mainly due to problems with the egg survey, it became apparent that improve-ments both in extraction methods and in the lab-oratory facilities were necessary.

Changes were made in the L-2 method and facilities to accomodate the expanded scale and importance of the survey. First, a facility was designed and built specifically for the L-2 process. A 22' x 18' building was renovated for the laboratory. Significant changes from former facilities were:

1. A mechanical, 4 shelf, vented, shaker box designed to provide constant sample agitation and to maintain water temperatures longer
2. Installation of an unlimited hot water supply
3. Segregation of the "washing" and "counting" rooms
4. A metered and temperature regulated water supply
5. An efficient, self-contained washing table which makes all chemicals available at one location
6. Multiple filtering and counting stations with vacuum regulated through a vacuum pump

Changes in the field procedure involved a change from 4 fir branches per point to 3 fir and 3 spruce branches per point.

Several facets of the laboratory method were evaluated to determine the optimum NaOH concen-tration and water temperature. Soaking time, the agitation system, the rinsing system, and total larval extraction were also tested. Regimes tested are as follows:

% NaOH	H_2O Temp. °F.	Treatment
1.5	100, 120, 140	2 hrs.+2 hrs.,2.5@120°
2.5	100, 120, 140	2 hrs.+2 hrs.,2.5@120°
3.5	100, 120, 140	2 hrs.+2 hrs.,2.5@120°
3.5	120	1 rinse vs. 2 rinses
2.5	120	3-2 hr. soaks
2.5	120	2 hrs. shaken vs. 4 hrs. on floor

All tests were done with a standard 6.0 liters of water at carefully regulated temperature. Buckets were stirred manually every 30 minutes while still in the shaker box.

The predictability of the L-2 method was checked by correlating L-2 counts with L-3 spring counts. Evaluations were made using stepwise multiple regressions and covariant analysis. Data analyzed was gathered as part of the regular MFS survey and includes fir and spruce assessments.

Results and Discussions

Initial tests of the new laboratory facilities and equipment were encouraging with regard to sample output. A laboratory staff of 4 workers was able to process 100 branches daily compared to less than 30 branches per day from 4 egg mass workers. The laboratory can be easily expanded to a capacity of 120 to 180 branches per day by adding 2 more workers. Spruce is only slightly slower to process than fir compared to being more than twice as time consuming with the egg method. All equipment worked extremely well after many initial design changes. One lingering equipment problem is the shaker box. Due to extreme stress on the vibrating shafts, bearings, and drive belts, parts fail often. Spares are always kept and can be installed quickly. The vibrator may be redesigned.

Trials of extraction efficiency were surprising and discouraging. Extraction efficiency was relatively consistent, but only 35 to 40 percent of the over-wintering larvae were being recovered on the filter paper. It was initially thought that the poor efficiency was due to the short soaking time, the NaOH concentration, or water temperature.

Before extensive method testing was started, brief initial trials were conducted to identify major problems with the method. The first surprise encountered was that NaOH percentage and water temperature, while important, did not account for loss of the major portion of unrecovered larvae. Another trial showed that most larvae were lost because of inadequate rinsing of foliage after soaking. Losses here could be as high as 30 to 40%. An intensified rinse system was established and brought recovery percentage into the 60 to 75% range. The new rinse method was used in all future tests.

Tests of NaOH percentage and water temperature were designed to determine optimums. Results of a statistical analysis of these tests are shown in Table 1.

Table 1. Statistical Analysis of Larval Extraction Variations.

	% Concentration NaOH		
Temp. °F.	1.5	2.5	3.5
100	60.9[1] a[2]	65.9 b	79.3 b
120	70.6 b	84.4 c	83.5 c
140	77.5 b	86.6 c	89.3 c

1. Percentage of total larvae recovered from 2 soaking trials with tje 1st soaking.
2. A common letter indicates no significant difference in larval recovery.

All NaOH concentrarions and temperatures extracted 60% or more of toral larvae recovered. Total larvae were estimated on the basis of 2 washes. Regimes of 2.5% NaOH at 120 and 140° F. extracted more than 83% of the larvae with the first soak. None of these 4 regimes gave statistically different results. As a result of this test, a standard regime of 2.5 percent NaOH in 120° F. water was adopted for the 1983 survey.

The question of what portion of the total larvae on a branch are extracted by 2 soakings was answered with a test involving 3 soakings. This test showed that the 3rd soaking yielded less than 2.5 percent of the total larvae recovered. This result shows that recovery percentages reported are probably accurate.

The rinsing process which had been established early in these tests was further evaluated to check its effectiveness. Results showed that a second rinse yields about 8% more larvae with a small increase in laboratory effort. As a result of this test a second rinse was added to the standard method.

A two hour soak in the shaker box was found to be more efficient and more consistent than a 4 to 6 hour soak with 15 minutes stirring.

The most important result of the 1982-83 L-2 trials in Maine was an understanding of the importance of each part of the method and its impact on accuracy. The current method as developed from these trials is as follows:

1. Use of the shaker box
2. Water at 120° F
3. NaOH at 2.5%
4. 2 Hour soak time

5. Hand stirring every ½ hour

6. Use of an aggressive rinse system using 2 rinses

Tests of the predictability of the L-2 method have been underway since 1978, but these tests were done using the former low efficiency extraction techniques. These tests will be repeated in 1983-84 with the new extraction techniques.

Results of the predictability test conducted in 1981 showed that L-2 counts are highly correlated ($r^2 = .75$) to spring L-3 counts. Correlation to L-3 counts can be improved to $r^2 = .84$ if spruce counts and past defoliation values are considered in the form of a stepwise regression analysis. Past evaluation of egg count correlations to L-3 values have yielded much lower correlations ($r^2 = .65$). In general terms, the Maine L-2 method is an accurate predictor, about 20% more often than the Maine egg mass survey.

Tests have shown that L-2 samples taken in September and October correlate very well with mid-winter samples ($r^2 = .90$). This information allows the MFS to conduct the general L-2 survey in a time frame which allows landowners to make management decisions based on this data.

It is encouraging that the apparently good population prediction survey using L-2 costs less than the egg survey. Field costs are equal, but laboratory costs are about 30% less with the L-2 method. Potential for L-2 method improvements is also significant. A sequential counting system for the laboratory could be developed. The L-2 method has much potential for mechanized counting using technology similiar to that used to count spray droplets. The present and future usefulness of the L-2 method will some day lead to its use as Maine's sole population prediction method.

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EVALUATING PARASITISM IN SPARSE SPRUCE BUDWORM POPULATIONS

Patricia M. Hanson

Research Assistant, University of Vermont, Entomology Research Laboratory, 655 Spear Street, So. Burlington, VT 05405

Current techniques used for sampling spruce budworm populations are discussed in light of the intrinsic difficulties presented by low pest densities. Methods of recovering parasitoids are reviewed. The need for continued observation of natural control factors through endemic periods is stressed.

Sampling Sparse Budworm Populations for Parasitoids

The eastern spruce budworm parasitoid complex has been relatively well-studied in epidemic populations (Dowden et al. 1948, Wilkes et al. 1948, McGugan and Blais 1959, Blais 1960, Miller 1963). Like many other host-parasitoid communities, only limited data have been obtained at endemic or sparse population levels, largely because of the major effort associated with finding sufficient numbers of spruce budworm (Miller and Renault 1976). Sampling to obtain valid estimates of the degree of parasitism in moderate to heavy populations of spruce budworm presents a difficult problem (Lewis 1960). In endemic situations, establishing population size of the host alone is onerous (Miller and Macdonald 1961). Dowden and Carolin (1950) found that determining the number of spruce budworm in an area is probably the most difficult research problem associated with this insect, and that it is not possible to present the true value of mortality percentage figures unless data on density of spruce budworm populations are available.

Spruce budworm sampling procedures have been reviewed recently (Sanders 1980). Procedures are grouped according to the stage of the insect's life cycle being sampled: egg, second instar larva, large larva, pupa, or adult. While gross estimates of population density are possible with many sampling methods, it is difficult to define the relationship between low density and required sample size (Miller 1964).

Egg mass sampling, a procedure for assessing and predicting spruce budworm population trends, has traditionally been tedious and time consuming, and some egg masses are missed even by experienced workers (Morris 1951). When populations are low, egg masses are too scarce to be sampled efficiently (Grimble 1981). Even when populations are in he outbreak stage, an adequate sample requires laborious searching of foliage to locate egg masses. To eliminate this problem, a conveyor-belt system for a prototype spruce budworm egg mass counter has been developed which detects and counts egg masses that fluoresce as they pass under a black light[1]. Large amounts of foliage can be searched with increased accuracy and efficiency.

The "wash out" procedure for overwintering second instar larvae (Miller and McDougall 1968, Miller et al. 1971) is applicable to sparse populations, but, again, large amounts of foliage must be examined to attain precision. Both the automated egg mass counting procedure and the second instar larval counting method help to reduce inaccuracies due to human oversight. Predictive values derived from these new methods must change to reflect this greater precision. Factors like egg mass size variation resulting from different host tree species also need to be considered in the development of predictive tables and regression equations (Washburn and Brickell 1973).

Miller and Macdonald (1961) suggested that indirect sampling methods, such as the analyses of bird gizzard contents, might be useful in population work since birds are efficient samplers of large larvae. Although the inherent population limitation of birds prevents them from increasing enough to check outbreaks, they may be valuable when the budworm population is low (Graham and Orr 1940). The analysis of the gizzard contents of four species of warblers from the Green River Watershed in New Brunswick showed 0.5 larvae/gizzard in 1959 and 0.27 in 1960, or a population reduction of 46 percent (Miller and Macdonald 1961). Actual population counts showed a reduction of 70 percent (0.275 to 0.082 larvae/m^2 foliage). For more exact predictions at these low levels, some refinement of technique is necessary.

The effect of killing birds to ascertain low spruce budworm populations can be detrimental. This was verified by Dowden et al. (1953) who found a far greater reduction in budworm populations in check areas where birds were unmolested than in areas where their numbers were reduced by shooting.

Certain species of birds show limited numerical response to increasing spruce budworm densities although they do not contribute significantly to the regulation of the spruce budworm at high densities (Morris et al. 1958). Sanders (1970) suggested that the reduction in numbers of certain bird species known to respond numerically to spruce budworm increase can be predictive of the population trend of the spruce budworm.

1/ Jennings, D.T., 1983, personal communication.

The use of pheromone traps for monitoring adults in low level spruce budworm populations is currently being evaluated (Allen and Abrahamson 1982). Field experiments are in progress in New England and the Lake States to gather trap-catch data for correlation with subsequent counts of egg masses, estimates of larval density, and defoliation. Researchers are also trying to determine the most effective placement and spacing of traps in such a monitoring system. The use of light trap data for assessing changes in endemic spruce budworm populations is being evaluated (Simmons 1980).

Some techniques useful in spruce budworm epidemics are not reliable when densities are low. For example, although reasonably accurate estimates of tree defoliation can be made by trained observers from aircraft when budworm populations are moderate to heavy (Waters et al. 1958), the absence of discernible defoliation is a weak guarantee that the spruce budworm is absent. Similarly, methods currently in use to evalulate and classify defoliation from the ground (Fettes 1950, Dorais and Hardy 1976) may not work as indicators of population levels when defoliation is negligible.

