AN OVERVIEW OF GYPSES
THE GYPSY MOTH DECISION SUPPORT SYSTEM

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Summary:
This paper summarizes GypsES, the vision driving its use for gypsy moth management, and the components that make up this emerging decision support system. This paper provides overview details on its many options, models (gypsy moth phenology, forest hazard-rating, defoliation prediction, forest stand damage, and FSCBG), and knowledge bases (hazard rating, survey and monitoring, and treatment).
Keywords:
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ABSTRACT

For the last five years a focused effort has been undertaken by the USDA Forest Service in the development and refinement of a decision support system for gypsy moth management. This system, called GypsES, contains mapping capabilities, database management, a forest stand damage prediction model, and the USDA Forest Service aerial spray prediction model FSCBG for the prediction of deposit and drift effects from gypsy moth spray projects. GypsES has been used in operational sites in the Northeast during the last twelve months, and it now seems reasonable to summarize the model itself, the vision driving its use, and the components that make up this emerging decision support system. This paper provides these overview details.

OVERVIEW

GypsES is a decision support system for gypsy moth (*Lymantria dispar* L.) management being jointly developed by the USDA Forest Service, Northeastern Forest Experiment Station and State and Private Forestry represented by the Northeastern Area, Region 8, and Washington Office Forest Health Technology Enterprise Team--Davis. GypsES provides decision support to gypsy moth managers by: (1) identifying areas of concern; (2) recommending areas to monitor; (3) recommending areas to treat using direct suppression for established populations, or eradication of localized spot infestations; (4) providing treatment support options for modeling losses with and without treatment; (5) uploading and downloading spray block and spray line information through global positioning system files; and (6) spray deposition and drift modeling. The system is based on GRASS, a public domain set of geographic information system routines. It has been extended to handle all geographic data, a spatially referenced database, and a full-featured map creation and edit facility using topographic backgrounds (1:24000 USGS quadrangles). The system was designed and created with a user-friendly interface written in C under UnixTM X-WindowsTM MotifTM. Rule-based logic and independent models are integrated to support the decision-making process. The system can produce reports, create maps, and export graphic files for use in other programs. The basic objectives of GypsES are to model the sequence of evaluations necessary for gypsy moth management decisions and to provide managers with a gypsy moth problem with useful tools to make their work more efficient, enable better decisions, and improve effectiveness of treatment.

INTRODUCTION

GypsES is a computer software package developed for forest pest managers who conduct gypsy moth (*Lymantria dispar* L.) management projects. Developed as a decision support system, GypsES provides pest managers with a toolbox of computer-based assistance. Options include:

- A geographic information system (GIS) framework enabling the creation of map sets, map analysis, and on-screen digitizing with topographic map backdrops;
- Geographic positioning system (GPS) files which can be imported and exported;
- The use of models to predict defoliation, hazard, risk, tree mortality, phenology, biological dose response, and spray deposit and drift;
- A pheromone trap survey assistance package for eradication projects; and
- An egg mass sample system design and data management module.

GypsES has several components or modules designed to assist in particular phases of gypsy moth management:

- A **FOREST** component uses forest data to calculate forest susceptibility. Susceptibility is overlaid with gypsy moth population data to create hazard. Hazard is overlaid with management values to create risk.
- A **TREATMENT** component can be configured for suppression in established population areas of eradication of localized spot infestations.
- An **ERADICATION** component assists in establishing pheromone trap grids at varying levels of intensity.
- A **SPRAY ADVISOR** component assists in spray area delineation, predicting potential forest damage within proposed spray areas, predicting spray deposit and drift, and incorporating actual flight lines obtained from geo-positional navigational systems.

GIS functions within GypsES extend a public domain GIS software package called GRASS (U.S. Army Corps of Engineers 1991; Shapiro et al. 1992), which has been tailored to fit the needs of pest management operations. A user-friendly interface has been developed for GIS functions, including on-screen digitizing, map editing, overlays, and import/export procedures. Mapping within GypsES may be done with 1:24000 scale geo-referenced USGS 7-1/2 ft quad topographic map backdrops. This approach allows users to actually "see" where they are when creating or displaying treatment areas.

The integration of knowledge into a toolbox-type framework is one of the key features of GypsES. For example, within GypsES, a user can use: (1) susceptibility research to determine the likelihood of gypsy moth defoliation; (2) population dynamics research to determine levels of defoliation and insect development rates; (3) impact research to predict tree mortality; and (4) insecticide deposition research to predict deposit within and outside proposed treatment areas.

