Canada
United States
Spruce Budworms
Program

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**Northeastern Forest
Experiment Station**
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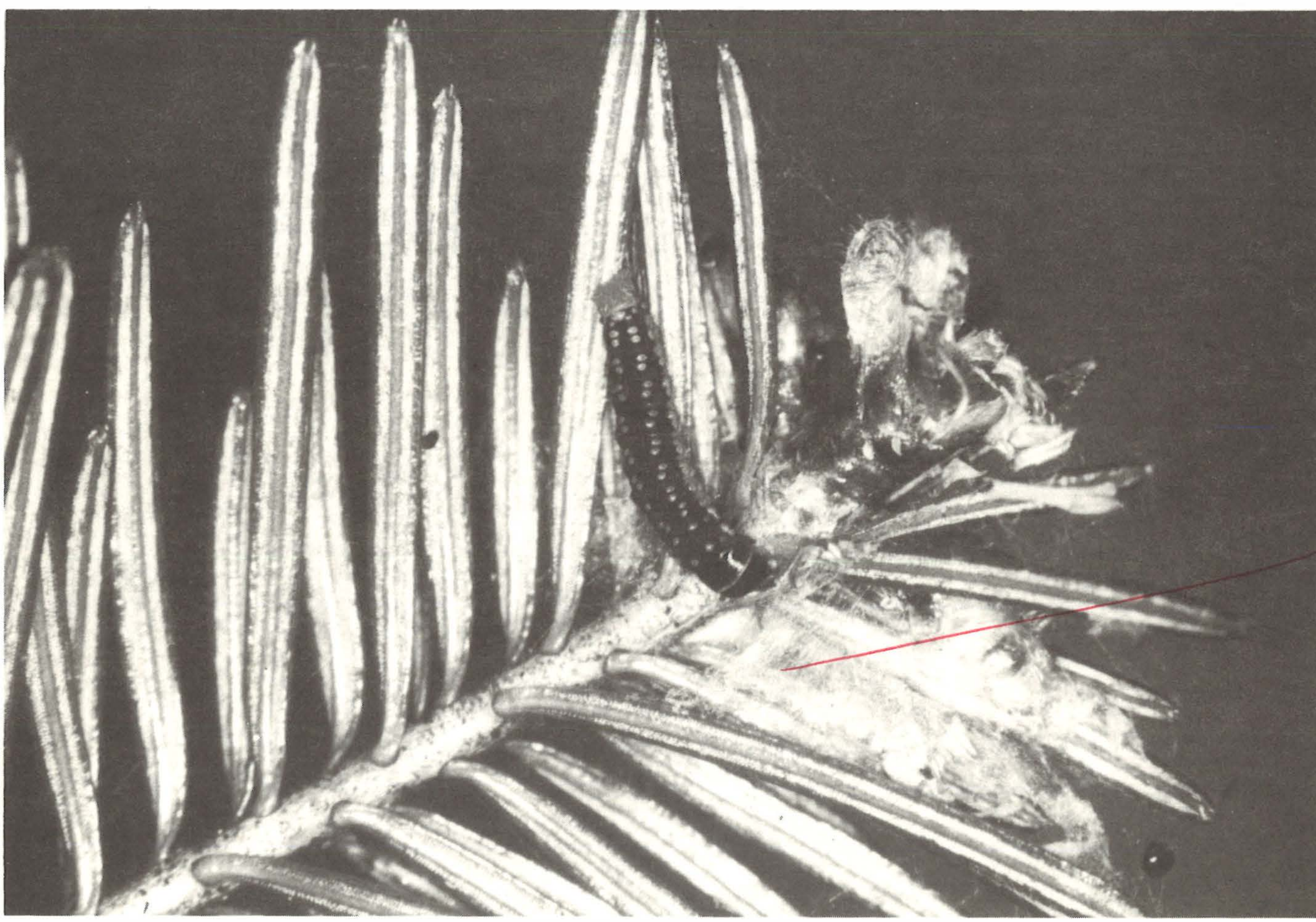
by David G. Grimble