When removing foliage for subsequent counting and classification, the number of sampling units required, i.e., 45 cm branch tips, whole-branch sample, or other units, increases rapidly as population densities decrease (Sanders 1980). Life tables become more difficult to construct because low pest densities discourage attempts to procure fixes at more than one or two of the insect's developmental stages. Consequently, year-to-year changes in one developmental stage, rather than survival within each age-interval, are analyzed (Miller and Macdonald 1961).

The difficulty in collecting sufficient numbers of individuals is reflected in the rarity of concrete assessments of mortality factors in endemic population studies. Blais (1959) and Fye (1963, 1965) investigated endemic poulations in the Gaspe Peninsula of Quebec and Ontario, respectively. Miller and Renault (1976) conducted parasitoid studies in endemic spruce budworm populations in New Brunswick.

Our investigations of the parasitoid complex associated with endemic populations in Vermont began in 1980. Spruce budworm population criteria for establishment of study plots were 1) that overwintering larval counts be $<3/m^2$ of foliage and 2) that the previous year's defoliation was $<30\%$. Degree days accumulated above a base temperature of $5.56^{\circ}C$ were used to predict the development of post-diapause budworm (Miller et al. 1971).

Spruce budworm larvae and pupae were collected from six plots at four periods of development. Collection periods (described below) represented optimal times to assess the incidence of certain species of parasitoids (McGugan and Blais 1959, Leonard and Simmons 1974).

1. Predicted mean of third instar. The best estimate of population density may be provided by third instar population (Greenbank 1963). Because mortality due to parasitoids is considered almost nil at this stage (Morris and Miller 1954) and because of rearing difficulties associated with the tiny larvae, few have undertaken collection of this instar in parasitoid studies.

2. Predicted mean of fourth instar. The abundance of early larval parasitoids and an indication of the sequence of attack of the late larval parasitoids can be derived from fourth instar budworm.

3. Predicted mean of sixth instar. This timing should coincide with the maximum abundance of late larval parasitoids.

4. Predicted mean of pupation. Incidence of pupal parasitoids can be measured from this collection.

The speed at which spruce budworm develop necessitates a concerted sampling effort to ensure that all samples are taken within the desired degree-day range.

Branch samples were clipped with pole pruners from random positions in the midcrown of sample trees. As larvae mature, the probability of their dropping off branches when disturbed increases (Sanders 1980). Therefore, basket attachments or branch holders on pole pruners were used for sampling large larvae.

The number of branches sampled during any collection depends on the number of insects present and the objectives of the survey. It is extremely important to record the number of branches sampled to find the desired number of spruce budworm.

Methods of Determining Parasitism

Several methods have been employed for the measurement of spruce budworm parasitoid activity. These range from indirect methods, such as trapping of adult parasitoids (Nyrop and Simmons 1982) and sampling foliage for parasitoid cocoons (Simmons and Chen 1974), to direct recovery of parasitoids from spruce budworm hosts.

Recovery of parasitoids is accomplished in two ways. They can be obtained by dissecting field-collected host larvae and pupae, or they can be reared from collected eggs, larvae, and pupae in the laboratory.

frequent occurrence in high density spruce budworm populations (McLeod 1977).

Thirty species of parasitoids, representing five Hymenoptera and one Diptera family, were reared from the spruce budworm during the course of this study. Most abundant were members of the Apanteles complex, then Glypta fumiferanae (Vier.), Meteorus trachynotus Vier., undetermined species of Encyrtidae, Charmon gracilis (Prov.), and Apechthis ontario (Cresson). Several hyperparasites were identified. Aggregate percentages of parasitism ranged from 89-98% in the study plots.

Forecasting Spruce Budworm Infestation Intensity and Damage

At a given time, some members of the spruce budworm parasitoid complex are relatively rare while others are common (McGugan and Blais 1959, Miller and Renault 1976). They may act singly, in combination, or in sequence. Some respond to changing host density, and their effectiveness varies as the population size grows (Knipling 1979).

It is not unusual for endemic host insects to have large complements of parasitoids (Force 1974). For the spruce budworm, 10 or more species of parasitoids may be associated with just one larval instar. Some ecologists attribute this degree of species packing to the extreme specialization of parasitoids (Force 1972). Where more than one species is exploiting the same host during the same or different life stages, methods of partitioning host resources are necessary (Price 1972).

On the other hand, a parasitoid that is capable of adapting to changing conditions or controlling hosts over broad geographical ranges has certain advantages (Graham and Knight 1965). The ability to feed on more than one host is beneficial during the collapse period. Then, the polyphagous parasitoid would not suffer from food shortage and higher population levels could be maintained. This advantage enables the parasitoid to retard the subsequent multiplication of the original host at a later time. Clearly, this ability can be modified by other variables, including the reproductive potential of the parasitoid.

Major differences in the abundance and diversity of parasitoids attacking epidemic and endemic budworm populations have been recorded. While the important species of the parasitoid complex associated with epidemic populations appear superficially similar throughout the range of the pest (McGugan and Blais 1959), data from endemic studies indicate that the complex is less predictable when spruce budworm populations are low (Fye 1963, Miller 1963, Miller and Renault 1976).

Continued observation of parasitoid fluctuations through endemic periods can yield insight and knowledge that may some day foster a management practice that can delay or prevent the next outbreak. Parasitoids could be a powerful predictive tool, providing an index to the spruce budworm population cycle.

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SILVICULTURAL PRACTICES OF SPRUCE-FIR STANDS TO MINIMIZE IMPACT OF SPRUCE BUDWORM OUTBREAKS

Kenneth F. Lancaster

Field Representative, Forest Management, Northeastern Area State and Private Forestry, USDA Forest Service, P. O. Box 640, Durham, NH 03824

A discussion of the silvicultural practices that can be employed in managing spruce-fir timber type to increase its resistance to the spruce budworm. The silvicultural options identified as being most effective include: shortening the rotation, reducing the fir component, converting to non-host species, and developing a patchwork of age classes.

Introduction

It is well documented in the literature that the application of chemicals as a spruce budworm management tool has its limitations and cannot be viewed as being entirely effective in controlling the insect. Silviculture also fits into this category. Silvicultural practices have long been recognized as a mechanism of reducing losses from a budworm attack, but not as the final answer to control. With the intensification of forest management of the spruce-fir timber type, the potential exists to successfully compete with the insect for the resource.

Essentially, we have reached the point of recognizing the spruce budworm as one of the perennial problems of the spruce fir type that must be shared with regeneration failures, overstocking, deteriorating stands and low-growth rate. Westveld (1953) alluded to this issue when he stated, "All the standard practices that form the repertoire of the practicing forester, ranging from cutting methods to stand improvement and protection measures, must be brought to bear on the problem(s) if the overall (production) goals are to be realized in a reasonable period."

Standard Silvicultural Practices

Uneven-aged Management

The spruce-fir timber type is well-suited for either uneven-aged or even-aged management. There are standard silvicultural practices established for both systems. Spruce and fir are tolerant species capable of regenerating in the shade of an overstory of brush or trees, or in the opening of clearcut areas. Of the two species, fir is by far the most aggressive. Fir seeds much more prolifically than spruce. Fir seedlings develop more promptly, have more rapid root development and seedling height growth. Spruce is weaker, more fragile, and grows slower than fir during the seedling establishment period.

Because fir has this inherent capability of rapid seedling establishment and development and the fragile nature of the spruces, special forestry measures are required to increase the spruce component in a new stand over and above what was present in the old stand. Under uneven-aged management, these special forestry practices are built into the system to favor spruce. By maintaining a continuous tall tree cover, removing the fir in periodic harvest operations and providing a good source of spruce seed, the management system holds fir seedling development in check and compensates for the slow seedling growth of spruce.

Even-aged Management

Under even-aged management, the regeneration method is the installation of a clearcut at the end of the rotation. The success of this practice is dependent upon the abundance of advanced regeneration of spruce and fir. If advanced regeneration is not present, invading hardwoods and shrubs such as mountain maple, hazel, and raspberries take over the site temporarily. It usually takes 10 to 15 years for the softwoods to overcome this brush stage and become fully established. Clearcutting without advanced regeneration favors fir and less desirable hardwood tree species such as red maple and poplar. In many cases, the site develops into a mixed stand of hardwoods and softwoods rather than a pure stand of softwood. In some instances, this can be a desirable change especially if the mix of species includes a representation of the more desired hardwoods such as white and yellow birch, white ash, and sugar maple on the upland secondary sites.

One of two harvesting methods can be used to correct a deficiency of advanced regeneration: (1) a two or a three cut shelterwood, or (2) a strip cut with strips at least as wide as the tallest trees or up to 150+ feet wide. Both methods provide excellent site conditions for regeneration and result in a high representation of spruce in the new stand--up to a 30% increase. Additionally, a time loss of 10 to 15 years to the brush stage is avoided for the most part.

Silvicultural Guide

Prescription guidelines for managing stands of spruce-fir are well established in the silvicultural guide (Frank et al 1973). Specifically, early thinning is recommended in sapling stands when they are about 10 feet in height. These early thinnings or cleanings in stands developed after a shelterwood cut can have the greatest impact on composition change. Experimental trials on the Penobscot Experimental Forest, Orono, Maine, have demonstrated an increase in the spruce component of over 50%. Although this degree of change cannot be expected in all cases, it does illustrate the importance of the measure in altering composition. Even with its potential, however, cleaning young stands is a practice rarely installed, mainly because of the high cost of the measure.

In pole and sawtimber stands, commercial thinning is recommended when stocking is above the halfway mark, between A and B levels, of the stocking chart (see Appendix). The chart identifies stands between the A and B levels as adequately stocked. Stands above the A level are overstocked; those at the C level are understocked, but represent a point where ten years of growth should raise the stand to the B level. B level represents minimum stocking for maximum individual tree growth. Since the intent of thinning young even-aged stands is to foster rapid growth of the individual crop trees while fully utilizing site capacity, reducing the stand to the B level is the intended thinning goal.

Silvicultural Options To Reduce Vulnerability

These clearly defined management strategies are directed toward timber production of the spruce-fir timber type without the interference of the spruce budworm. To compete with the budworm, however, adjustments must be made in these practices with the expectation that these alterations will not seriously reduce timber production. The intent here is to identify silvicultural options that are considered most effective in growing the resource at the lowest possible level of vulnerability, with the main thrust being to: shorten rotation, reduce the fir component in spruce-fir stands, convert to non-host species where the opportunity arises, and develop a patchwork of age classes.

Uneven-aged Management

Uneven-aged management of spruce-fir has many attributes that are highly appealing to the non-industrial private landowner. It is a system that provides periodic income, maintains a continuous tall tree cover and provides a minimum amount of disturbance during harvest operations. Aesthetic values are protected throughout the entire period of management.

Even with all these points in its favor, uneven-aged management needs a critical evaluation as to its effectiveness in reducing vulnerability. The system is man-made, requiring a high degree of professional input and a lengthy time span to develop the uneven-aged structure. Additionally, severe infestations have converted many uneven-aged stands to even-aged in a matter of a few years, undoing the professional work of many years. These are factors which tend to cause the system to be looked on by many professionals with disfavor. Baskerville (1975) addressed this issue. He stated, "The net result of the practice of selection forestry would be the preservation of large areas of mature (or near mature) forest which would be ideal for budworm survival. It would appear that the concept of the selection forest has no place in management for control of the budworm." With these points considered and the degree of uncertainty that exists, it would indicate that research in this area would rate top priority.

Even-aged Management

Although less appealing aesthetically, even-aged management is without these critical limitations. It is easy to apply and has proven to be most effective in reducing vulnerability. The system provides the landowner with the best options such as converting to pure stands of hardwoods or mixed stands, or converting to white pine, black spruce, and other non-host species by planting.

