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DEVELOPMENT AND IMPLEMENTATION OF A GYPSY MOTH INTEGRATED PEST MANAGEMENT PROGRAM

by R. Reardon, M. McManus[1], D. Kolodny-Hirsch and R. Tichenor[2], M. Raupp[3], C. Schwalbe[4], R. Webb[5], and P. Meckley[6]

Abstract. The current approach to gypsy moth management in the United States involves applying insecticides to eliminate isolated infestations, and to suppress populations in areas of regulatory concern or where socioeconomic impacts are projected to occur. An alternative approach, integrated pest management, is being implemented over a wide range of ecological, geographic, and land-use areas within a three-county area in Maryland to evaluate the feasibility of managing gypsy moth populations at low levels. This project is structured around a comprehensive biological monitoring system that provides an annual data base on the distribution, density, and trend of gypsy moth populations. This information, in conjunction with ancillary data for landscape features (e.g., soil type, vegetation cover type, and land use) and stand susceptibility to defoliation rating, provides guidelines for prescribing an array of intervention activities. This program also supports ongoing cooperative studies in data-base management, refinement of sampling methods, and evaluation of intervention activities.

The decade of the 1970's was characterized by a significant increase in funding for research and development on the gypsy moth. The reason for this was the tremendous increase in moth populations and associated impacts that began in 1969 and continued through the decade. The need to develop an integrated pest management (IPM) approach to the problem was recognized early in the planning stages and remained a central theme throughout the period of accelerated research and development. During this time, multidisciplinary research and development programs were initiated against the gypsy moth *(Lymantria dispar),* Douglas-fir tussock moth *(Orgyia pseudotsugata), Dendroctonus* spp. bark beetles, and spruce budworms *(Choristoneura* spp.) (9, 28). These programs differed from those in agriculture in that primary emphasis was placed on the insect rather than on the crop. A generalized system structure was used in developing an IPM system for all of the aforementioned forest insects except the gypsy moth (27). Computer-based models were developed for stand dynamics, pest population dynamics, socioeconomic impacts, and resultant intervention activities.

The gypsy moth situation is such that the modeling approach employed for other forest insects is not practical (16). The bark beetles, budworms, and tussock moth are pests of conifers that inflict extensive tree mortality and affect forest stand dynamics and management objectives.

The gypsy moth, however, is a polyphagous defoliator of hardwoods in the extensive mixed oak forests of the East. Over 90% of this forested land is in private ownership, with little management of resource; and stand dynamics models are virtually nonexistent. Public concern about the gypsy moth is greatest with respect to the urban forest interface. Tree mortality has been highly variable, site specific, and apparently is not the

1. Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, CT 06514.
2. Maryland Department of Agriculture, Annapolis, MD 21401.
3. Maryland Cooperative Extension Service, Department of Entomology, University of Maryland, College Park 20742.
4. Animal and Plant Health Inspection Service, USDA, Otis ANG, MA 02542.
5. Agricultural Research Service, USDA, Beltsville, MD 20705.
6. Maryland Department Forest, Park and Wildlife Services, Annapolis, MD 21401.
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major impact in the eyes of the public. Of particular concern is the nuisance created by the caterpillars and their associated defoliation. As a result, it has been impossible to specify an economic threshold (ET) or economic injury level (EIL) for the gypsy moth. The EIL is considered the decisionmaking point for control in most IPM systems for agronomic crops (17).

The current approach to gypsy moth management by government agencies in the United States is based on the combined objectives of the State and Federal cooperative programs and entails the use of various intervention activities, especially insecticides to eliminate isolated infestations, and to suppress populations in areas of regulatory concern or where socioeconomic impacts are projected to occur. Ravlin et al. (19) conducted an extensive survey of current gypsy moth management programs in the United States, and concluded that there is a serious need to develop a unified management approach.

In recent years it has become apparent that the suppression approach employed by many states to generally infested sites in the East is providing only temporary (1 to 3 year) control of the pest and its associated impacts. Further, the public has become sensitized to the potential effects of insecticides in the environment, particularly when applied aerially over large areas.