CANUSA

Mid-Program Report

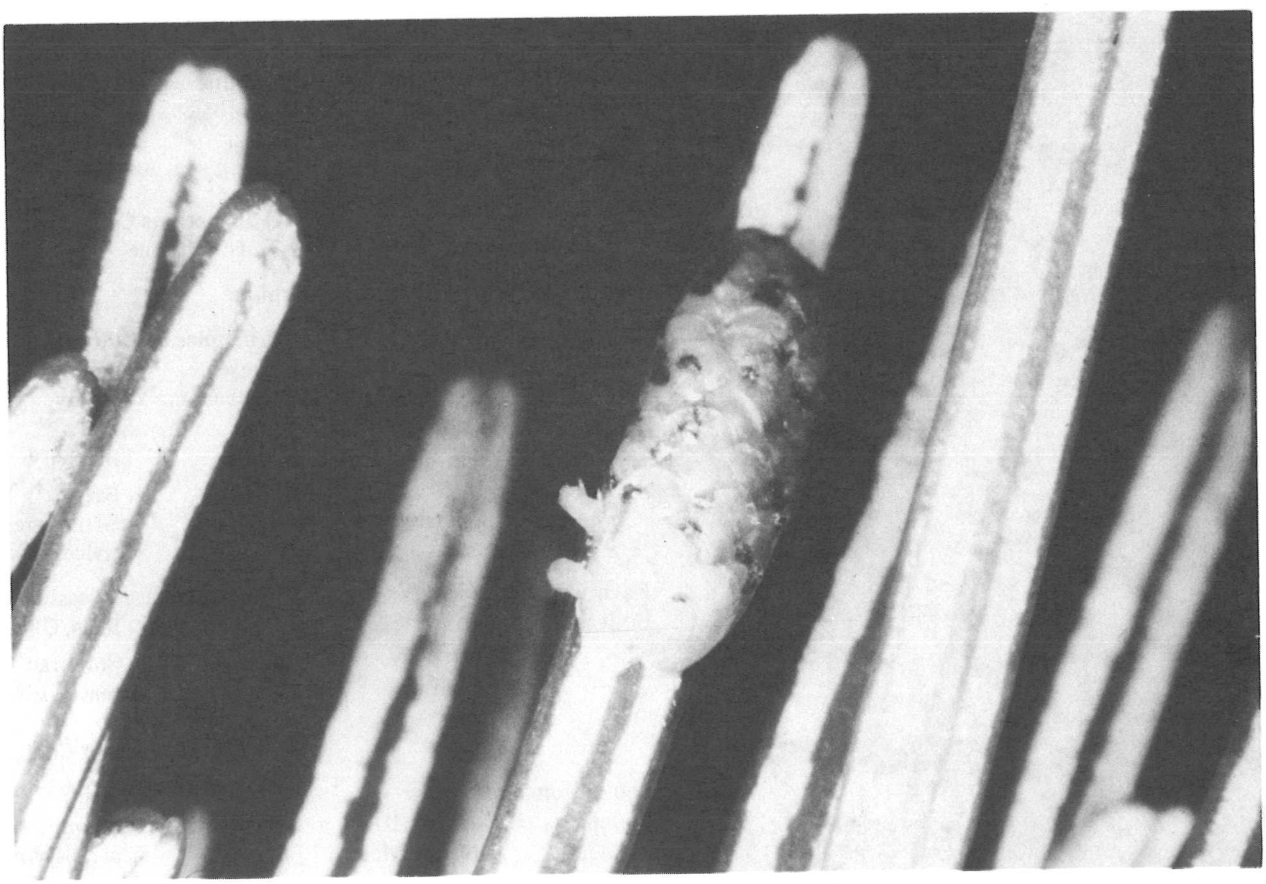


Half-grown spruce budworm larva feeding
on host foliage.

The Budworm

The spruce budworm *(Choristoneura fumiferana* [Clem.]*)* has been called the most damaging forest insect in all of North America. Certainly, for the past few years, while it has been at outbreak levels and because of massive chemical control programs carried out in Maine and in Canada, the budworm has been a most controversial insect pest. Spruce budworm is a native insect, the larvae of which feed on buds and needles of balsam fir and spruce trees. Budworm populations usually are held in check by natural control agents such as parasites and predators, and by unfavorable weather; but periodically the budworm seems to escape its natural checks and explodes into widespread massive outbreaks, defoliating and even killing fir and spruce over vast areas of North American boreal forests. At least five such outbreaks have occurred in the past 200 years—each usually lasting about 10 years before collapsing. The current outbreak in the Northeastern United States and Canada began about 1968 and shows no signs of abating.

Eggs are laid on host tree needles in mid-July. The eggs hatch in about a week, and new larvae immediately seek a sheltered spot in which to spin hibernacula for overwintering. In spring (May), the young larvae emerge and bore into and feed within needles of the previous year. As they grow, passing through six stages, the larvae web together and eat clusters of new needles from branch tips. When fully grown (June), larvae pupate in place for transformation into the adult moth.



First-stage spruce budworm larvae emerging from an egg mass on balsam fir needle.

No one knows when the present outbreak will subside, or even for sure what causes outbreaks to collapse. Bad weather (a cold, wet spring) apparently can cause sufficient mortality to result in a collapse. Some say that only starvation—when budworms have eaten nearly all of their food supply—is likely to depress budworm populations again, and that that cannot occur so long as widespread chemical treatment programs are carried out yearly. One thing we *do* know: The budworm is present in large numbers in Maine and eastern Canada and is killing or slowing the growth rate of trees needed by a wood fiber-hungry society.

Balsam fir tree after severe defoliation by the spruce budworm.

The Canada-United States Spruce Budworm Program

The Canada-United States Spruce Budworms Program (CANUSA) is a 6-year joint effort by the Department of the Environment, Canada, and the USDA Forest Service to develop methods for controlling spruce budworms in the Eastern and Western United States and in Canada. The CANUSA Program was initiated in Fiscal Year (FY) 1978—thus, with the close of 1980, the Program is half completed. The four goals of the program are to:

1. Develop integrated pest management plans.
2. Register biological controls.
3. Minimize adverse effects on the environment of control activities.
4. Provide effective management guidelines for coping with outbreaks.

Program Management teams are located in Broomall, Pennsylvania, for the Eastern United States, and in Portland, Oregon, for the Western United States. National leadership is located in Washington, D.C., and Ottawa, Ontario. The following shows the organizational structure for CANUSA-East, including the seven Working Groups organized to coordinate research activities by major subject area.

Program Manager
D. M. Schmitt

Research Coordinator
R. L. Talerico

Applications Coordinator
D. G. Grimble

Working Groups

Population Monitoring
Co-leaders: L. Sippell, CFS
G. Simmons, Michigan State University

Principles of Outbreak Causes
Co-leaders: Y. Hardy, Laval University
H. Batzer, USDA Forest Service

Environmental Impacts
Co-leaders: J. Trial, University of Maine
P. Kingsbury, CFS

Forest Damage Assessment
Co-leaders: R. Blais, CFS
D. Corcoran, Great Northern Paper Co.

Population Treatments
Co-leaders: P. Shea, USDA Forest Service
C. Nigam, CFS

Habitat Manipulation
Co-leaders: J. Dimond, University of Maine
C. Miller, CFS

IPM Planning and Decision Modeling
Co-leaders: C. Shoemaker, Cornell University
J. C. Mercier, Quebec

This report describes the progress of CANUSA-East research activities through FY 1980, and includes a discussion of each of the six Program-funded research targets, and a list of studies related to each target.

Target 1: Improve Methods for Assessing and Predicting Budworm Population Levels and Defoliation

Forecasting budworm population trends and estimating the degree of feeding damage caused by larval populations has always been difficult and time consuming. When budworm populations are low, egg masses are too scarce to be sampled efficiently. Even when populations are in the outbreak stage, an adequate sample requires laborious searching of foliage to locate the masses. CANUSA-funded researchers are trying to develop new tools to replace or expedite traditional egg-mass sampling procedures.