It is the opportunity to breakup spruce-fir stands into a patchwork of age classes rendering each subunit of the stand to a lower level of vulnerability. Even-aged management provides for the rapid development and growth of each age class unit--seedlings, saplings, poles and sawtimber.

Conversely, uneven-aged management favors rapid sawtimber growth, with less than maximum growth of many of the smaller size classes. This is because the saplings and poles are below the main crown canopy and many of them are not free to grow and under competition stress, causing them to be less vigorous. This subjects the smaller size classes to greater danger of loss by the spruce budworm.

Rotation Age

Most spruce-fir stands are presently being managed rather extensively on a 70-90 year rotation or longer. The literature suggests that the most important step to reduce vulnerability is to shorten the rotation to age 50 (Hatcher 1960). This requires the intensification of forest management practices so that trees are free to grow without competition throughout the entire rotation.

The most critical first step in intensifying management of natural stands is cleaning young sapling stands. With this practice, followed by a thinning of pole stands, the growing of a crop of pulpwood and small sawtimber in 50 years is within the realm of possibility. Without the cleaning measure, it is questionable whether trees can be grown to sawtimber size in this short period of time.

Conversion To Non-host Species

Conversion to hardwoods is an option that should be considered, particularly on the best upland sites. If desirable hardwoods are present in the stand or in the surrounding stand, this is a promising, viable option. To avoid the invasion of less desirable hardwoods, red maple and aspen for example, a two cut shelterwood can be employed to bring about the conversion to more desirable hardwoods--sugar maple, yellow birch or white ash. If paper birch is present and paper birch is desired, clearcutting the area leaving behind birch seed trees would be the appropriate method. If desirable hardwoods are not present, the obvious choice would be to manage for spruce-fir.

Planting of non-host species such as white pine, red pine or black spruce is a strategy that needs to be employed to a greater extent. Plantations can serve as buffer strips to breakup large continuous areas of spruce-fir forests. Over a period of 50-60 years, plantations can make a significant contribution to the forest industry without any need of protection from the spruce budworm.

Patchwork Of Age Classes

The breakup of spruce-fir stands into a patchwork of different age classes is a management strategy "most likely to succeed" in reducing vulnerability (Baskerville 1975). Even though it is more appropriate and effective on a regional basis, the starting point is the individual landowner. This is a concept that is easily understood by the landowner and easily sold to him. Also, the strategy has the potential of serving as the key to implementing forestry practices. If each woodlot is approached with the intent of breaking it down into smaller units, then the forestry practices needed for each unit would be within the grasp of the landowner. The large job would be reduced to several small jobs.

To illustrate, assume a landowner has 40 acres of an even-aged sawtimber stand of spruce-fir. This tract can be broken down into four 10-acre units with a long-range goal of: 10 acres in regeneration stage; 10 acres in seedling and sapling stage; 10 acres in young poles; and 10 acres in large poles and small sawtimber. The immediate prescription towards meeting this goal would be to clearcut a 10-acre block. If advanced regeneration is not present, plan on planting. On another 10 acres, install the first cut of a two cut shelterwood to increase the spruce component or to convert to sugar maple. On the remaining 20 acres, thin to the B level favoring spruce.

The next entry into the stand in 10 or 15 years can include: 10 acres of cleaning in sapling stands; 10 acres of shelter trees can be removed; 10 acres--the first cut of a shelterwood can be applied; 10 acres--can be thinned again. In a period of about 30 years, this 40-acre tract can have a well-balanced age structure that can be maintained indefinitely.

This concept can be applied to all existing condition classes, including pure stands of pole timber or stands made up of scattered patches of seedlings and saplings, poles and sawtimber. In each case, it is essential to break the area down into smaller units, possibly no smaller than 5 acres in size, followed with the removal of trees to create the even-aged structure for each unit.

Harvest Methods

As the intensification of forest management activities is essential in developing less vulnerable spruce-fir stands, harvest methods of clearcut areas must be adjusted to accommodate forestry efforts. The planting of cleared sites or the cleaning of young stands requires ease of access and movement of personnel and equipment on the site immediately after the harvest, or long before the logging slash has decayed. Whole tree harvesting methods applied to clearcut areas would remove the accumulated litter of tops and branches, making the site much easier to work on and at less cost.

Such a method of harvest requires the piling of slash at the landing site, but this material can be easily disposed of by chipping or burning. Certainly, this method is preferred to leaving the tops on the site where they hinder work and increase cost of accomplishment for many years.

Protection

The foregoing are the silvicultural tools the land manager has in diminishing the impact of the spruce budworm. They are designed to develop fast, vigorous growing trees capable of producing an acceptable crop in 50 years or less, to produce stands with more spruce than fir, and to provide the encouragement to convert to non-host species where conditions permit. The closer the landowner comes to matching these conditions, the greater impact can be expected in favor of the resource. The resource is conditioned to withstand and recover from a budworm attack. Additionally, in this situation, the landowner is provided a choice of spraying or not spraying, without the complete loss of his resource if he chooses the latter.

As protection must be an integral part of management, it is essential that field foresters be trained to identify stands that need protection, stands that need to be salvaged, stands that need no protection, and made aware of the implications of not applying protection measures. Hazard indicators, such as top kill, should have some meaning as to risks involved and management action necessary. Only through this basic knowledge of the spruce budworm's actions, along with silvicultural skills, can the field forester be effective in growing spruce-fir timber in competition with the budworm and offer the landowner the best technical advice.

Conclusion

It is generally agreed that as more of the spruce-fir timber type comes under management and a diversity of age classes has been created on a wider scale, a more resistant forest will be created. Presently, there is a critical shortage of reliable data that can pave the way of removing many uncertainties in managing the timber type continuously being exposed to the spruce budworm. A concentrated long-range research effort to evaluate various silvicultural practices is long overdue.

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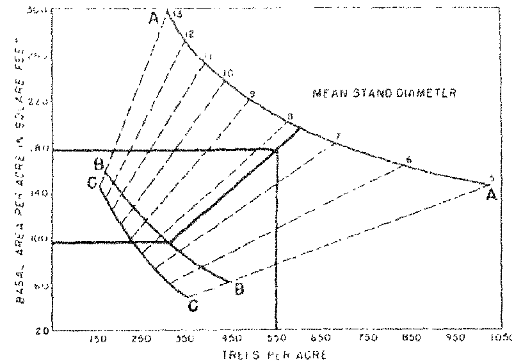
Appendix



Stocking chart for even-aged spruce-fir, based on the number of trees in the main canopy, average diameter, and basal area per acre. The area above the A-level represents overstocked stand conditions. Stands between the A- and B-levels are adequately stocked. Stands between the B- and C-levels should be adequately stocked within 10 years or less. Stands below the C-level are understocked. (Frank et al 1973).

To use the chart, obtain from cruise data the average number of trees and basal area per acre. Plot the two values on the stocking chart to determine the recommended level of management (B level). For an example, a stand of spruce-fir averaging 550 trees and 180 square feet (ft^2) of basal area intersects on the stocking chart below the A line. From this point, follow diagonally, parallel to the nearest broken line of mean stand diameter and mark the point at which the B line is intersected. From this point, draw a horizontal line to the vertical ordinate for the basal area at this level (100 sq ft). The mean stand diameter is about 7.7 inches DBH or the point at which the A line is intersected.

MINIMIZING IMPACTS OF FUTURE SPRUCE BUDWORM OUTBREAKS

Philip J. Malerba

Project Forester, St. Regis Corporation, Northern Timberlands, Bucksport, Maine 04416

St. Regis timberlands in Maine are presently experiencing extreme levels of spruce budworm populations which are impacting balsam fir, eastern hemlock and the spruces. Pest management strategies are discussed which will minimize both the present and future impacts of spruce budworm populations.

HOW DO OUTBREAKS START?

Yvan Hardy

Dean, Universite Laval, Faculte De Foresterie ET Geodesie, Quebec, Canada G1K 7P4

Introduction

Between 1976 and 1979, the known epicenters from which the current spruce budworm outbreak originated in Quebec were studied and compared. One of the major conclusions derived from that study, and reported by Hardy et al. 1983, was that the outbreak gained its initial momentum in meridional forest associations where host-species were outnumbered by non host-species and non boreal species. The epicenters were further characterized by severe ecological perturbation which promoted the establishment of pioneer species and ultimately an abundance of fir and spruce. The same methodology was later applied to areas outside Quebec where spruce budworm infestations are a major concern. Manitoba, Ontario, New Brunswick and Maine were included in this portion of the study.

Methodology

Assistance was first sought from local provincial and state authorities in order to pinpoint the year and location(s) of appearance of new outbreaks in each state or province. Thus, the expertise of Mr. Hildalh, (Manitoba) G. Howse (Ontario), E. Kettela (New Brunswick), and H. Trial (Maine) supplemented the use of defoliation maps. To be considered an epicenter, an incipient infestation had to be distant from any ongoing outbreak by at least 150 km, or known as a lasting residual outbreak, such as those of Chatham and Nashwaak, N.B. and Oxbow, Me. The epicenters were further expected to expand geographically from year to year. A total of 22 such epicenters, including 7 from Quebec, were identified. Among those, four were to the same general area in Ontario and later called Cobden I, II, III and IV. A control plot, where no sign of advanced budworm activity had been recorded, was added in a red spruce association in Southern Quebec, to compare the vegetation types. This was later referred to as Quebec Sud. A vegetation survey was carried out in each epicenter according to the methodology described by Brawn-Blanket (1932) and Hardy et al (1983), to provide a qualitative and quantitative description of the vegetation of the various strata. A total of 617 1/100 ha sample plots were thus established. A map showing the major climactic forest associations was also prepared by integrating the various forest classifications available for the area under study.

The mean annual and summer (April to August) temperatures of each epicenter were determined by reference to nearly meteorological stations in similar situations. From these data, the mean annual and summer temperatures were calculated for the whole region and the smallest variance which included the warmest and coldest epicenters was used to construct annual and summer isotherms for the region.

Results

The buffering effect of the sea on the climate of the maritimes is apparent in Figure 1, where the mean annual isotherm of 1.2^{o}C swings deeply north along the north shore of the St. Lawrence river and the gulf of St. Lawrence. The opposite effect is observed in more continental western Ontario and Manitoba. In this case, the summer temperatures isotherm, converted into day-degrees above 5^{o}C, goes deeply north in response to the high summer temperatures observed in these longitudes, while cold winter temperatures bring the annual isotherm to a more southern location. Since the physical conditions prevailing during both summer and winter are equally important for budworm survival, both extremes were limiting. Budworm survival was limited in the east by inadequate summer heat and in the western part of the range by extremely low winter temperatures. The result is shown in Figure 2 which, in our opinion, best describes the preferential thermal zone of the spruce budworm.

On the other hand, when we consider the position of the epicenters by reference to forest associations, it can be seen that the vast majority belong to a northern hardwoods association, with a configuration almost identical to that of the isothermic corridor previously defined (Fig. 2). A closer look at the vegetation recorded in the epicenters (Table 1), confirms the universal presence of meridional species along with numerous pioneers species and an abnormal amount of host-species.