An alternative approach to coping with gypsy moth problem is to manage populations at innocuous densities. This requires implementing a systematic surveillance network to annually determine the distribution, abundance, and biological quality of gypsy moth populations, maximize natural controls and apply artificial controls when necessary, in an integrated, compatible and environmentally acceptable manner based on sound ecological and economic criteria.

This article describes the structure of a pilot IPM program that has been implemented in Maryland and represents an alternative approach to managing the gypsy moth. The State of Maryland was selected as the site for the project over other states because:

1. Maryland had gradients of gypsy moth infestations, with defoliating populations restricted to the northeastern tier of countries, while the remainder of the State was sparsely infested.
2. Gypsy moth populations had been monitored statewide since 1978 with a male moth survey that incorporated a standardized grid of traps and, at times, burlap banding to estimate larval densities.
3. There is diversity of forest types, from the highly susceptible (to defoliation) areas in Cecil County to the highly resistant stands in Howard County.
4. The forest is not contiguous as in much of New England and Pennsylvania, but rather interspersed with farmland, rural, and urban areas so that tactics could be prescribed for somewhat isolated management parcels.
5. An organized gypsy moth program already was in place that included activities designed to suppress populations and retard the natural spread of the insect.
6. Data about Maryland's natural resources and other important parameters believed to influence gypsy moth population dynamics are readily accessible in graphic form through an automated geographic data base—the Maryland Automated Geographic Information System (MAGI) (14).

Program Structure

The Maryland Gypsy Moth Integrated Pest Management Pilot Project is a 5-year (1983-1987) cooperative effort of the Maryland Department of Agriculture and the United States Department of Agriculture. Project funding and coordination are provided by the USDA Forest Service, State and Private Forestry, Forest Pest Management, and direction is provided by a technical committee consisting of representatives from: Maryland Department of Agriculture; the Maryland Forest, Park, and Wildlife Service; the University of Maryland Cooperative Extension Service; and the Forest Service, Agricultural Research Service, and Animal and Plant Health Inspection Service of the U.S. Department of Agriculture.

The technical committee meets regularly or as needed to develop annual plans, review accomplishments, and provide general direction to the project. The goal of the pilot project is to evaluate the feasibility of managing the gypsy moth at low densities over a wide range of ecological, geographical, and land-use areas. There are five major components:

- *Survey and monitoring* for regularly recording quantitative and qualitative observations of populations of gypsy moth and natural enemies, along with other variables indicating changes in the forest environment.
- *Decisionmaking* based on review of survey results and supportive data available within the project area.
- *Intervention* activities used to manage gypsy moth populations at various densities.
- *Evaluation* system to determine the effectiveness of project actions over the short and long term.
- *Supportive methods,* including cooperative research and methods development, data base management, and technology transfer.

Major emphasis has been placed on evaluating the new technology that emerged from the accelerated research and development of the 1970's and subsequent years. The project provides an opportunity to test monitoring and intervention activities, modify them as necessary, and implement them in an operational system. Although the project is viewed as a prototype system (pilot program), a number of related research and development studies are being conducted adjacent to the boundaries of the project areas.

Project Area

In 1983, the technical committee of the Maryland IPM Project determined that information on the distribution and abundance of gypsy moth in Maryland was not sufficient to delineate a specific project area. Therefore, a survey and monitoring system was established on a 1-km grid within a four-county area comprising of Prince Georges, Anne Arundel, Calvert, and Charles Counties. At each accessible grid point a standard milk carton pheromone trap (22) was placed on one tree, and two 15 x 23 cm plastic flaps (5) were placed on the north and south aspects of 10 preferred host trees (20-36 cm dbh) surrounding the pheromone trap.

The committee reviewed the gypsy moth population data collected in 1983 and selected a project treatment and project comparison area (Fig. 1). The size of the areas selected was related to how large an area could be managed with available resources. The project treatment area consists of approximately 102,243 hectares, about 51,041 hectares of which are forested. The project comparison area consists of approximately 99,410 hectares, 41,140 hectares of which are forested. These areas were selected for the following reasons:

1. A gradient of pest population densities was present, some populations having the potential for increasing to outbreak densities within the planned duration of the project.
2. Forest types susceptible to gypsy moth were present and continuous.
3. Urban and suburban forested areas were available that represented various land-use categories with different management objectives.
4. The area of manageable size and readily accessible for conducting population surveys.