Light traps for moths have been used for many years by State pest control officials, including those with the Maine Forest Service. The traps are based on the principle that at night moths are attracted from long distances to an artificial light. The trapped moths die and are counted as an index of species abundance, so the traps are an efficient tool for gathering general information about population trends. In Maine, a CANUSA-funded researcher has analyzed catch data from traps at 10 locations to determine whether traps can provide early warning of an impending budworm outbreak. The data spanned 15 years (1961-76) and were collected where no recent defoliation by budworm had occurred, but where severe attack was noted by 1976. Curves fitted to these time-series data showed that trap catches *can* indicate impending outbreaks of budworm from 4 to 7 years before significant defoliation is visible (Fig. 1). Such early detection methods may prove useful to forest managers, since fully 8

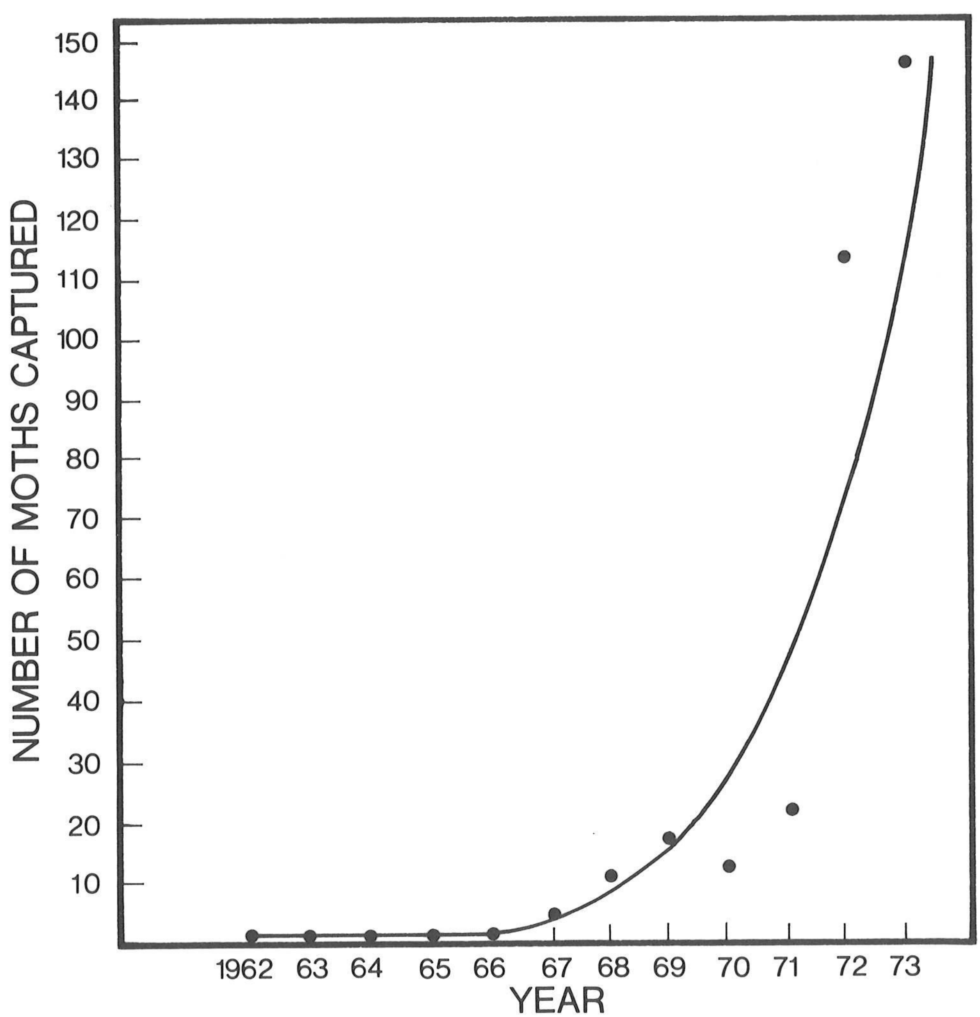


Figure 1.—Free-hand curve fitted to light-trap catches of spruce budworm moths at Eustis, Maine, 1962-73. (Source: Simmons, 1980)

to 10 years would pass before tree mortality would be expected. A report on this study (Simmons, 1980) is available to interested readers.

A second technique being developed to monitor low-level budworm populations, and thus give advance warning of outbreaks, entails the use of sticky traps baited with small amounts of the budworm sex pheromone. The pheromone is an odor (chemical) emitted by virgin female moths that attracts male moths to facilitate mating. When used with sticky traps, the pheromone entices males into the trap, where they become entangled and die. Field experiments have begun in Maine and the Lake States to gather trap-catch data for correlation with subsequent counts of egg masses, estimates of larval density, and defoliation. Scientists also are trying to determine the most effective placement and spacing of traps in such a monitoring system.

Most forest pest management agencies routinely evaluate budworm infestations by sampling the foliage of host trees (balsam fir) and counting the current egg masses. However, in this labor-intensive procedure, egg masses are difficult to see and many go undetected because of worker fatigue or carelessness. To eliminate this problem, researchers in Maine have developed an automated egg-mass detection process that shows great promise for increasing the accuracy and reducing the cost of counting budworm egg masses.