These findings suggest that the current outbreak gained its initial momentum in a rather clement physical environment normally occupied by meridional forest associations, which had been gradually invaded by host-species in reaction to various forms of perturbation such as, harvesting, forest fires, and natural reforestation of abandoned farm lands. Although our data on forest composition are minimal, changes in the forest composition should not be underestimated since they are confirmed by various other sources. For example, Bonnor (1982), in a synthesis work of Canada's most recent forest inventory, shows that the better part of the maple associations of eastern Canada are now typed as mixed wood, suggesting the recent invasion of these hardwood associations by softwood species. Similar indications were also given by recent vulnerability ratings of New Brunswick and Nova Scotia forests, as well as Quebec (Mac Lean 1982; Blais et Archambault 1982), which indicate that the most vulnerable forests are those of central N.B. and the St. Lawrence valley in Quebec. The abundance of host-species being the major factor along with general climatic condition to determine vulnerability, it appears quite clear that host-species have become more abundant in those predominately hardwood associations of central N.B. and southern Quebec.

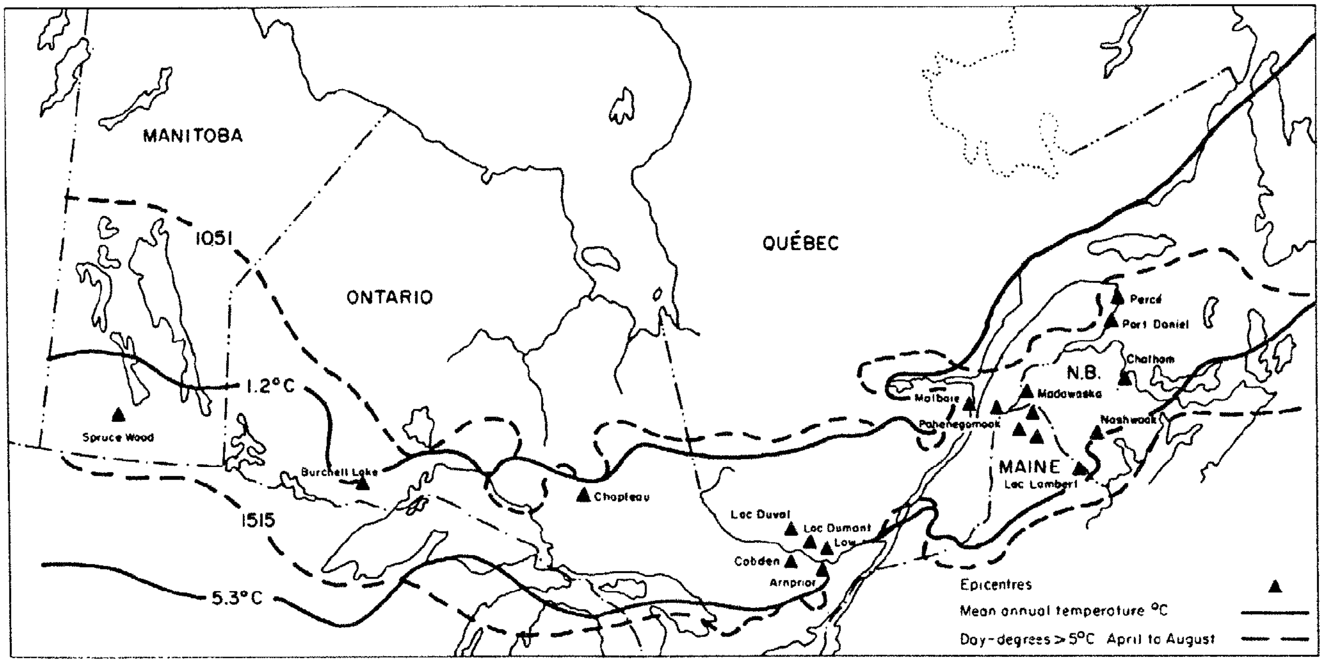


Figure 1.--Annual and summer isotherms corresponding to the narrowest corridors that include the warmest and coldest epicenters

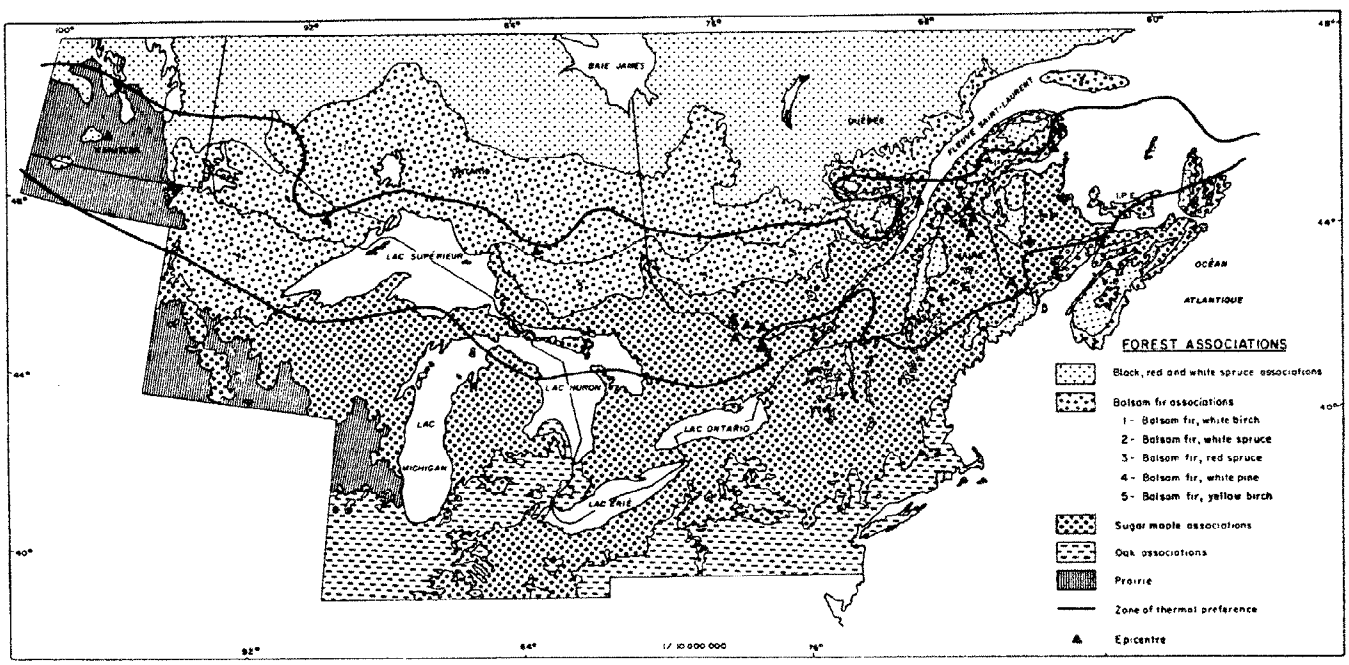


Figure 2.--Zone of thermal preference of the spruce budworm in eastern North America in relation to the major forest assocations

Table 1. Relative Abundance of the Principal Tree Species Found in the Epicenters.

X: abundant species .: presence 1: Host species
2: Meridional species 3: Other species *: Pioneer species

Tree Species	Manitoba	Ontario							Quebec									Nouveau-Brunswick					Maine	
	Spruce Wood	Burchell Lake	Chapleau	Cobden I	Cobden II	Cobden III	Cobden IV	Arnprior	Low	Lac Dumont	Lac Duval	La Malbaie	Pohenegamook	Perce	Port-Daniel	Quebec Sud	St-Jacques	Lac Madawaska	Chatham	Nashwaak	Lac Lambert	Oxbow	Fish River Lake
1 Abies balsamea		x	x	x	x	x	.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1 Picea glauca	x	.	x		x	x	.	x	.	x	.	x	x	x	.	x	.		.	.		.	
1 Picea mariana		x	x	x			.			.	.			.	.				.				
1 Picea rubens		.	.					.			.		x	.	x	x	.	x	x	x	x	x	x
2*Acer rubrum				.	x	x	x	.	x	.	x	.	x	x	x	x	.	.	.	x	.	x	.
2*Acer pensylvanicum												.	.		.	.	.					.	.
2 Acer saccharum				.	x	x	.	x	x	x	x		.	x	x	.	x	.		.		.	.
2 Betula alleghaniensis				.			.	.	x	.			.	x	x	x	x	.		x	.	.	.
2 Fagus grandifolia					.	.			.		.						.			.	.		x
2 Fraxinus americana					x	.	x	x	.														
2 Ostrya virginiana					x	x	x	.	x	.	.												
2 Pinus strobus		.	.	.	x	x		x	.	.	x								.		.		
2*Quercus macrocarpa	x																						
2*Quercus rubra	.				x	.	x		.	.	x												
2 Tilia americana						.	x	x	.	.													
2 Tsuga canadensis				.	.	.		.	x							.		.		.	.	.	.
2 Ulmus rubra				.	.	.	x	x															
3*Acer spicatum		.	.		.	.		.	.			.			.	x	.						
3*Betula papyrifera	.	x	x	.	x	x	x	x	x	x	x	x	x	x	x	x	.		.	.		x	.
3*Populus tremuloides	x	x	x	.	x	.	x	x	x	x		.	x	.		.			.	.		.	
3*Populus sp.		.		.	x	x	.	x	.	.	.	.								.		.	
3*Prunus sp.	.					.	.		.						.		.						
3Thuja occidentalis		x	.	x	.	.	x	x	.	.		.	x				.	x	.		x	.	.

Discussion

The pattern observed at the beginning of the current outbreak differs quite drastically from usual beliefs about the initiation of a spruce budworm outbreak. Instead of seeing the outbreak originate from vast boreal regions of mature spruce-fir forest, this outbreak acquired its initial momentum in a more southern environment, where host-species are outnumbered by non host-species and where over-maturity was not a characteristic of spruce and fir. These apparent contradictions, coupled to the fact that most recent outbreaks have been more widespread, of longer duration and appeared at shorter intervals (Blais, 1983), are indicative of a new equilibrium between the major components of this ecosystem. However, when these discrepancies are viewed within the framework of the concept of "zones of abundance" first proposed by Cook (1929), the behavior of the current outbreak becomes more easily understandable. According to Cook, the range of an insect is divided into three zones, the principal characteristics of which appear in Table 2.

Table 2. Principal characteristics of Cook's concept of zones of abundance.

Zones of abundance	Environment		
	Climatic	Biotic	
		Food	Predation
Normal	Optimal	Rare	High
Occasional	Acceptable	Abundant	Low
Possible	Unsuitable	Rare	Very low

Within the zone of normal abundance favored by optimal physical conditions, the equilibrium is normally maintained either by the absence of a abundant source of food and habitat or by the effectiveness of parasites and predators to respond rapidly to a population change of the pest. Most outbreaks should start within the limits of the zone of normal abundance, but should be of short duration due to the relative scarcity of food and the biological resilience of this environment.

Outbreaks can also be initiated within the zone of occasional abundance, but such an event should be less frequent since it will have to happen within the confines of a particularly suitable microenvironment, or after a period of climatic release which would make the physical conditions in this area comparable to those normally experienced in the zone of normal abundance. On the other hand, once an outbreak is initiated in this zone, the abundance of food and the lesser predacious activity will favor outbreaks of longer duration.

Finally, it is possible for an outbreak to originate in the zone of possible abundance, but this event will be of lesser importance since both the physical and biological conditions are not favorable to the insect. Under the conditions prevailing in the zone of possible abundance, outbreaks should be rare and of short duration and would have to be fueled by incoming populations from outside areas.