MODELS INTEGRATED INTO GYPSES

A number of models have been integrated into the GypsES toolbox. These include: (1) GMPHEN, a gypsy moth phenology model; (2) a forest hazard-rating model; (3) defoliation prediction models; (4) a forest stand damage model; and (5) FSCBG (Forest Service Cramer-Barry-Grim) spray deposit and drift model. Additionally, the Gypsy Moth Life System Model is being converted to UNIX to be added into Version 2.0 of GypsES. A short description of each of these models follows.

GMPHEN--A Gypsy Moth Phenology Model

The gypsy moth phenology model GMPHEN was developed from several published papers on various aspects of gypsy moth development relative to temperature, via degree-day accumulations (Sheehan 1992). It was originally developed as part of the Gypsy Moth Life System Model and has been extracted as a stand-alone version for GypsES. The model uses daily minimum and maximum temperatures to calculate heat accumulation measured in degree-days. The user can access built-in 30-year averages for gross estimates of timing of egg hatch and larval development, or input the actual temperature data up to the current date and then use the model to extrapolate into the future. After the phenology model is run for data from a specific weather station, the results are displayed across the landscape by using the elevation data from digital elevation models (DEMs) to

adjust for differences using an adiabatic gradient (Schaub, Logan and Ravlin 1990). The phenology layers calculated within GypsES can then be used for planning many operations, including: (1) organizing spray blocks into units of similar phenology; (2) timing spray applications for maximum efficacy; (3) planning pheromone trap placement and pickup; and (4) timing pheromone application for mating disruption.

Hazard-Rating Model

The hazard-rating model is designed to incorporate all elements of the forest conditions and management considerations necessary as a precursor to any gypsy moth-related activity. These elements primarily include information on the types of trees in the areas of concern, so that the system can determine their susceptibility to gypsy moth defoliation. Vulnerability to damage is calculated based on the stocking, vigor, and prior disturbance history as described by the user (following Elmes, Liebhold and Twery 1993; Twery et al. 1993; and Bennett 1995). The effects of defoliation and damage on management objectives are then incorporated to produce a hazard rating. This rating can be used to help determine sampling needs. In return, information from the defoliation prediction model is used within the hazard-rating model to predict current risk of a gypsy moth infestation significant enough to suggest management intervention.

Defoliation Prediction Models

Two defoliation prediction models have been included in GypsES, with the user able to select the model desired. Gansner, Herrick and Ticehurst (1985) developed a model based on counts of egg masses per acre. A similar model that uses forest site information in addition to egg mass counts is also available (Montgomery 1990). Both models are used to estimate defoliation for either an individual egg mass sample plot or from an egg mass surface generated by GypsES using the egg mass sample plots. The estimated defoliation is used by the hazard-rating model to estimate risk. When managers have management objectives that call for reducing defoliation, they can use estimated defoliation predictions to determine areas that need suppression treatments.

Stand Damage Model

The stand damage model is a stand-alone model that was developed as part of the Gypsy Moth Life Systems Model (Colbert and Sheehan 1995). It simulates forest growth, mortality, and regeneration, and includes the ability to apply defoliation percentages to trees present in the simulated stand. Gypsy moth outbreak effects on growth and mortality can be compared to simulations of the same stand without defoliation. The model requires that data on tree species and number of stems in each diameter class be input. The model can be run in two modes: interactively or via pre-defined scenarios. When run interactively, the user actually leaves GypsES, runs the stand damage model independently, and then returns automatically to GypsES after exiting stand damage (currently, the outputs from interactive runs cannot be used within GypsES without first re-entering the results into a database file). Interactive runs can also compare the results of silvicultural treatments the user can apply to the stands. Predicted defoliation from the hazard rating system can be used as input to examine the impacts of gypsy moth on stands.

The pre-defined scenarios take the stand data present in a database file in GypsES, run the stand damage model, and return tables and graphical output back to GypsES. These scenarios are for no defoliation (baseline), light defoliation, and heavy defoliation, all run

for two five-year identical defoliation sequences to provide a decade-length projection. Output from these scenarios include stem counts, board foot volume, saw log volume, and total merchantable volume for all three scenarios, as well as values for the no-defoliation minus the light-defoliation and the no-defoliation minus the heavy-defoliation scenarios. These differences provide direct estimates of basal area or volume losses and permit users to estimate discounted total dollar losses when species-specific board-foot values ($/MBF) are supplied.