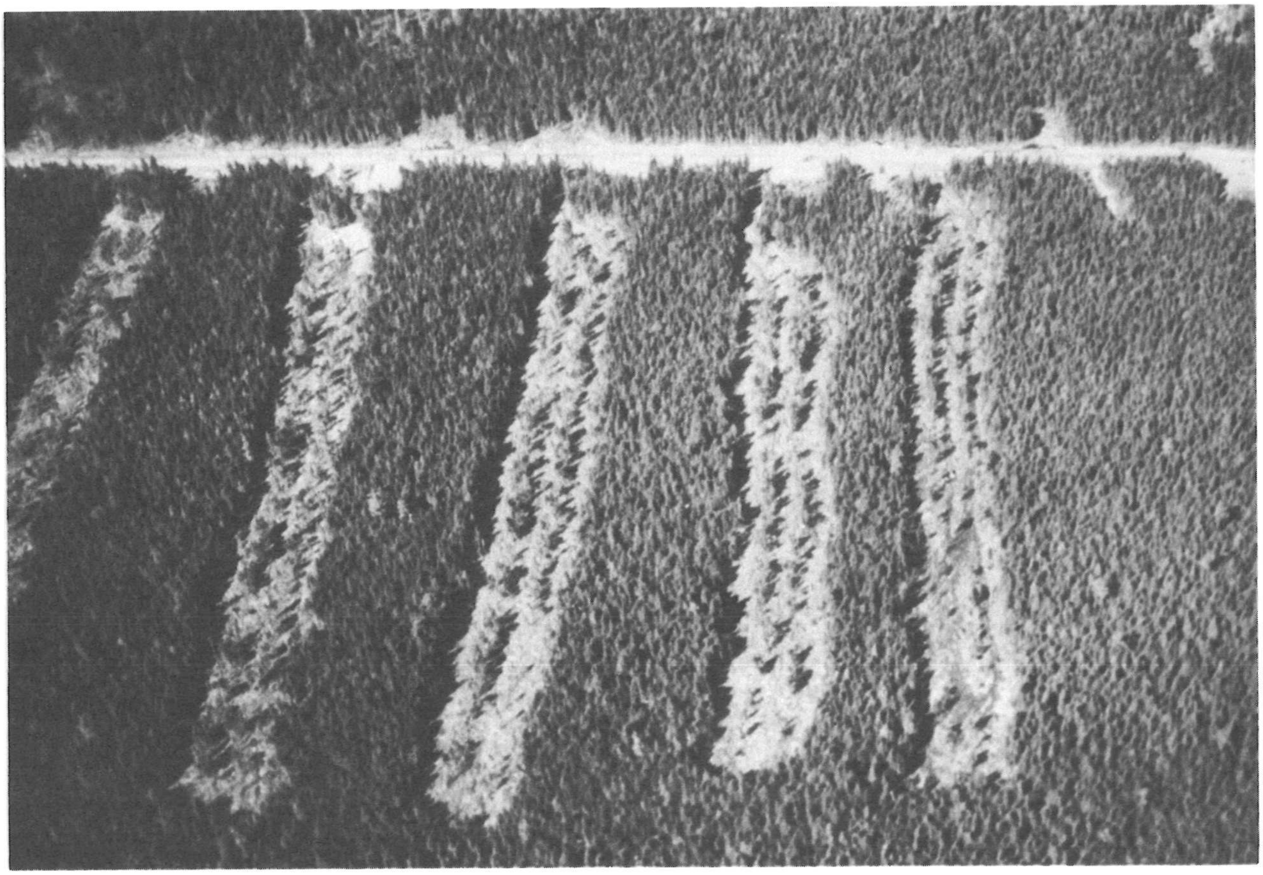
Aware that budworm egg masses fluoresce in ultraviolet light, scientists have constructed an automated egg mass counter. When foliage is passed under black light via a conveyor system, the machine detects and counts the "glowing" egg masses. In tests comparing the machine's counting efficiency with that of a crew of workers, results showed that the machine counts were as accurate as those of the workers, and were made at a considerable savings in time and money.

Entomologists from the Western United States and Lake States and some Canadian scientists have expressed great interest in using the automated egg-mass counter. Currently, through cooperative efforts, scientists at the USDA Forest Service's Missoula Equipment Development Center are making several needed modifications to this potentially valuable research tool.

Forest entomologists have never been able to explain fully why spruce budworm periodically irrupts to outbreak levels. Understanding the mechanisms of population release might allow forest managers to manipulate the habitat to prevent or delay the outbreaks. Results of Program-funded research are now beginning to illuminate the long-suspected effects of alternate host trees (white spruce) and foliage quality on the survival and development of budworm larvae. Spruce has been shown to provide a different microclimatic and phenological environment from balsam fir, a climate that may favor larval growth. The microhabitat of white spruce clearly is warmer than that of balsam fir. Also, researchers are determining the nutritional values of spruce and fir needles grown under different site conditions and the needles' effects on larval growth. Insect geneticists at the North Central Forest Experiment Station have found that host species (fir vs. spruce) can affect the genetic composition of budworm populations infesting them. These subtle influences—quality of foliage, genetic changes in larvae, differences in microhabitat—may help explain how budworm outbreaks originate, and how budworm populations are maintained at outbreak levels.

Reducing the environmental pressures on the budworm (e.g., less parasitism or predation) also may favor outbreaks. Accelerated research in Maine is aimed at determining the species, abundance, and relative importance of the major budworm parasites and predators. *Trichogramma minutum*, a tiny, egg-destroying wasp, might offer potential as a natural control agent. However, since budworm eggs are only available for a short period in late summer, the wasp requires alternate hosts in the same stands to carry it through the remainder of the year—until budworm eggs are again present. Researchers are trying to identify the best alternate host eggs for *Trichogramma* in hopes of developing techniques to build up the numbers of beneficial wasps before budworm eggs are deposited.

Ground beetles, spiders, certain wasps, and birds are known predators of budworm. Surveys are beginning to define the abundance and relative effectiveness of various species in these groups within spruce-fir forests, while concurrent research on different tree harvesting techniques has as its goal the manipulation of the spruce-fir environment to favor budworm predators. Strip cutting and shelterwood cuts, or any process that increases stand diversity and reduces conifer density, can be expected to result in more and different kinds of predators. At the same time, mortality would increase during the budworm's dispersal periods.



Strip cutting (harvesting) of spruce-fir forest in Maine following attack by the spruce budworm.

Studies Related to Target 1 (FY 1978-80)

Conveyor-belt system for prototype spruce budworm egg-mass counter.
D. B. Young, University of Maine

The significance of nonhost and alternative host tree species on populations of larval spruce budworm—with emphasis on improving sampling techniques.
W. B. Kemp, Environmental Associates, Inc.

Pheromone chemistry and development of pheromone sampling systems for eastern spruce budworms.
R. Carde, Michigan State University, and W. Roelofs, Cornell University

Microclimatic and phenological differences on balsam fir and white spruce in relation to the development of the spruce budworm.
Y. Hardy, Laval University

Use of light trap data to assess changes in endemic spruce budworm population.
G. A. Simmons, Michigan State University

Improvement of spruce budworm population sampling for low and moderate population levels.
G. A. Simmons, Michigan State University, and G. W. Fowler, University of Michigan

Photometric derivation of analytical parameters for large area forest management.
J. E. Walker, Calspan Corporation

Effects of moisture stress on foliar chemistry of balsam fir and survival and growth of spruce budworm.
W. J. Mattson and N. Koller, USDA Forest Service

Genetic variation of spruce budworm populations.
N. C. Lorimer, USDA Forest Service

Nutritional values of spruce and fir foliage related to spruce budworm infestation and site conditions.
M. M. Czapowskyj, USDA Forest Service

Bioassay system for detection of spruce budworm pheromone.
E. A. Meighen, McGill University

Development and application of a sensitive bioassay to monitor air levels of the pheromone of the spruce budworm.
E. A. Meighen, McGill University

Physiological and chemical basis of host plant selection by eastern spruce budworm larvae.
P. J. Albert, Concordia University

A model to predict the dispersal of spruce budworm larvae.
C. J. Mason, Aeromatrix, Inc.