This brief description is not without parallel with the current spruce budworm outbreaks. The northern hardwood associations where this outbreak was first observed correspond almost perfectly to the zone of normal abundance. Favorable climatic conditions and relative scarcity of food are intrinsic to this zone, while a high biological activity could be inferred by the diversity of this environment. The southern boreal forest which contains the white spruce-fir-birch association is, for it's part, closely linked to the zone of occasional abundance. These associations provide an almost inexhaustible source of food. Climate has often been reported as responsible for the collapse of outbreaks in this area and parasitic activity has always been considered marginal with respect to its influence on the course of an outbreak. Finally, the black spruce associations of the northern boreal forest would correspond to the zone of possible abundance, along with the meridional hardwood associations where hickory is a normal component of the forest associations.

Conclusion

This analysis strongly suggests that the changes in the species composition of the meridional forests are responsible for the tragic budworm situation that is experienced throughout eastern Canada and Maine. By favoring the establishment of host-species in an already favorable environment, a new and powerful source of infestation has been created in addition to those already in existence. This phenomenon can explain the rapid succession of more widespread outbreaks of longer duration and even the chronic outbreaks observed in parts of Maine and New Brunswick.

Forest management practices should be reviewed accordingly and a hard look should be given to our current harvesting and reforestation practices which tend to increase the spruce and fir content of the meridional forest. If drastic steps are not taken in this direction, the future will follow the trend of the past fifty years and spruce budworm outbreaks will become an integral part of the biotic balance.

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"PLANNING NOW TO REDUCE, POSTPONE OR PREVENT THE NEXT SPRUCE BUDWORM OUTBREAK"

W. Lloyd Sippell

Research Scientist, Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario, Canada P6A 5M7

Ten characteristics of outbreak patterns are recognized in Ontario infestation maps for the period 1947-1983, for which explanations are available in recent scientific literature. A related long-term strategy of outbreak prevention is proposed for implementation internationally (Canada, U.S.A.) over the next decade.

Introduction

Recently I have had the opportunity to update my knowledge of the scientific literature on the spruce budworm and to step back after 35 years of close association with research and surveys to analyze and describe changing patterns of infestation (infestation dynamics) reported in the Province of Ontario.

Yet this assigned topic was approached with a degree of apprehension for three reasons. Firstly, because the insect has created such an array of sensitive, chronic and firmly entrenched problems in North America. Secondly, my main source of information consists of pooled monitoring data with a heavy mix of associated observations not regarded as sound proof. My data are much more than anectodal but on the other hand they are not strictly speaking thoroughly scientific. Thirdly, the original approach for dealing with spruce budworm emergencies in Canada involved both research and coordinated surveys, and most conceptual models concerning system function seem to have emerged from theoretical research rather than from observed conditions. As a consequence, I have a great deal to cover in a single presentation.

The literature update has confirmed my opinion that so far man's approach to the spruce budworm problem has of necessity been largely defensive in nature, i.e., responding to developments without influencing the dynamics of infestations in positive ways. There are numerous examples: monitoring and evaluating situations, protecting vulnerable forests of high value, establishing biological relationships, measuring impact, learning how to live with the budworm, etc.; all essential pest management activities--but reacting to events more than influencing them.

So far only two attempts have been made to deactivate outbreaks and the results were of qualified success in both instances. The first was in the Kedgwick Lake area of Quebec (Blais 1963) and the second was begun near Burchell Lake, Ontario (Sippell, et al. 1969) and continued over 9 years before being abandoned in 1977 (Howse, et al. 1979). In other instances, spruce budworm infestation was virtually eliminated from stands in part of an operational spray program (Dimond, 1976), but the objective was different.

The research community is continually being challenged to more ably express its genuine interest in controlling the spruce budworm by discovering and promoting more effective outbreak prevention strategies.

This paper introduces to this workshop some new entomological concepts, based on 37 years of intensive surveys and infestation history, and asks as well as suggests how they may be used to develop an international strategy to reduce, postpone or perhaps even prevent future outbreaks from occurring through at least part of the range of the spruce budworm in North America. It introduces more of the "learn by doing" approach to outbreak prevention. Hopefully it will also change the focus of our mind's eye in thinking about and discussing a more influential plan of future action in managing this major forest pest.

Materials and Methods

Beyond cited literature references, the information presented on infestation patterns and change is taken from the reports and files of the Forest Insect and Disease Survey (FIDS) project at the Great Lakes Forest Research Centre in Sault Ste. Marie. Liberal use is made of their maps published annually in numerous reports such as Meating, et al. (1982), Howse et al. (1983), and Applejohn and Howse (1982). Observations of field conditions throughout the province were acquired through contact with and the assistance of many staff members of the Centre, mainly those associated with the FIDS project for which the author was project leader for 25 years.

The total area to which historical observations apply (Ontario) covers 891,000 km^2 (343,000 sq. mi.) of which almost half 430,000 km^2 (165,000sq. mi.) are forested. In the interest of simplicity, the term "infestation" as applied to this large land mass refers to the condition in which populations of spruce budworm are or have been of sufficient numbers in any year to cause detectable feeding damage when viewed from the air.

Analysis

General information is available as to where infestation has occurred each year in Ontario since 1920 or so. But each year since 1947 the Canadian Forestry Service through the cooperation of the Ontario Ministry of Natural Resources (formerly Ontario Department of Lands and Forests) obtained complete and detailed information on areas affected. The series of 37 annual infestation maps being flashed on the screen for each of the years 1947-1983 have been vital to this general and long-term study of natural infestation dynamics. "Natural" is used here in the sense that Ontario outbreaks, by and large, have been allowed to run their course uninfluenced by widespread aerial spraying.

Ten Characteristics of Ontario Outbreaks

Ten generalized and somewhat interrelated characteristics of infestations in Ontario are compiled and described, some of which are newly recognized, some have long been recognized but explanation has been lacking or imprecise, others either remain to be more fully elucidated and conceptualized in published form, and still others must be more adequately demonstrated in future series of annual infestation maps. For most of the 10 characteristics numerous examples could be given, however in the interest of time and space one or in a few instances two are presented by way of illustration to help clarify.

C-1. Over the long term, the extent of infestation fluctuates to the extremes.

A comparison of the infestation map for 1964 (Fig. 1) when less than 40 ha (100 acres) of infestation was recorded, with the map for 1981 (Fig. 2) showing a gross area of infestation equal to 18 million ha (45 million acres) provides a striking illustration of the wide differences that occur in infestation extent over time. Moreover, population levels may become extremely low over large areas during an inter-outbreak period so as to be considered virtually absent. Figure 3 shows the results of beating samples, i.e., 20 samples of larvae beaten from a m^3 volume of foliage over a m^2 tray, 2 from each of 10 trees and timed for fifth and sixth instar larvae (L_5, L_6).[1] In a scattering of 15 points within an area of roughly 60,000 km^2 (23,000 sq. mi.) not one larva was collected by beating in any of the 5 years of sampling, 1969-73. This is not to imply that the insect became temporarily extinct however, since an occasional larva or adult was collected in the same area and time-frame by other methods including search techniques and light traps. But clearly the level of incidence during the 5-year period was extremely low.

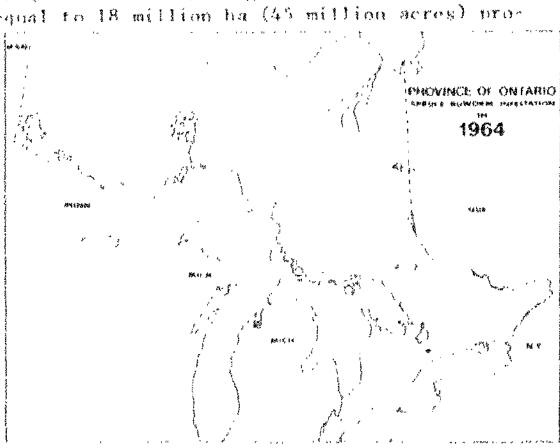


Figure 1. Infestation map for 1964.

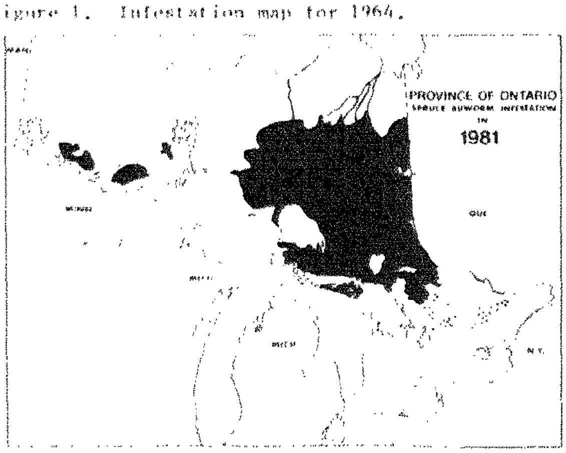
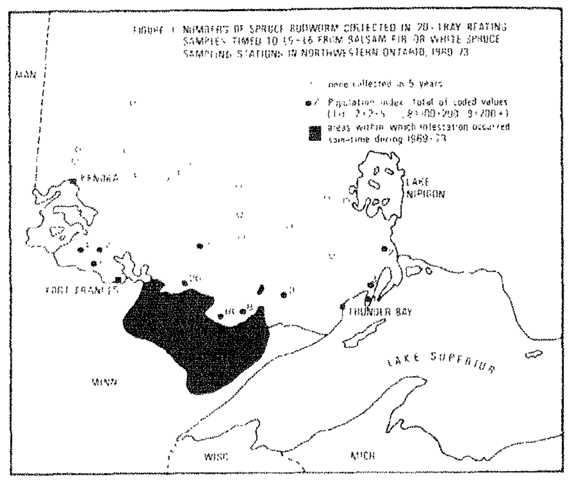


Figure 2. Infestation map for 1981.



Extremes of unusual abundance, on the other hand, are so much better known that illustration is unnecessary.

C-2. Infestation is present every year somewhere in Ontario or in adjacent provinces or states.

The 37 annual infestation maps dating back to 1947 in themselves substantiate this claimed characteristic. The years 1964 to 1966 show only minor points of infestation in Ontario, however, when the broader situation is applied to include adjoining provinces and states (Fig. 4), this second characteristic emerges clearly. Before 1947, despite the less precise definition of infestation boundaries, continuous infestation in Ontario can be predated to at least 1922 (Brown 1970). In other words, infestation has been present in Ontario or adjacent provinces or states for at least the past 62 years.

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[1] Sippell, W.L. 1969. Monitoring low or incipient levels of spruce budworm populations in eastern Canada. Mimeographed report. Forest Research Laboratory, Box 490, Sault Ste. Marie, Ontario, 4 pp. (available upon request.)

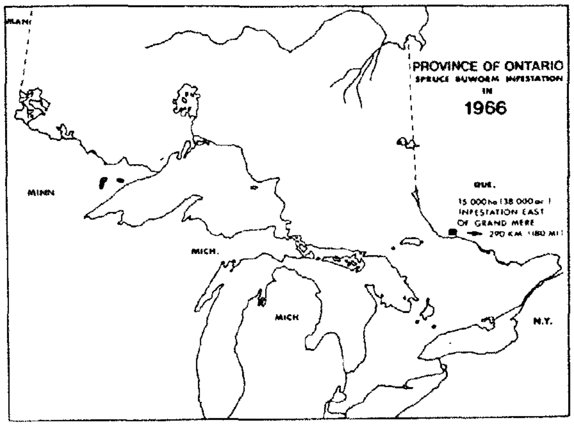


Figure 4. Infestation map for 1966 including northern Minnesota and western Quebec.