FSCBG Spray Deposit and Drift Model

The Forest Service Cramer-Barry-Grim (FSCBG) spray deposit model developed by the USDA Forest Service under the direction of John W. Barry, Forest Health Technology Enterprise Team, Davis, CA, is used within GypsES as the method for calculating potential deposit within a treatment area, and potential drift to exclusion zones nearby (Teske et al. 1993). A user-friendly interface has been created within GypsES, providing simple user access to FSCBG. GypsES passes FSCBG a user-selected spray block with a proposed or actual flight line (or lines), and expected or actual weather conditions at the time of spraying. FSCBG then runs a simulation based on these conditions and the aircraft type, nozzles, and other factors, to predict the amount of spray material that lands within the spray block and the amount that drifts outside the spray block. Contours are returned to GypsES for the various droplet densities that occur. These contours are then displayed over the spray block boundaries to estimate the extent of the spray deposition and drift on the selected spray block and the area surrounding it. Enhancements currently under development include calculation of success zones using known gypsy moth biological dose-response relationships, and fitting actual spray flight lines from GPS with predicted flight lines.

KNOWLEDGE BASES INCORPORATED INTO GYPSES

Knowledge bases developed by teams of experts in the areas of hazard rating, survey and monitoring, and treatment have been incorporated into the GypsES program structure. Short descriptions of these knowledge bases follow.

Hazard Rating

Hazard rating is important because it allows efficient allocation of financial and other resources to meet challenges from particular dangers to the management goals. Rating of forests with regard to hazard from forest insects has been done extensively for many insects in many forest types (see for example Hedden, Abarras and Coster 1981) and is generally regarded as a useful management tool. To be helpful, however, a great deal of information is needed about the individual forest stand and the pest insect population. In general terms, the necessary stand information includes species composition, stocking level, tree vigor, and stress levels. The population levels of the pest insect are also important in estimating timing of potential damage, but are not necessary to estimate long-term hazard.

Gypsy moth hazard rating includes the determination of where a problem is most likely to occur--given certain conditions--and how severe any damage is likely to be. Although gypsy moth may be a problem across very large areas at certain times, the specific areas of forest where the gypsy moth is found may vary considerably from year to year. Also, individual stands within the same major forest type and in the same geographic area may

have very different potential hazard levels. Under some management objectives, such as high-use recreation areas, damage may be defined differently and include the mere presence of high insect populations rather than any apparent damage to the trees.

Definitions of four terms are necessary to understand the current hazard rating system for gypsy moth. *Susceptibility* is the term used for the likelihood of defoliation of a given tree or stand when and if the gypsy moth were present. *Vulnerability* is the probability that damage (such as mortality, growth loss, or reduced scenic beauty) will result if defoliation occurs. *Hazard* combines the probability and severity of damage with its effects on management goals for a specific area. *Risk* incorporates insect population trends to predict the probability that such an event damaging to the management goals will occur in the short term.

Gypsy moth hazard rating is based on information of varying quality. It is well documented that gypsy moth larvae feed on particular host species (Mosher 1915; Montgomery 1991). Susceptibility is a straightforward function of species composition modified by site and stand characteristics (Gansner et al. 1987). Vulnerability is a more complicated relationship. The primary complicating factor is the amount of additional stress to which an individual tree has been subjected. Estimates of individual tree vulnerability to mortality have been compiled for many species in Pennsylvania (Gansner et al. 1987; Hicks and Fosbroke, 1987) and are still being refined. Stand-level vulnerability to mortality, which is a more useful scale to the forest manager, can be: (1) accumulated from individual tree data from sample plots; (2) estimated by applying individual tree probabilities to stand tables; or (3) estimated using a stand-level equation based on plot surveys. The stand-level survey is easiest to calculate, but is somewhat more variable because of the information it necessarily omits.