Pheromone variability within and between spruce budworm populations.
W. L. Roelofs, Cornell University

Stand factors favoring and limiting exploitation of low and moderate budworm populations by its parasite complex.
G. A. Simmons, Michigan State University

The association of weather and past outbreaks of the budworm as derived from dendrochronology.
H. J. Heikkenen, American Institute of Dendrochronology, Inc.

Field monitoring test with budworm pheromone.
In Michigan: J. Witter, University of Michigan
In Vermont: D. Parker, University of Vermont

Host plant nitrogen utilization by spruce budworm.
M. E. Montgomery, USDA Forest Service

Developing *Trichogramma* as a potential suppression strategy against spruce budworm.
D. Jennings, USDA Forest Service

Alternate hosts for *Trichogramma* egg parasites attacking spruce budworms.
D. Jennings, USDA Forest Service

Target 2: Improve Methods for Assessing and Predicting Effects of Budworm on Host Trees, Stands, and Plant Communities

Recognizing that significant growth loss and tree mortality has already occurred both in the Lake States and in Maine, and that reliable estimates of those losses are essential for planning, CANUSA-East is sponsoring field work to gather these data. In Maine, through a cooperative effort with the Cooperative Forestry Research Unit, University of Maine, mortality has been estimated by a sample design based on the Forest Survey. This 5-year effort concluded in 1980.

Meanwhile, the Biometrics Group at the Northeastern Forest Experiment Station is developing estimates of natural mortality by size class. Data from the 1970 Maine forest survey that were collected before the current budworm outbreak are being used in this study.

On the Ottawa and Hiawatha National Forests of Upper Michigan, 136 ground plots have been established and impact data have been gathered for 2 years. Damage, including defoliation, is being assessed through an adaptation of the stratified three-stage cluster sampling method. Ground plot data will be compared with data obtained from aerial photographs of these 136 plots. From these assessments, scientists hope to estimate the budworm impact on these National Forests, develop a hazard-rating system, and prepare stand models for infested and noninfested spruce-fir stands.

In Maine, Program researchers have established a major demonstration area on which the hazards of individual stands are rated and salvage operations are carried out. Targeted harvesting and normal insect-control operations also are conducted on this demonstration area. This project involves three cooperators and infested forest lands encompassing six entire townships. Activities are planned and executed by a project management team consisting of industrial and State forest district managers and USDA Forest Service and University of Maine scientists. The major aim of this group is to demonstrate the best available techniques for utilizing and protecting the forest resource, while reducing the need for chemical protection.

In a similar but smaller demonstration project in the Lake States, scientists are using a hazard-rating system based on research at the North Central Forest Experiment Station. There is no direct control of budworm and, in most cases, harvesting is simulated or experimental. Also, scientists at the North Central Station are examining historical plots in Minnesota to document normal forest succession following a spruce budworm outbreak.

At Durham, New Hampshire, research has shown that readings of cation concentration in phloem with a pulsed-current meter may have value as indicators of tree stress. If these studies are successful, these readings may be incorporated into standard line-plot or transect inventory procedures. When used with cover type mapping, site-specific hazard rating maps can be produced.

Studies Related to Target 2 (FY 1978-80)

Spruce budworm: techniques and plot establishment for forest damage assessment.
J. A. Witter, University of Michigan

Forest succession following a spruce budworm outbreak in Minnesota.
H. O. Batzer, USDA Forest Service

The effect of continued spruce budworm defoliation on the volume growth of spruce-fir stands.
D. S. Solomon, USDA Forest Service

A bole-volume growth model for spruce-fir stands.
D. S. Solomon, USDA Forest Service

Plant composition and production following fire and clear-cutting for salvage in budworm-infested stands.
H. S. Crawford, USDA Forest Service

The Shigometer and spruce budworm hazard indices.
D. Olson, University of New Hampshire

Target 3: Develop methods for Predicting Short- and Long-Term Socioeconomic Impacts of Budworm on Forest Resource Uses, Values, Management Plans and Operations.

Insects affect forest resources in both beneficial and harmful ways. Further these effects of insect infestations can occur at the infestation site, or "downstream", or at other noninfested locations. With this in mind, researchers in Michigan are evaluating budworm-caused impacts on forest land values and management. Their objectives are to (1) develop an economic model for estimating both the cost of detrimental effects and the value of beneficial effects of budworm, and (2) to develop and demonstrate the use of a guidebook of resource value estimators to be used by forest managers in planning forest insect and disease control strategies.

Presalvage (removing weakened trees before their actual death) is sometimes used to minimize losses from budworm outbreaks. A CANUSA-East demonstration project in Michigan was initiated to investigate the economics and potential of presalvage as a management tool. Workshops are being held to acquaint landowners with the budworm/spruce-fir ecology and with currently available management tools (including spraying, salvage or presalvage, site conversion, and economic decisionmaking), and to discuss the current and projected markets for the wood supply in the Lake States. The first workshop was held in Escanaba, Michigan, in December 1979. Instructors and discussion leaders were drawn from Michigan State University, Michigan Technological University, University of Michigan, Michigan Department of Natural Resources, and the USDA Forest Service (CANUSA). Through participation in workshops, managers are expected to be able to correctly evaluate the potential for damage to their infested forests and the options available to them for making effective decisions to minimize losses.

Harvesting cost could be a key factor in plans for managing stands damaged by the budworm. Using simulation models developed at the North Central Station, USDA Forest Service researchers in Minnesota are analyzing the productivity and cost of several harvesting systems, emphasizing multiproduct recovery (sawlogs, pulp and flakeboard, roundwood, chipped pulp, fuelwood). These harvesting models are flexible enough to handle expected stand and machine variation. Stand replicas have been constructed from forest inventory data, and simulated harvesting experiments will be carried out for three average stand diameter classes, four stocking levels, and six species group mixtures. Thus, these models will simulate the harvesting of 72 stand types. A report of this work will be available in 1982.

Studies Related to Target 3 (FY 1978-80)

Demonstration of presalvage in high-risk balsam fir stands.
R. P. Ford, USDA Forest Service

The economics of presalvage alternatives as a method of minimizing spruce budworm losses.
G. A. Simmons, Michigan State University

Estimating harvesting costs of damaged stands of balsam fir/white spruce.
D. P. Bradley, USDA Forest Service

Evaluating spruce-budworm-caused impacts on forest land values and management.
R. J. Marty, Greentreee Consultants, Inc.