C-3. Between outbreaks, numbers generally vary inversely with distance from infestation.

Evidence is becoming overwhelming that the emigration and immigration of moths carrying a partial complement of eggs as described by Greenbank, Schaefer and Rainey (1980) are influential forces in infestation movement and change during an outbreak. Sanders (1977) reported that the dispersal of egg-bearing females takes place only at high population densities. Because moths biologically cannot differentiate the size of infestation of which they are a part, it must be assumed that moth populations behave in a similar manner whether they represent a small heavy infestation between outbreaks or part of a major outbreak.

The results of the m^2 beating-tray sampling done in northwestern Ontario between 1969 and 1973 (Fig. 3) show that, in general, population levels decrease with increasing distance from areas of infestation which in this instance were located in the vicinity of the International Border between Thunder Bay and Fort Frances. However it should be pointed out that determinations of population trends influenced by wind direction can be expected to be imprecise especially when moth flights take place after dark and cannot be substantiated by direct observation.

C-4. Forests show a degree of natural resistance to low levels of moth invasion.

The influx of moths from infestations to spruce-fir forests which are supporting very low numbers of spruce budworm must occur from time to time. Evidence of such occurrences and the subsequent result is available again in the m^2 beating tray samples, Table 1. Marked increases in numbers collected in 1971 at four locations in the Kapuskasing District following 2 years of nil returns reflects a probable influx of moths

Table 1. Numbers of spruce budworm collected in beating tray samples, 2 per each of 10 trees, 1969-73, in Kapuskasing District, Ontario.

Location\Year	1969	1970	1971	1972	1973*
Gill Twp.	0	0	11	7	2
Fergus Twp.	0	0	7	1	2
Howells Twp.	0	0	2	2	0
Tenton Twp.	0	0	14	8	0

* year of spring frost

in 1970 from extensive infestations 80 km (50 mi.) or more to the south. Resistance is evidenced by a consistent decline in numbers for the subsequent 2 years. Eventually however a large part of Kapuskasing District did become infested, presumably as the result of repeated inflows associated with a northward advancing front. The resistance indicated is probably more in the form of predacious birds and arthropods rather than insect parasitoids specific to spruce budworm, because before 1971 hosts upon which parasitoids depend for survival were rare. Populations that surge upwards as the result of moth influx in circumstances of this kind can be expected to show particularly low incidences of parasitism since the parental stock of parasitoids is left behind during dispersal--a hypothesis currently being tested.

C-5. New infestations appear to be the result of moth influx from active infestation.

Two characteristics are common to new infestations originating by moth influx. During the first year, noticeably greater damage occurs on white spruce in stands where both white spruce and balsam fir are present, followed in subsequent years by damage on both species. Secondly, defoliation patterns indicate an abrupt rise in damage levels, i.e., markedly higher levels of defoliation on the current new shoots than on shoots of previous years.

Observations of the initial stages of new infestation are all too uncommon but when made usually provide evidence that points to moth influx as being the source. Over the 37-year history since 1947 only three valid case histories of outbreak eruption were detected, all three of them in 1967 (Fig. 5). All three showed evidence of dependence on active infestation located elsewhere: the northwestern Ontario infestation western Ontario infestation linked by association with infestations in northern Minnesota; the Ottawa valley possibly associated with the 150 km^2 (60 sq mi.) infestation near Grand Mere, Quebec (Martineau and Oulette 1967) located some 290 km (180 mi.) to the east, or some other unknown source; and the Chapleau infestation from what appeared to be surviving remnants of a previous outbreak in the form of small active infestations.

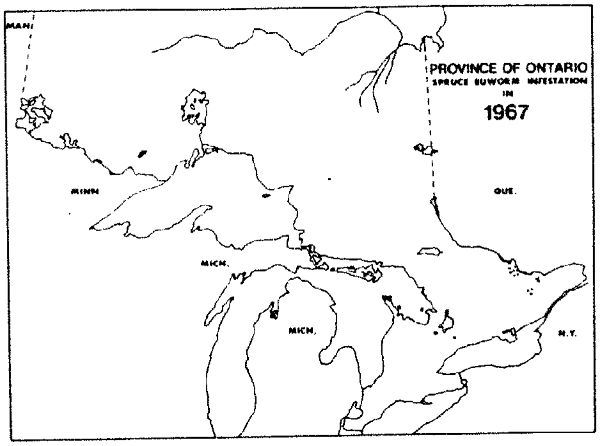


Figure 5. Infestation map for 1967.

So far we have considered the initiation of outbreaks since 1947. In the 15-year period previous to 1947 only two outbreaks erupted namely, the Lake Nipigon and Lac Seul outbreaks. A third outbreak had occurred continuously in northeastern Ontario since 1921. Recent enlightenment concerning the considerable distances over which moths can disperse, such as from New Brunswick to Newfoundland (Dobesberger et al. In press), a dispersal distance of 600 km (370 mi.), will not permit me to rule out the suggestion that both earlier outbreaks (Lake Nipigon and Lac Seul) could have originated through moth dispersal. The probable source would have been the older northeastern Ontario outbreak which in 1943 (Fig. 6) had reached its peak and lay approximately 320 km (200 mi.) from Lake Nipigon and 560 km (350 mi.) from Lac Seul.

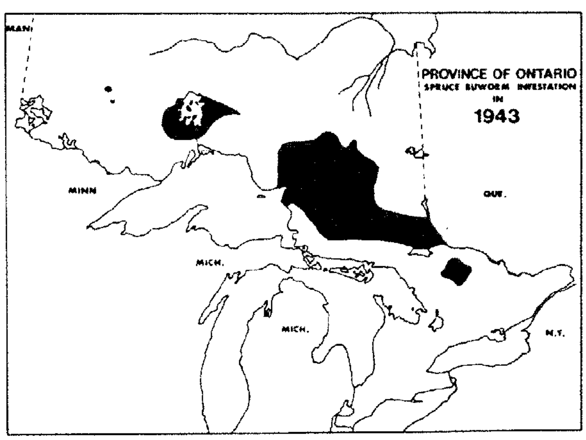


Figure 6. Infestation map for 1943.

C-6. <u>Infestation once initiated tends to spread, and give rise to new infestation in the direction of the prevailing winds.</u>

Historically the tendency for infestation to spread eastward and southward has been well known. This trend has been evidenced both in the extension of infestation boundaries, and in the appearance of separate new infestations beyond the boundaries of current infestation. The infestation maps for 1949, 1952, 1955 and 1958 illustrate the results of this trend in north-western Ontario in the direction and magnitude of infestation development as shown in Figures 7, 8, 9 and 10. In contrast, the spread of an outbreak

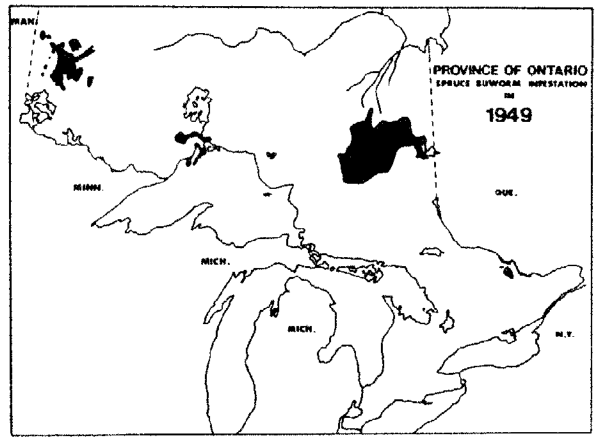


Figure 7. Infestation map for 1949.

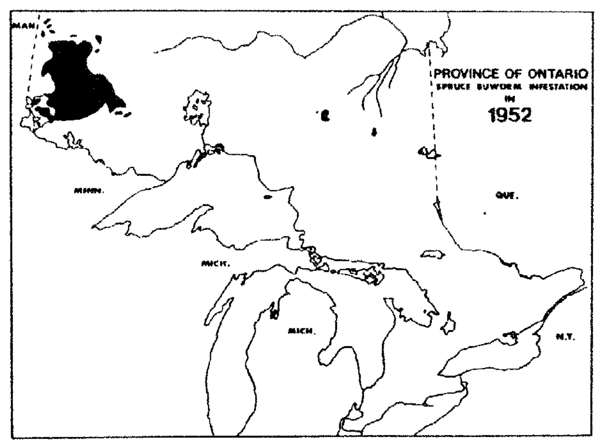


Figure 8. Infestation map for 1952.

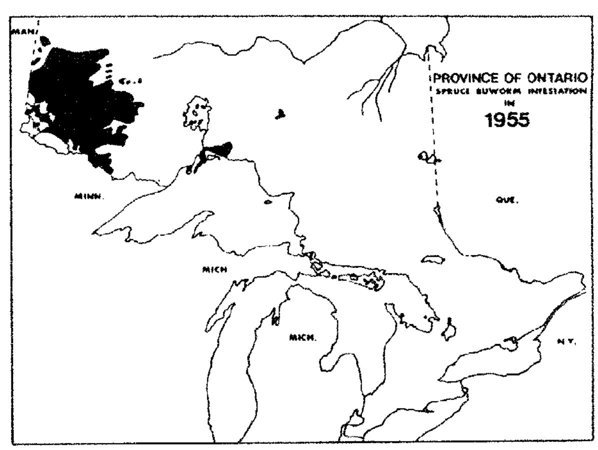


Figure 9. Infestation map for 1955.

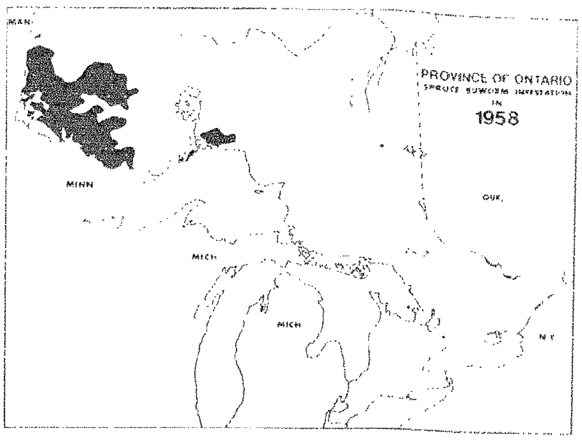
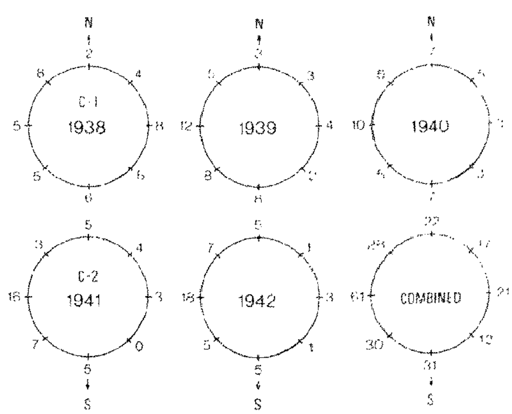


Figure 10. Infestation map for 1958.

towards the northwest has usually been slower and involves shorter distances. It has long been assumed that this southeastward shift was the influence of prevailing NW winds on the dispersal of both small larvae and moths.