Project Components

Survey and monitoring. The Maryland IPM Project is structured around a comprehensive yet intensive system of surveillance and biological monitoring that is designed to provide an annual data base on the distribution and abundance of

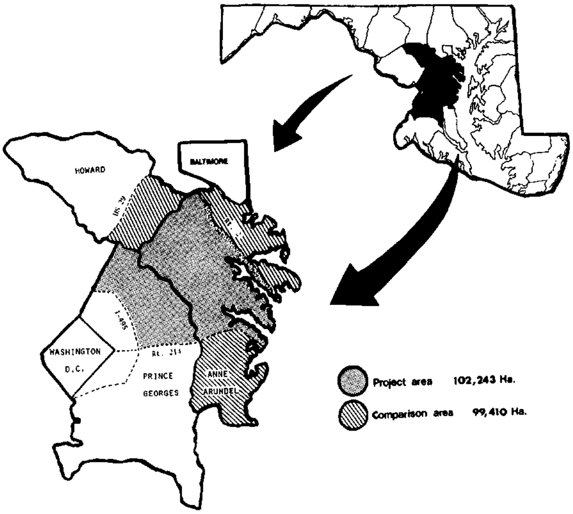


Figure 1. County areas used in the gypsy moth integrated pest management pilot project.

gypsy moth populations and their natural enemies. The project and comparison areas are overlaid with a permanent 1-km fixed-point sampling grid established on Universal Transverse Mercator (UTM) coordinates and designed to provide a broad qualitative profile of gypsy moth populations. At each accessible grid point, a male pheromone trap is attached to one tree, and two 15x23-cm plastic flaps are placed on the north and south aspects of 10 preferred host trees (20-36 cm dbh) surrounding the pheromone trap. The plastic flaps are used as resting sites by late-stage larvae and serve as a relatively inexpensive alternative to using burlap bands for collecting larvae (6); when used in conjunction with the standard milk carton pheromone trap, these devices serve as a practical method for detecting gypsy moth life stages. The susceptibility of the forest stand to defoliation at each grid sampling point also is determined using the methodology developed by Valentine and Houston (25).

Surveys are conducted in the fall and winter at each grid sampling point and in adjacent 1-km cells to estimate egg-mass densities and delineate boundaries of potential problem areas. One 0.01-ha plot is surveyed at each grid sampling point while an alternative system is used for the adjacent cells based on egg-mass densities at the surrounding grid sampling points and on land use: a maximum of eight 0.01-ha plots/1-km cell are surveyed in forested stands, while a maximum of six 0.04-ha plots/1-km cell are surveyed in forested residential communities. Since the number of egg masses/ha is not necessarily a good predictor of the potential number of hatching larvae/ha, field crews collect representative numbers of egg masses from the infested areas in late winter and determine the number of eggs/mass, percent viability, and percent parasitism. These data provide valuable information on the quality of the population and are used when the committee assesses the need for intervention activities.

Decisionmaking. The technical committee's decisions regarding the need for and the selection of intervention activities are based on a review of survey and other supportive data.

- Egg-mass density and quality
- Larval and pupal counts
- Male moth captures
- Population trends (egg mass, male moth)
- Parasite and disease incidence
- Defoliation estimates
- Size of infestation
- Proximity to other infested areas
- Stand susceptibility to defoliation
- Environmental sensitivity
- Vegetative cover type
- Land-use category

The survey data are displayed graphically for each grid sampling point and overlaid onto the MAGI data (e.g., vegetation cover type, soil type, and land use). In this manner, the committee can identify areas of primary concern based on host population levels and site conditions (susceptible stands, recreational areas).