The production of wood in balsam fir and spruce stands as influenced by varying degrees of budworm attack.
D. S. Solomon, G. A. Hughes, and R. A. Gregory, USDA Forest Service

Target 4: Develop Silvicultural, Chemical, and Biological Techniques for Managing Budworm-Susceptible Forests and Budworm Populations

Forest managers must develop new techniques or, in some cases, refine existing ones to keep budworm damage within tolerable bounds. Improved budworm/forest management has been a major effort for CANUSA-East.

With partial CANUSA-East funding, International Paper Company has established a series of long-term plots on its lands in Maine and in Canada to evaluate the effects of various silvicultural treatments on budworm populations and their overall impact on the forest. Thinning, shelterwood cuts, and planting of resistant species are being tested. Because partial conversion of the forest to more resistant tree species (spruce) may offer lasting protection, USDA Forest Service researchers in the Lake States are analyzing micro-environmental requirements for planted white and black spruce.

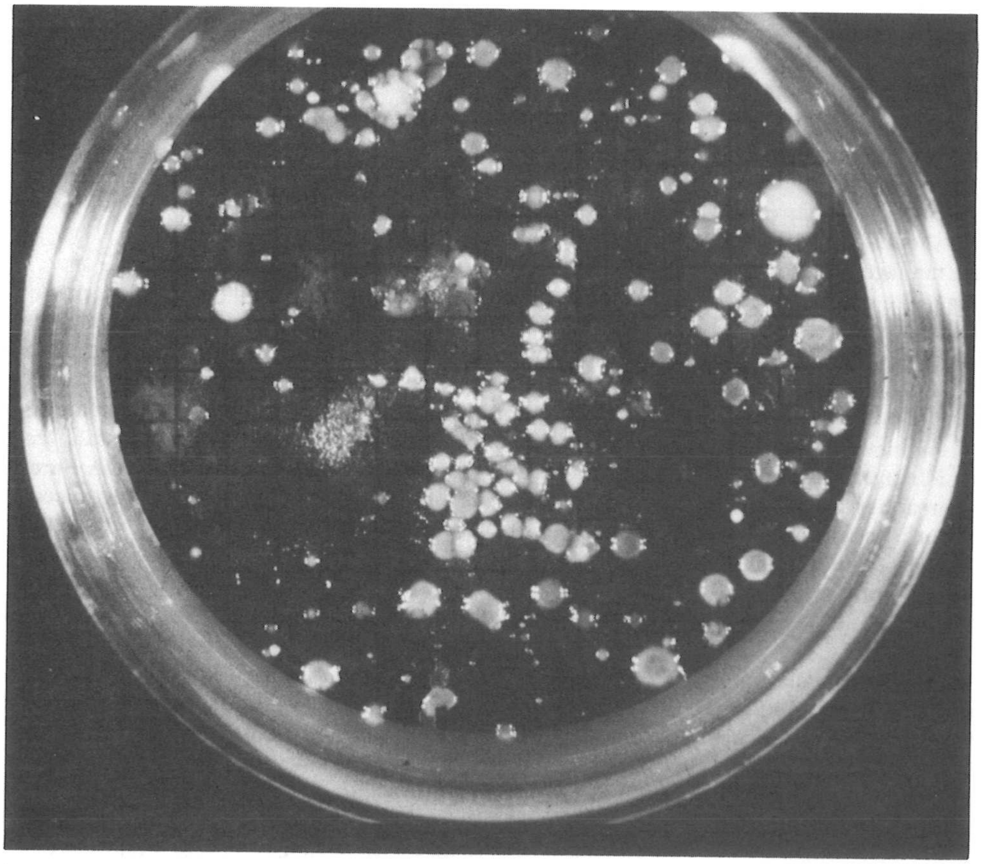
As the result of many years of severe defoliation, some coniferous forests in the Northeast have suffered significant damage. Balsam fir has been especially hard hit by the budworm. At the University of Minnesota, researchers have developed and are now testing a waferboard product made from balsam fir. This new product promises to provide additional options for salvaging weakened or dying fir stands.

Chemical insecticides have been used almost exclusively in recent programs for direct control of budworms. Because public opposition to chemicals is growing, chemical insecticides soon may not be acceptable for forest use. In anticipation of that event, CANUSA is giving increased attention to microbial insecticides. Microbials are more specific in their action than chemicals and pose little or no danger to other organisms in the environment.

Bacillus thuringiensis or *B.t.* is a bacterium that is toxic to certain caterpillar species, including the budworm. *B.t.* can be applied like conventional sprays, but, unlike chemicals, it does not kill beneficial insects and other nontarget organisms. Although the insecticidal properties of *B.t.* have been known for years, it has not been used widely for forest pest control because chemicals are less costly and more effective. To help remedy this situation, new formulations of *B.t.*, sometimes with specific additives, have been field tested by CANUSA-East researchers in Maine. Combinations of *B.t.* plus chitinase (an enzyme) or *B.t.* plus Orthene (a chemical insecticide) have *not* proven to be more effective than *B.t.* alone.

Scientists seem to agree that the key to improving the efficacy of *B.t.* as a budworm control agent lies in improved formulations (i.e., *B.t.* carrier plus additives to the spray), more uniform applications and coverage of the target trees, and more effective deposit of spray materials on foliage.

CANUSA researchers are trying to stimulate uniform field testing and regional replication of *B.t.* test plots so that the underlying reasons for unsuccessful trials can be more easily identified. During 1980, for example, field trials of two *B.t.* formulations were replicated in Maine, New Hampshire, Wisconsin, and Arizona. Under a uniform work plan, the same data were generated in each regional location. Data from these locations will be compiled and analyzed in one composite report. The results will be reviewed by a committee of knowledgeable specialists who will search for sources of variability in performance, and then recommend to CANUSA-East the next step in the development program.



Colonies of *Bacillus thuringiensis*, a microbial control agent for spruce budworm, growing on cultured filter used in detecting aerial spray deposits.

Although considered years away from operational use, *Zoophthora* fungus and budworm viruses are two other kinds of microbial agent which seem to offer some potential. CANUSA researchers at Cornell University recently infected budworms in a small field test in which *Zoophthora* was used on individual infested trees. Apparently, this is the first time that this fungus has been tested under field conditions.