This characteristic, C-6, though true in a general sense, can be misleading as shown in the example that follows. During an investigation of possible sources of the early Lake Nipigon and Lac Seul infestations discussed under C-5. I examined wind data[1] from three weather stations in northern Ontario, Sioux Lookout, Thunder Bay and White River (Fig. 11). Overall, evening

FIGURE 11 SUMMARY OF WIND DIRECTION FREQUENCIES BY 8 COMPASS POINTS RECORDED AT 2100, JULY 1-15 1938-42 AT THREE NORTHERN ONTARIO WEATHER STATIONS WHITE RIVER, THUNDER BAY, AND SIOUX LOOKOUT



winds at the time of peak evening moth flight (2100) during the period July 1-15, the most probable period of moth activity for the years 1938-42, revealed prevailing westerlies, as shown in the combined data for all 5 years. However wind directions were anything but consistent and during the period of moth flight in the summer of 1938 were frequently from the east and south, the direction of the extensive northeastern Ontario outbreak referred to earlier. Information on the timing of moth flights and its geographic variation is a prerequisite for more precise studies of infestation dynamics so that the proper data on evening wind directions as recorded by weather stations can be analyzed and influences interpreted.

[1] Courtesy of the Climatological Archives Unit, Atmospheric Environment Service, Environment Canada, Downsview, Ontario.

In summary, C-6, though generally true, must be applied with extreme caution. Prevailing winds merely identify the most frequent direction of winds and certainly are not the only winds that influence moth dispersal or change in infestation borders.

C-7. <u>Infestations that develop in forest types of low vulnerability tend to be short-lived.</u>

One feature of infestation dynamics which reveals in a most convincing way the influence of moth dispersal is the sudden appearance of infestation over large tracts of non-vulnerable forest type in which host trees are scattered. A moth flight on July 11/71 which invaded southern Ontario from the north and east and which gained public attention by invading the city of Toronto, gave rise to damage in 1972 to ornamental host trees throughout a large agricultural zone of southwestern Ontario. Numbers gradually tapered off during the subsequent two growing seasons. Another striking example is the extent of infestation on spruce growing along rivers flowing into James Bay in 1980, Figure 12. It is diffi-

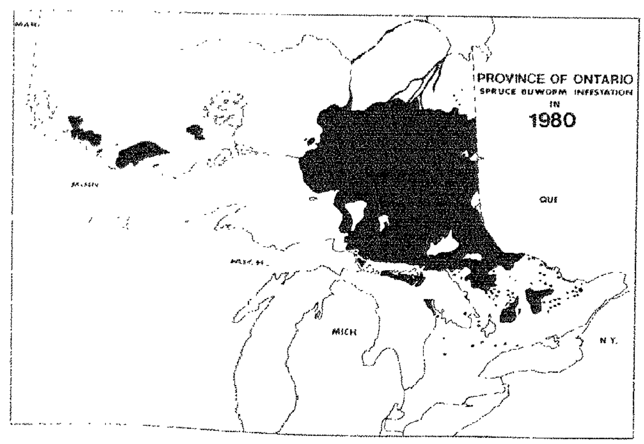
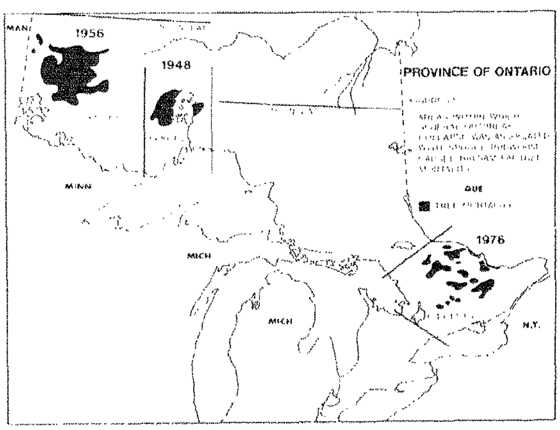


Figure 12. Infestation map for 1980.

cult to imagine how these infestations could possibly have arisen in an area where the cover type is predominantly bog or tundra except through the influx of egg-laden moths from the south. These infestations reappeared in 1981 but not in 1982.

C-8. The intensity of infestation once initiated is governed by stand character and climate.

A vulnerability index system developed by a Canadian Forestry Service Working Group led by J.R. Blais and of which the author was a member uses inventory data and climate ratings. The vulnerability ratings were applied successfully to forest management units in Quebec (Blais and Archambault 1982) and in New Brunswick-Nova Scotia (MacLean 1982). The system could not be extended to Ontario because data on stand age were unavailable, yet there is clear substantiated evidence that infestation intensities reach their highest levels where mature balsam constitutes the major stand component, and that a relatively small area of undesirable stand character and climate for outbreaks exists in Ontario where infestation has declined prior to the onset of appreciable tree mortality. Generally these areas are located north of 50°N Latitude across northeastern Ontario and north of 52°N Latitude in northwestern Ontario as depicted by maps of cumulative areas of host tree mortality, Sippell (1983), see also Figure 13.



C-9. General collapse of an outbreak is fully dependent on the development of host tree mortality.

Past outbreaks have suffered major setbacks by late spring snowstorms, at the time of year when controlling forces such as parasitoids would be little affected. This kind of event occurred north and east of Chapleau in late May, 1973 when snowstorms and freezing temperatures destroyed virtually all the new shoots of balsam fir and directly or indirectly eliminated a large proportion of spruce budworm populations. A reduction of infestation resulted as shown by the defoliation maps for 1972, Figure 14, compared to 1973, Figure 15. Biologically the expected result would be a major shift of numerical advantage in favour of parasitoids over hosts with accompanying collapse of populations. Yet, infestation intensities rebounded rapidly over the subsequent 2 years and the outbreak continued almost unabated as shown in Figure 16.

Historically the single circumstances under which outbreaks have begun a general collapse in

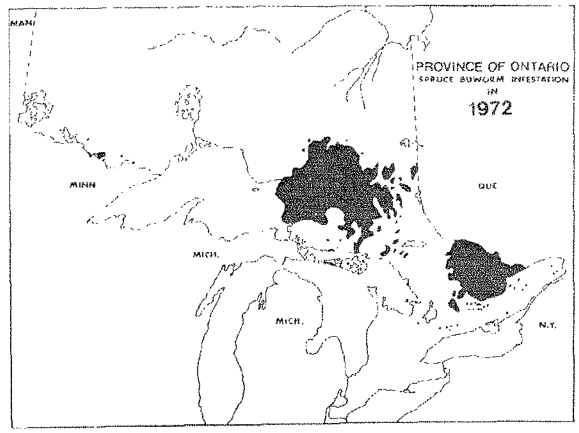


Figure 14. Infestation map for 1972.

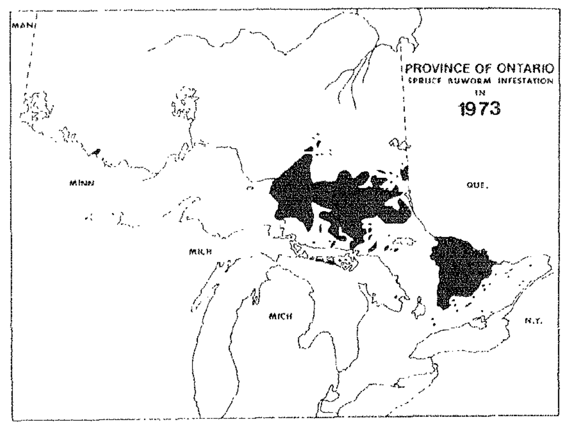


Figure 15. Infestation map for 1973.

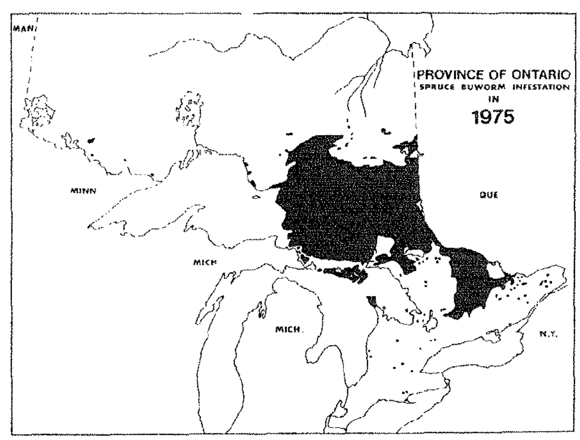


Figure 16. Infestation map for 1975.

vulnerable forest is the occurrence of extensive and continuous balsam fir mortality. The extent of mortality associated with three collapses as depicted in Figure 13 ranged from 400,000 ha (1 million acres) in 1948 through 640,000 ha (1.6 million acres) in 1976 (Howse et al. 1977) to 2 million ha (5 million acres) in 1956.

C-10. Small remnants of infestation persist following outbreak collapse.

Infestation subsequently occurs within the same general area as an outbreak has collapsed. The condition tends to shift location from year to year, disappearing in one area and reappearing in another. Other small areas of infestation may linger in stands at much the same intensity for many years. The area east of Sault Ste. Marie where a major outbreak collapsed in the late 1940s is used to illustrate this point. Here heavy infestation was discovered in 1966 in the upper crowns of mature balsam fir trees in one stand southeast of Sudbury. This infestation was reported only in 1 year. Another infestation in Parkinson Twp. near Thessalon persisted at low levels for at least 10 years, 1959-68, with little change in intensity year after year.

These small lingering infestations appear to have an important role in outbreak eruption and upon discovery, some of them show clear-cut budworm caused tree mortality somewhere within their boundaries. The presence of tree mortality in a newly discovered infestation signifies previously undetected and unrecorded defoliation. In reality these small pockets of tree mortality could be overlooked in the flurry of concern over the development of new infestation. Furthermore they could be misconstrued by those unaware of mapping programs to represent survey omissions on the part of field staff. However, it must be recognized that intensive aerial mapping during interoutbreak periods when numbers are very low have been considered (a) until now largely unnecessary and (b) ineffective for the specific purpose of detecting small infestations.

The role of small persistent infestations occurring during periods of endemism has not been studied in depth. However biologically these infestations represent a natural state from which dispersing adults could be expected to emigrate on a regular basis.

Summary of Ten General Characteristics of Spruce Budworm Infestation in Ontario

C-1. Over the long term, the extent of infestation fluctuates to the extremes.

C-2. Infestation is present every year somewhere in Ontario or in adjacent provinces or states.

C-3. Between major outbreaks, numbers generally vary inversely with distance from infestation.

C-4. Forests show a degree of natural resistance to low levels of moth invasion.

C-5. New infestations appear to be the result of moth influx from active infestation.

C-6. Infestation, once initiated tends to spread and give rise to new infestation in the direction of the prevailing winds.

C-7. Infestations that develop in forest types of low vulnerability tend to be short-lived.

C-8. The intensity of infestation once initiated is governed by stand character and climate.

C-9. General collapse of an outbreak is fully dependent on the development of host tree mortality.

C-10. Remnants of infestation persist following outbreak collapse.

Discussion

Greenbank, Schaefer and Rainey (1980) determined through the use of canopy observations, radar and specially equipped aircraft in New Brunswick that moths, including a proportion of females with up to half of their complement of eggs regularly make vertical exits from infested stands during evening hours usually between about 1930 and 2130 hours, under a fairly broad range of conditions. They subsequently orient their flight downwind and displacement distances of upwards of 450 km (280 mi.) were considered feasible over 7-9 hours of flying.

Potential for the spread of infestations is being further elucidated by Dobesberger, Lim and Raske (In press) who describe the premature appearance in July, 1982 of moths in central Newfoundland before local moths had begun to emerge and who provide evidence that these moths originated from mainland New Brunswick.

These new concepts eminating from research provide a scientific basis for interpreting numerous observations made over past decades relating to patterns of infestation. Whereas previously most of the 10 characteristics described could not have been explained without speculation, now new hypotheses can be structured.