The following management decisions are considered for each grid sampling point and adjacent 1-km cells:

1. *No action.* When gypsy moth population density is low ($<$ 25 egg masses/ha); population trend (n/n-1) is decreasing ($<$ 1); and other data (e.g., stand susceptibility to defoliation, proximity to other infested areas) indicate low potential for impact (nuisance created by caterpillars and/or associated defoliation). Only surveillance activities may be prescribed.
2. *Preventive action.* When population densities are low ($<$ 25 egg masses/ha) or moderate (25-250 egg masses/ha) and the trend is stable or increasing ($\geq$ 1); and other information indicates risk of impact or spread. This type of action is designed to prevent the expansion of pest populations, or to augment natural enemies.
3. *Suppressive action.* When population densities are high ($>$ 250 egg masses/ha), the trend is stable or increasing, and other information indicates a major risk of economic damage or nuisance.

Intervention. Any activity intended to modify pest density is considered intervention. Activities currently used in most State and Federal cooperative gypsy moth programs (e.g., aerial application of chemical or biological insecticides) were developed for and are directed against high-density (more than 1,250 egg masses/ha) populations. Their efficacy has not been demonstrated adequately at low population densities. When the need for intervention on low-level populations is indicated, the committee must rely on these efficacy data or, whenever possible, on the results of cooperative evaluations being conducted as part of the project to select the appropriate activities.

Three intervention activities are currently considered for use in this project:

1. *Chemical insecticides.* The aerial application of chemical insecticides is restricted to areas where gypsy moth densities are greater than 2,500 egg masses/ha; population trends show at least a 10-fold increase; and there is a risk of an impact. At present, only one chemical insecticide, Diflubenzuron (Dimilin^{R}), is considered for use within the project. Dimilin is the insecticide of choice based on its mode of action (it interferes with chitin biosynthesis), efficacy (average $>$ 90% population reduction), low application dose (1 to 4 oz Al/acre), persistence ($>$30 days on foliage), and lack of effect on parasites and predators of the gypsy moth. Its use is restricted to nonaquatic habitats. The ground application of chemical insecticides such as Dimilin is restricted to urban residential areas containing high-value ornamental trees or where defoliation and/or larval nuisance impacts are anticipated.
2. *Microbial insecticides.* The aerial application of microbial insecticides has been the major intervention activity implemented in the project area. The entomopathogenic bacteria, *Bacillus thuringiensis (Bt),* and the gypsy moth nucleopolyhedrosis virus (NPV) are applied at a range of host densities and population trends. *Bt* is a widely used, naturally occurring pathogen which has a minimal effect on parasites and predators (7) but may affect some species of Lepidoptera. It is applied using various formulations, doses, rates, and numbers of applications (4). The gypsy moth NPV is specific to gypsy moth and usually is the major factor in causing the natural collapse of dense populations (2). Gypchek^{R}, the formulated gypsy moth NPV (12), does not adversely affect natural enemies or other species of Lepidoptera. Both microbials remain viable on foliage for 3 to 5 days, depending upon meteorological conditions following application.
3. *Biological controls.* The use of applied biological controls, including natural enemies (parasites, predators, and pathogens) and behavior modifying materials for intervention, has been limited due to our lack of understanding about how and when to use them. Parasites are the only component of the natural enemy complex that we have attempted to manipulate. Emphasis is placed on maximizing their diversity, abundance and effectiveness through augmentation. This is accomplished by collecting and redistributing the parasites that are established in the generally infested area but not abundant in the project area. Also, since techniques are available to mass rear *Cotesia melanoscela* (20, 11), augmentative releases of the Korean strain of this species have been attempted in both small ($<$ 3 ha) isolated woodlots and in larger contiguous forested areas following the application of *Bt* (24, 29). The synthetic formulation of disparlure, the chemical attractant of the gypsy moth female, has been used in attempts to disrupt communication and mating behavior between the sexes. Schwalbe et al (23) have demonstrated that disparlure is most effective against low-level populations ($<$ 25 egg masses/ha). The ground placement of disparlure as Luretape-GM has been used in low-density populations or following the application of *Bt.*

Evaluation system. Posttreatment evaluation of all intervention activities is conducted using standardized survey techniques (larval traps and egg-mass and defoliation surveys) to assess changes in population density and the forest environment over time. Additionally, a long-term evaluation of the 5-year project is being conducted to assess the broad implications (cost/benefit) of using the IPM approach (treatment area) compared to the suppression approach (comparison area). There are many factors to be considered beyond cost alone (e.g., possible reduction in the use of chemical insecticides and associated environmental effects) that are difficult to document.