Some scientists believe that the budworm pheromone offers potential both as a control tool (by confusing males and thereby interfering with mating success) and as part of a technique for monitoring populations. Consequently, CANUSA in 1980 supported in part a small test of the pheromone on two plots in Maine. The sex attractant was applied aerially in greatly different concentrations. Dispersal was accomplished by impregnating the pheromone into tiny plastic chips that were designed to adhere to tree foliage and permeate the air. Cooperating on the evaluation of this technique were scientists from University of Maine, Canadian Forestry Service, and Hercon Corporation.

Other researchers are developing a rapid bioassay system to measure concentrations of the pheromone in air and determine the field responses of male moths to various blends of pheromone components. Pheromones may someday be an important part of an integrated pest management program for suppressing outbreaks through a combination of techniques.

Studies Related to Target 4 (FY 1978-80)

Field studies of fungi as pathogens of spruce budworm, *Choristoneura fumiferana*.
R. Soper, Boyce Thompson Institute

Bacillus thuringiensis: field tests of alternate formulations.
J. Dimond, University of Maine

Delineation of selected variables which affect the loss of *Bacillus thuringiensis* crystals from aerial sprays.
F. D. Harris and D. B. Smith, University of Missouri

A sunshine ultraviolet simulator for microbial insecticide testing.
C. J. Mason, Aeromatrix, Inc.

Wind tunnel evaluation of aerodynamic drag coefficients of spruce foliage elements.
D. F. Potts, SUNY College of Environmental Science and Forestry

Economic potential of marketing and utilizing spruce-fir timber from forests threatened or damaged by the budworm.
S. A. Sinclair, University of Minnesota

Production of spruce budworm baculovirus in larvae of the cabbage looper, *Trichoplusia ni.*
G. R. Stairs, Ohio State University

Metacil and long-term microbiological side effects in fresh water ponds.
D. J. Wildish, Fishery Environmental Science, New Brunswick

Controlled drop atomizer for aerial applications on forestry.
W. E. Yates and N. Akesson, University of California

Insect growth regulators for management of eastern spruce budworm populations.
J. Granett and J. Brushwein, University of Maine

Efficient aerial sprays from new analytical biophysical systems for mass and droplet transport.
C. Himel, University of Georgia, and A. J. Howitt, Michigan State University

Entomophthora fungi as mycoinsecticides for spruce budworm control.
R. S. Soper, Boyce Thompson Institute

Early detection of nucleopolyhedrosis (NPV), cytoplasmic (CPV), and entomopox (EPV) virus infections in *C. fumiferana* (Clem.) larvae.
N. R. Dubois, USDA Forest Service

Determination of the potency of selected *B. thuringiensis* strains against *C. fumiferana* (Clem.)
N. R. Dubois, USDA Forest Service

Effect of spray delivery system on the potency of *B. thuringiensis* tank mixes against *C. fumiferana.*
N. R. Dubois, USDA Forest Service

An analysis of some microenvironmental requirements for planted white spruce and black spruce.
D. A. Perala, USDA Forest Service

Silvicultural practices to minimize spruce budworm impacts.
S. E. Goldman, International Paper Co.

Canada/U.S. cooperative *B.t.* treatments evaluation.
C. H. Buckner, CFS

Selection of strains of baculovirus of *C. fumiferana* resistant to near ultraviolet radiation.
G. R. Stairs, Ohio State University

Evaluation of pathogenicity and virulence of granulosis viruses of budworm.
W. Yendol, Pennsylvania State University

Evaluation of the impact of two formulations of *B. thuringiensis*, Thurcide 16B, and Dipel 4L, on spruce budworms and associated parasites in Wisconsin.
P. J. Shea, R. C. Reardon, and D. R. Johnson, USDA Forest Service

Core field test of two formulations of *B.t.* in New Hampshire.
S. Swire, University of New Hampshire

Core field test of two formulations of *B.t.* in Maine.
J. Dimond, University of Maine

Cooperative Canada/U.S. pheromone disruption test.
M. D. Barry, Hercon Group, Herculite Products, Inc.

Target 5: Improve Capabilities for Evaluating and Monitoring Major Management Strategies to Establish Environmentally Acceptable Levels.

So far, activity in this target area has related to the environmental impacts of chemical pesticides used for budworm control. An annotated bibliography of the ecological impacts of chemicals used in forest protection has been published. Also, the Program has contracted for the production of a field manual which will outline in detail useful procedures and tools for monitoring the impacts of insecticides on nontarget species. The manual should be available for distribution next year.

In addition, the Program has supported studies at the University of Ottawa for the development of two sensitive bioassay techniques (agar and liquid culture) that will be useful for determining the toxicology of pesticides and adjuvents in the field. A third and even more sensitive method (using fluorometry) also is being developed. These techniques will allow onsite evaluations of pesticides.

Also at the University of Ottawa, researchers are evaluating the environmental impacts of Matacil (aminocarb) in aquatic systems. Matacil is the pesticide of choice used in much of the spraying in Canada. Nanogram and picogram levels of Matacil can be detected in water and lethal doses for trout and bullhead have been determined. The effects of Matacil on the development, reproduction, egg diapause, and embryogenesis of dragonflies and damselflies are being investigated. In a concurrent study at Saint Andrews, New Brunswick, the long-term microbiological effects of Matacil in fresh water ponds are being evaluated.

Studies Related to Target 5 (FY 1978-80)

Problem analysis: environmental impacts of insecticides.
T. May, University of Maine

Ecological impacts of forest insecticides: an annotated bibliography.
J. Bart, Cornell University

Environmental monitoring of the 1979 field test of Matacil.
H. L. Brown, Eco-Analysts, Inc.

Development of a rapid and sensitive bioassay technique to determine toxicity of pesticides, solvents, and emulsifiers.
P. Weinberger, University of Ottawa

Evaluation of the environmental impact of Matacil using aquatic microcosms.
P. Weinberger, University of Ottawa

Target 6: Develop Spruce Budworm/Forest Resource Management Policies, Decision Systems, and Alternative Management Actions

Simulation models of budworm/forest interaction can be useful to the forest manager in the decisionmaking process. Used correctly and with sufficient reliable data, these models allow the manager to compress time. We can sometimes learn the probable result of anticipated actions before committing the manager's time and resources. But current budworm management models are incomplete and some are unreliable. CANUSA is supporting an effort at Cornell University to modify the Holling model to reflect better the situation in Maine. New information is being incorporated into the model as it is developed.