Forests in the Northeast have been classified as to their general susceptibility and vulnerability to gypsy moth. The various types of mixed oak forests are most susceptible because the trees are preferred hosts for gypsy moth. Classification of vulnerability to mortality is more difficult, because it must incorporate stand history, current stand conditions, presence of secondary mortality agents, insect population trends, and predictions of future conditions of the trees. Several attempts have been made to predict mortality of stands, but the equations do not fit other geographic areas or different stand conditions because of the specific characteristics used. After the biological factors influencing the impact of gypsy moth have been estimated, a useful hazard rating system must account for the objectives of the land managers and how a potential disturbance from defoliation will influence those objectives. As with most sociological factors, principles can be framed, but little real information is available. Highly reliable information on the relationship between defoliation levels and insect population levels is also still lacking.

Existing gypsy moth hazard ratings are based primarily on species and the condition of individual trees. When such information is available, it is the best source from which to predict hazard to a forest. However, many areas of forest or partially forested land will not have such detailed information, but a decision still will be needed on how to deal with the potential threat of gypsy moth.

Survey and Monitoring

Techniques and methodology for sampling gypsy moth and its associated natural enemies have been developed and in some instances tested and validated. The treatment threshold concept is central not only to sequential sampling but also to integrated pest management in general. Sampling for research purposes varies with the nature of the study and is usually more intensive than techniques actually used by forest managers. Managers usually require samples over large areas of variable habitat, and are constrained by time and economics. For gypsy moth, egg mass, late instar larvae, male adult, frass, and head capsule sampling can be used, but none has proven totally effective for making management decisions. Pheromone traps are a sensitive means of detecting male moths but are limited to detecting and delimiting new infestations. Egg-mass counts are routinely used by managers to decide on the need for suppression tactics. Currently used methods are fixed-area plots (Wilson and Fontaine 1978) and sequential sampling (Kolodny-Hirsch 1986; Fleischer, Ravlin and Reardon 1991) that provide only number of egg masses per acre and have not been a dependable predictor of defoliation (Liebhold et al. 1994). Factors such as forest site, foliar biomass, insect population trends, egg mass size, and phenology are important components of predicting defoliation for purposes of initiating management action.

The sampling support component of GypsES provides the means to design the layout of sampling grids for pheromone, egg mass, or larval sampling. The user can tract the placement of pheromone traps or sampling plots, record sampling data, and use the results to generate density estimate layers within GIS. Data derived from initial surveys can be used to extend or articulate further sampling programs. The results of sampling programs provide data used along with other information to set up and prioritize management strategies, including eradication, suppression, or silvicultural alternatives. Currently, the implementation of truly integrated gypsy moth management programs is constrained by an inability to forecast outbreaks with adequate accuracy. There is substantial evidence that many areas designated for treatment never reach damaging densities. Conversely, populations in stands rejected for treatment often increase to defoliating levels.

Treatment -- Suppression and Eradication

The survey portion of GypsES includes two modes of operation: suppression and eradication. *Suppression* mode is used when gypsy moth populations are high enough that defoliation or nuisance is expected to have significant effects on management objectives for the area. *Eradication* mode is used in spot infestations outside the generally infested area and its transition zones. The objective in these spot infestations is to eradicate the gypsy moth. Both modes include expert knowledge on insecticide treatments, mass trapping, delimitation trapping, and pheromone-based mating disruption (Schaub et al. 1990). FSCBG also contains expert knowledge related to insecticide applications, and spray deposition and drift. Treatment effectiveness can be evaluated by comparing pre- and post-treatment values for egg masses, defoliation, pheromone trap catches, and other measures.

Differential GPS files are used to assist pilots in spraying designated areas. DGPS files, created while spraying, show actual flight paths over the treatment area. DGPS files are imported to GypsES and overlaid onto digitized treatment blocks, and can also be entered

into the Spray Advisor to locate the actual flight lines for FSCBG prediction of drift and deposition.

SUMMARY

While the final touches are being placed on the Version 1.0 release, we are actively pursuing additional enhancement to Version 2.0 of GypsES. These enhancements include: (1) incorporation of the Gypsy Moth Life System Model; (2) further development of the FSCBG interface and its capabilities; (3) addition of economic analyses to the stand damage model; (4) incorporation of silvicultural guidelines rulebases; (5) development of a revised GMPHEN model; and (6) evaluation of other data input to phenology.

As the reader can see, the GypsES development team has set its goals high -- to provide a field application-oriented, user-friendly toolbox to support decisions and to continually improve on that toolbox as new information and techniques become available. Further information about GypsES, computer system requirements, and availability may be obtained by contacting any of the authors of this paper. A companion paper and presentation (Ghent et al. 1996) reviews the actual operation of GypsES.

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