The major components of this project are continually being evaluated and updated. IPM protocols are expected to be modified as the project progresses.

Supportive Methods

Extension. The public was introduced to the IPM Project through meetings hosted by the University of Maryland Cooperative Extension Service and the Maryland Department of Agriculture. Also, these agencies initiated a public information program that included publishing a monthly newsletter, producing a leaflet entitled "Maryland Gypsy Moth IPM Pilot Project," and scheduling meetings and workshops to keep county agents informed of the project's progress. Individual property owners within the treatment and comparison areas were contacted for approvals before the establishment of grid sampling points and the implementation of any intervention activity. A pictorial display and a slide presentation of the pilot project were developed for use at public and professional meetings. A symposium on the IPM project was organized with representatives from various State, Federal, political, and environmental groups in attendance. We have attempted to maintain social acceptance and scientific soundness of the Project through our ongoing extension efforts (See 3).

Data-base management. Data collection and entry have been identified as one of the most resource-consuming components in gypsy moth management (18). Life-stage data are collected yearly at 1,760 bark-flap sites during the summer months and at approximately 1,850 sites during the fall and winter months. Until recently, each scout recorded data on forms that were designed to be read easily by keypunch operators. To develop a more efficient and less costly means of data acquisition and entry, a decision was made to follow the prototype system developed by the Virginia Polytechnic Institute and State University (VPI & SU) using optical scanning technology (19). This system is both rapid and cost-efficient, and reportedly reduces the number of recording errors (1, 18).

Once data are assembled, commercially available software (e.g., Oracle[R]) is used to facilitate decisionmaking by providing an interactive capability between the user and the data base.

Because of the extent of the grid-based sampling employed and the size of the geographic area covered, the IPM Project presents an ideal opportunity to view population data using spatial interpolation models. Through a cooperative agreement with VPI & SU, computer cartographic techniques are used that provide, in part, displays of male-moth and egg-mass density survey data between 1-km grid points. The simplest type of representation, a posting, shows sample site UTM coordinates and survey results. Also, using several types of interpolating algorithms, density and trend data are displayed as contour maps (Fig. 2A) and 3-D graphs (Fig. 2B). Population densities and trends are shown as contours on mylar overlays. The presentation of data in this manner provides a valuable decisionmaking tool. Isolated versus generally infested areas, as well as populations undergoing rapid increases, can be discerned quickly.

Research and development. Several commonly used sampling methods for egg masses have been evaluated in terms of precision and cost, and sequential sampling plans have been developed for use in the project areas (10). An enzyme-linked immunosorbent assay (ELISA) technique that was developed to detect the incidence of the natural virus in the population (13), also is being evaluated in the project area.

Intervention activities are being evaluated in a traditional research mode using replicated treatment and control plots. Six intervention activities have been evaluated thus far:

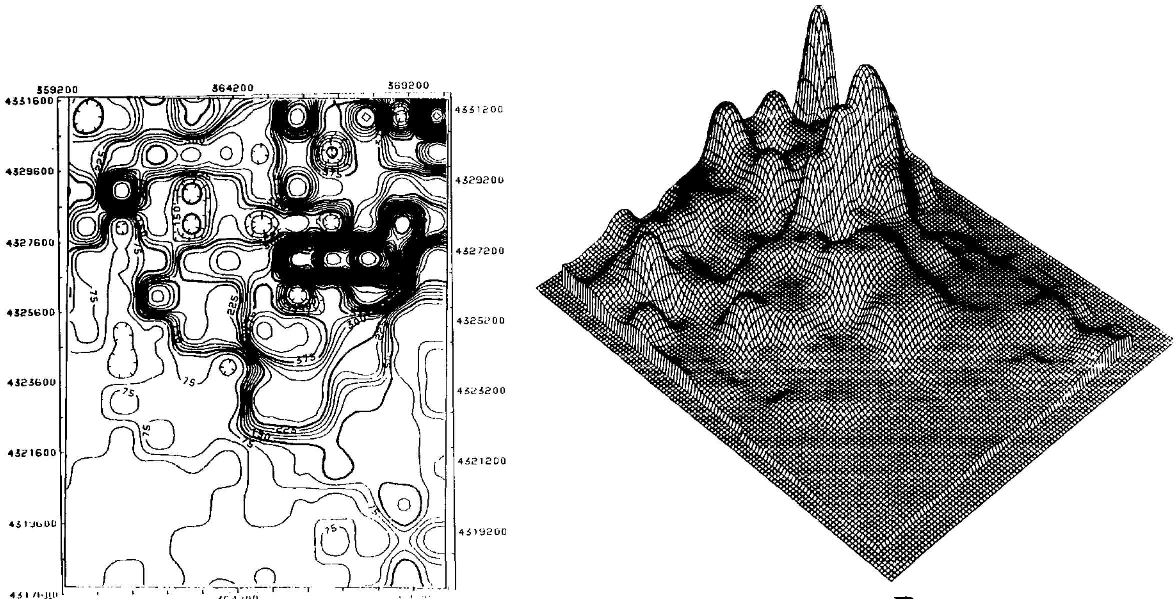
1. Ground application of Gypchek. Gypchek has been applied to egg masses and early-stage larvae, using mist blower and hydraulic equipment, to suppress low-density populations, to evaluate improved formulations, and to initiate virus epizootics.
2. Aerial application of the NRD-12 strain of *Bt.* In the laboratory, this strain has demonstrated increased efficacy and causes more rapid termination of feeding of small-stage larvae than the commercially available HD-1 strain of *Bt.* The NRD-12 strain, for-

mulated as SAN-415, is being evaluated for reduction of low to moderate (250 egg masses/ha) populations.

3. Genetic control. The aerial and ground release of F_1 sterile eggs derived from substerilized males and untreated laboratory females is being evaluated as a means to prevent the expansion of populations in a generally infested area. The F_1 adults that develop from these eggs are sterile. Feral females that mate with F_1 steril males produce egg masses which do not hatch (15).
4. Parasite release. The classical biological control approach using foreign exploration to identify species associated with sparse populations, and which may be more adaptable to the mid-Atlantic region, is continuing. One such species, *Glyptapanteles flavicoxis* was laboratory reared and released without detectable establishment.
5. Entomogenous nematodes. The ground application of two species of nematodes, *Steinernema feltiae* and *S. bibionis,* was evaluated to suppress large-stage larvae as they use resting niches (21).
6. Systemic insecticides. Mauget Systemic Units[R] and Acecaps[R] containing the systemic insecticide acephate are being evaluated to protect high-value individual trees. Both methods provide a portable, closed system that minimizes the loss of the insecticide into the environment and could be used in urban situations or in environmentally sensitive areas (parks, campgrounds) where applications of insecticides are discouraged (or unacceptable).

Summary

Our ability to manage the gypsy moth at any density will depend on our understanding of how and why populations explode at irregular intervals in a somewhat unpredictable fashion, and whether these eruptions originate from focal areas or epicenters. "Primary foci" is a term used to denote sites where the gypsy moth preferentially survives and thrives and from which outbreaks may develop and expand (26). Historical data indicate that sites fitting this description occur in New England and probably occur elsewhere within the currently infested region (8). Ideally, these sites could be identified and then managed using protocols similar to those that we have



A B

Figure 2. Contour map (A) and 3-D graph (B) of gypsy moth male counts, in increments of 25 moths, for Round Bay Quadrangle, Maryland, 1985.

developed for use within the project area.

Although the overall success of the IPM Project is yet to be determined, the technology being used for monitoring populations and arriving at management decisions will have direct application to current and future programs directed at managing the gypsy moth. Also, intervention activities evaluated in this program will provide new insights in managing gypsy moth populations at low densities. In this way, the objective of cost-effective, socially acceptable, and environmentally sound pest management will be a greater reality.

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Northeastern Area
State and Private Forestry
Forest Service, USDA
Morgantown, West Virginia 26505