A portion of this target area deals with technical information services and technology transfer to the user. In this regard, program scientists have published and distributed a "Spruce Budworm's Bibliography" and a "Spruce Budworms Thesaurus." In addition, a computerized inventory of all current budworm research and development work is maintained, and printouts are supplied to interested investigators to help them keep abreast of work related to their own.

CANUSA is producing two state-of-the-art field manuals that should be of interest to researchers and managers. The first manual will include descriptions and illustrations of the most abundant and biologically important parasites of the budworm, and suggests methods for conducting surveys to evaluate the effects of these important natural control agents on budworm populations at specific locations.

The second manual will outline the advantages and disadvantages of various field tools and techniques used in assessing the impacts of insecticides used in budworm control on aquatic environments. Data needs and suitable species for monitoring also will be discussed.

CANUSA-East is building and maintaining a file of quality 35-mm color slides of budworm-related subjects. The slides are available to cooperators upon request and should prove useful for meetings and for publications. The file includes an excellent selection of slides that show the biology of the budworm and various spray project activities.

Finally, communication is maintained between Program Management and cooperators partly by newsletters. "Dear Colleague" letters are mailed periodically to a list of over 400 persons and an international newsletter, with news coverage on the entire CANUSA Program in the United States and Canada, is sent from the Washington Office every other month.

Studies Related to Target 6 (FY 1978-80)

Foster the dissemination and application of spruce budworm pest and forest management information and technology.
M. Houseweart, University of Maine

Spruce budworm simulation modeling and simulation results.
J. Stedinger, Cornell University

Analysis of the integrated management of spruce budworm.
C. A. Shoemaker, Cornell University

The integration of targeted harvesting of balsam fir with precision direct protection of fir-spruce forests.
J. B. Dimond, University of Maine

Management alternatives for nonindustrial private ownerships in budworm-infested situations.
R. S. Manthy, Greentree Consultants, Inc.

Spruce budworm literature file and retrieval system.
F. B. Knight, University of Maine

A field manual on common insect parasites of the spruce budworm.
David Tilles, Center for Natural Areas

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Projected Accomplishments of CANUSA-East Program

The following is a list of projected accomplishments of the CANUSA-East accelerated research program.

1. For budworm population assessments:

- Detailed procedures for evaluating light-trap moth catches.
- An operational model of an automated budworm egg-mass counter.
- Techniques for implementing a pheromone trap network to monitor low to medium budworm populations in the Lake States and Maine.
- A two-phased budworm monitoring system that includes the use of pheromone traps at endemic levels (until budworm populations appear to be escaping the the control of natural agents) and an improved egg-mass sampling system.
- Procedures for rating the effects of specific budworm populations by stand or site conditions and climate.

2. Toward improved forest management:

- Tables of expected stand mortality as a result of an outbreak, considering stand composition and site characteristics.
- Guidelines for reducing stand vulnerability.
- Guidelines for planting more resistant host tree species (spruce).
- Utilization and marketing guide for balsam fir.
- Allocation-of-cut procedures, based on stand vulnerability risks, to maximize salvage opportunities.

3. For direct control of outbreak populations:

- Evaluations of new *B.t.* strains and improved *B.t.* formulations.
- Recommendations for effective use of *B.t.* in control projects.
- Decision guide to facilitate treatment (insecticide) decisions.
- Guide for evaluating environmental impacts of selected insecticides on aquatic ecosystems.

4. Toward long-term budworm/forest management strategies:

- Development of economic criteria for establishing suppression zones in Maine.
- Manual on integrated pest management of spruce-budworm-infested forests.
- Joint USDA Forest Service/CFS symposium with published proceedings that summarize current knowledge in all facets of the spruce budworm problem and management of spruce-fir forests in the Northeast.

Program area	FY 1978 (6 studies)	FY 1979 (43 studies)	FY 1980 (42 studies)
		Dollars	
Population evaluation, outbreak causes	2,900	407,111	411,284
Damage assessment	—	257,333	205,562
Direct control techniques	7,000	295,990	318,310
Environmental monitoring	6,000	149,420	65,131
Socioeconomic impacts	—	88,951	178,224
Alternative management	12,200	415,472	441,474
Total	28,100	1,614,277	1,620,474

CANUSA Program Cooperators Through 1980

USDA Forest Service

- Northeastern Forest Experiment Station
- North Central Forest Experiment Station
- Pacific Southwest Forest and Range Experiment Station
- Pacific Northwest Forest and Range Experiment Station
- Missoula Equipment Development Center
- Northeastern Area, State and Private Forestry
- Eastern Region (R-9)

USDA Agricultural Research Service (formerly Science & Education Administration)

- Systematic Entomology Laboratory, Insect Identification and Beneficial Insect Introduction Institute

Canadian

- Forest Pest Management Institute
- Great Lakes Forest Research Centre
- Maritime Forest Research Centre
- Fisheries and Marine Service
- Laurentian Forest Research Centre
- Newfoundland Forest Research Centre

Private Organizations

- International Paper Company
- St. Regis Paper Company
- Great Northern Paper Company
- Seven Islands Land Company
- Baxter State Park Authority
- Hercon Group, Herculite Products, Inc.
- Environmental Associates, Inc.
- Center for Natural Areas
- Aeromatrix, Inc.
- Boyce Thompson Institute
- Calspan Corporation
- Greentree Consultants, Inc.
- Eco-Analysts, Inc.
- American Institute of Dendrochronology
- Abbott Laboratories
- Sandoz, Inc.

State Agencies

- Maine Forest Service
- Michigan Department of Natural Resources
- Minnesota Department of Natural Resources
- Wisconsin Department of Natural Resources
- New York State Experiment Station

Universities and Colleges

- SUNY College of Environmental Science and Forestry, Syracuse
- The Pennsylvania State University
- University of Maine
- University of Vermont
- University of New Hampshire
- Michigan State University
- University of Georgia
- University of California (Davis)
- University of Minnesota
- Cornell University
- University of Missouri
- Ohio State University
- University of Maryland (Baltimore)
- University of Ottawa
- Laval University
- McGill University
- Concordia University

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Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- University Park, Pennsylvania, in cooperation with the Pennsylvania State University.
- Warren, Pennsylvania.