Proceeding from the more obvious and distinct to the less apparent and interrelated of the characteristics, new hypotheses are herewith offered. C-6 concerning the shift of infestation, in the direction of prevailing winds, though widely recognized and described over many years, had remained largely unexplained. The hypothesis can now be readily developed that moth dispersal governed by accompanying wind directions greatly influence infestation dynamics particularly in relation to the speed and direction of spread.

Likewise concerning C-7 relative to short-lived infestations in stands of low vulnerability, new insight leads naturally to the hypothesis that infestation of this kind is the direct result of moth influx from active infestations elsewhere.

In the general collapse of outbreaks (C-9) it can be postulated that proportions of egg populations may be wasted when moths disperse into extensive areas of continuous host tree mortality, an event that would further debilitate already declining populations and contribute to outbreak demise.

Several other characteristics (C-2, C-3 and C-10) when viewed in the perspective of long-range dispersal, provide a backdrop for formulating many new and exciting hypotheses on the biological mechanisms involved. Similarly, characteristics C-4 and C-5, concerning the response of the forest to low levels of influx and to the initiation of new infestation, also broaden the background upon which new hypotheses can be advanced.

To illustrate, it may be postulated that numbers of moths emigrating from a persistent heavy infestation of limited size would disperse in a variety of directions. The result would be an influx of small numbers over a large area. Owing to the natural resistance of stands affected, C-4, the result might be expected to be negligible. However, according to C-9 the original infestation could be expected to persist and eventually through single or repeated chance dispersals, moths will become concentrated, at which time new infestation could develop.

Unfortunately improved new hypotheses taking into account our new appreciation of moth dispersal have been slow to develop. Hopefully the above set of general infestation characteristics will assist. However, additional information is urgently required concerning the precise conditions under which moth dispersal occurs, and does not occur, as well as details of dispersal occurrences and their implications in terms of infestation dynamics on a broad scale.

Collectively the various new hypotheses emerging from infestation characteristics C-1 to C-10 lead me to a general control strategy, which if applied offensively could conceivably have major implications in managing future outbreaks.

Proposal

Characteristics of infestation based on 37 years of intensive surveys combined with recent findings on moth dispersal reveal a logical long-term outbreak control strategy that aims simply at the removal of source infestation. The concept has been developed that in the absence of infestation a widespread outbreak might not develop. The key question is: Could the next outbreak be avoided in Ontario if during a period of history when the extent of infestation was extremely low, all infestations including those in adjoining areas within the range of moth dispersal were eliminated or retained at levels below which moth dispersal would occur? A more general and futuristic version of the same question might be: could the next outbreak be avoided in North America? Recognizing existing circumstances in which some jurisdictions are applying a 50+ year projection to an assumed continuous infestation (Baskerville 1983) it is unrealistic to contemplate the elimination of infestation throughout the range of spruce budworm at this time. However, it might be appropriate to consider outbreak prevention for the western sector of its range over the next 10 years. This would require detailed and coordinated monitoring including the detection and evaluation of all infestations over a large area crossing the International Border, followed by international action against centers that constitute a source of dispersal.

A major limitation in such a suggestion is the narrow window in the extensive time frame through which man could effectively influence infestation development, namely, subsequent to the decline of one outbreak and before the start of another.

Beyond the enormous economic advantages success would have, the concept also offers the challenge of applying integrated control methods over limited forest areas. It is unlikely that any intense infestation discovered on either side of the International Border could be allowed to develop unimpeded while the forces of integrated control took hold. However, abatement treatments begun immediately could be followed by integrated methods to reduce populations further. The concept offers alternative strategies for forest management on a grand scale and provides for management action commensurate with historical reality.

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CANUSA WORKSHOP

NEW & IMPROVED TECHNIQUES FOR MONITORING AND EVALUATING SPRUCE BUDWORMS

Burlington, Vermont
September 13-15, 1983

Attendance List

1) Larry Abrahamson
SUNY College of Environmental Science and Forestry
Syracuse, New York 13210

2) Cedric Alexander
Vermont Fish & Game
180 Portland Street
St. Johnsbury, Vermont 05819

3) Douglas C. Allen
SUNY College of Environmental Science and Forestry
Syracuse, New York 13210

4) Louis Archambault
Canadian Forestry Science
Laurentian Forest Research Centre
P.O. Box 3800
Ste. Foy, Quebec G1V 4C7

5) Michel Auger
Quebec Department of Energy and Resources
175 St. John Street
Quebec G1S 3L1

6) Al Avery
New Hampshire Division of Forests and Lands
P.O. Box 856
Concord, New Hampshire 03301

7) Bernie Barton
Department of Forests, Parks and Recreation
R. D. #1, Box 2300
Morrisville, Vermont 05661

8) Jim Bean
Sumitomo Chemical
R.F.D. #3
Waldoboro, Maine 04572

9) Robert J. Blais
Canadian Forestry Service
Laurentian Forest Research Centre
P.O. Box 3800
Ste. Foy, Quebec G1V 4C7

10) Harold Brown
Eco-Analysts, Inc.
Kennebec Point Road
Georgetown, Maine 04548

11) John Buck
Vermont Fish & Game
Barre District Office & Court House
255 North Main Street
Barre, Vermont 05641

12) Michel Chabot
Quebec Department of Energy and Resources
175 St. John Street
Quebec G1S 3L1

13) Jonathan Connor
Maine Forest Service
P.O. Box 540
Old Town, Maine 04468

14) Michael Devine
Maine Forest Service
P.O. Box 540
Old Town, Maine 04468

15) Louis Dorais
Quebec Department of Energy and Resources
175 St. John Street
Quebec G1S 3L1

16) Robert P. Ford
U.S.D.A. Forest Service
NA - S&PF
1992 Folwell Avenue
St. Paul, Minnesota 51108

17) Richard Greenwood
Department of Forests, Parks and Recreation
180 Portland Street
St. Johnsbury, Vermont 05819

18) David Grimble
Applications Coordinator, CANUSA-E
U.S.D.A. Forest Service
370 Reed Road
Broomall, PA 19008

19) Patricia Hanson
University of Vermont
Entomology Research Lab
655 Spear Street
So. Burlington, Vermont 05401

20) Yvan J. Hardy
Universite Laval
Faculte de Foresterie et geodesie
Cite Universitaire
Quebec 10 G1K 7P4

21) Lester K. Hartling
New Brunswick Department of
Natural Resources
P.O. Box 600
Fredericton, New Brunswick

22) Robert L. Heyd
Michigan Department of Natural
Resources
Forest Management Division
1990 U.S. 41 South
Marquette, Michigan

23) Craig Howard
Forest Protection Ltd.
1030 P.O. Box
Fredericton, New Brunswick

24) Samuel Hudson
Department of Forests, Parks
and Recreation
R.D. #1, Box 2300
Morrisville, Vermont 05661

25) H. J. Irving
Forest Protection Limited
P.O. Box 1020
Fredericton, New Brunswick
Canada E3B 5C3

26) Daniel T. Jennings
U.S.F.S. Northeastern Forest
Experimental Station
U.S.D.A. Building
University of Maine
Orono, Maine 04469

27) Luc Jobin
Laurentian Forest Research Centre
P.O. Box 3800
Ste. Foy, Quebec
Canada G1V 4C7

28) Ronald Kelley
Department of Forests, Parks
and Recreation
R. D. #1, Box 2300
Morrisville, Vermont 05661

29) David M. Kendall
U.S.F.S. Northeastern Forest
Experimental Station
U.S.D.A. Building
University of Maine
Orono, Maine 04469

30) Davniel Kucera
U.S.D.A. Forest Service
370 Reed Road
Broomall, Pennsylvania 19008

31) Jay Lackey
Department of Forests, Parks
and Recreation
Barre District Office & Court House
255 North Main Street
Barre, Vermont 05641

32) Bruce H. McGauley
Supervisor
Ontario Ministry of Natural Resources
Pest Control Section
Maple, Ontario L0J 1E0

33) Marcia McKeague
Great Northern Paper Co.
Woodlands Department
1024 Central Street
Millinocket, Maine 04462

34) Melvin E. McKnight
Program Leader, CANUSA/US
Forest Service, U.S.D.A.
P.O. Box 2417
Washington, D.C. 20013

35) Immants Millers
U.S.D.A. Forest Service
P.O. Box 640
Durham, New Hampshire 03824

36) Bruce Montgomery
University of Michigan
School of Natural Resources
Ann Arbor, Michigan 48109

37) William Moulton
Department of Forests, Parks
and Recreation
180 Portland Street
St. Johnsbury, Vermont 05819

38) K. D. Murray
U.M.O. Department of Entomology
304 Deering Hall
University of Maine
Orono, Maine 04469

39) Kay M. Peters
Uniroyal Chemical Division
32 Spencer Street
Naugatuck, Connecticut 06770

40) Hollis Prior
Department of Forests, Parks
and Recreation
180 Portland Street
St. Johnsbury, Vermont 05819

41) Pete Reed
Department of Forests, Parks
and Recreation
111 West Street
Essex Junction, Vermont 05452

42) Chris Sanders
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
Sault Ste. Marie
Ontario P6A 5M7

43) Dan Schmitt
Program Manager, CANUSA-E
U.S.F.S. Northeastern Forest
Experiment Station
370 Reed Road
Broomall, Pennsylvania 19008

44) Janet L. Searcy, CANUSA/E
Information Coordinator,
U.S.D.A. Forest Service
P.O. Box 2417, Rm. 605 RP-E
Washington, D.C. 20013

45) Gary Simmons
Michigan State University
Department of Entomology
East Lansing, Michigan 48824

46) W. Lloyd Sippell
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
Sault Ste. Marie, Ontario P6A 5M7

47) Thomas A. Skratt
U.S.F.S. Northeastern Forest
Experiment Station
U.S.D.A. Building
University of Maine
Orono, Maine 04469

48) Dennis Souto
U.S.D.A. Forest Service
P.O. Box 640
Durham, New Hampshire 03824

49) John St. Arnauld
Department of Forests, Parks
and Recreation
180 Portland Street
St. Johnsbury, Vermont 05819

50) Stanley R. Swier
Extension Specialist/Entomology
Entomology Department
University of New Hampshire
Nesmith Hall
Durham, New Hampshire 03824

51) Robert Talerico
Research Coordinator, CANUSA-E
U.S.D.A. Forest Service
370 Reed Road
Broomall, Pennsylvania 19008

52) Brenton H. Teillon
Department of Forests, Parks
and Recreation
79 River Street, Heritage II Bldg.
Montpelier, Vermont 05602

53) A. W. Thomas
Canadian Forestry Service
P.O. Box 4000
Fredericton, New Brunswick
Canada E3B 5P7

54) Henry Trial, Jr.
Maine Forest Service
P.O. Box 415
Old Town, Maine 04468

55) Dr. Frank E. Webb
Forest Protection Ltd.
P.O. Box 1030
Fredericton, New Brunswick
Canada E3B 5C3

56) Mel Weiss
U.S.D.A. Forest Service
P.O. Box 640
Durham, New Hampshire 03824

57) Howard Weymouth
Great Northern Paper Co.
Woodlands Department
1024 Central Street
Millinocket, Maine 04462

58) Jerry R. Williams
Coordinator/Spruce Budworm
Silviculture
International Paper Company
9 Green Street
Augusta, Maine 04330

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Presents new or improved methods available for monitoring and evaluating spruce budworm populations.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—705-029/507

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