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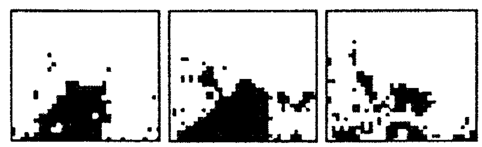
Proceedings

Spatial Analysis and Forest Pest Management



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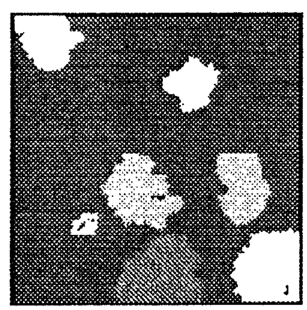

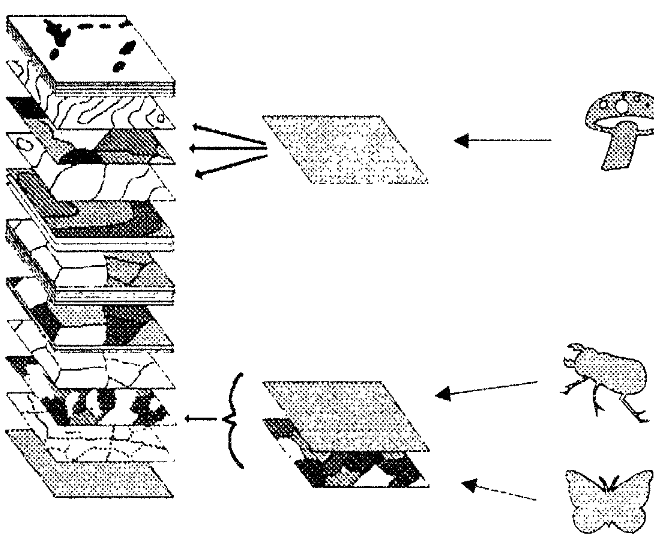

Northeastern Forest Experiment Station
5 Radnor Corporate Center
100 Matsonford Road, Suite 200
Radnor, Pennsylvania 19087-8775

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PROCEEDINGS

SPATIAL ANALYSIS AND FOREST PEST MANAGEMENT

April 27-30, 1992
Mountain Lakes, Virginia

Edited by

ANDREW M. LIEBHOLD AND HOPE R. BARRETT
USDA Forest Service
Northeastern Forest Experiment Station
180 Canfield St.
Morgantown, WV 26505

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FOREWORD

Over the last 20 years technologies have been developed that provide new tools for analyzing and modeling spatial processes. These tools have allowed scientists to overcome the conceptual problems and data management complexities that in the past prohibited exploration of spatial problems. These new technologies include geographic information systems (GIS), which are software for managing and manipulating spatial data, more powerful computer systems that are able to handle the computationally intensive needs of spatial data analysis, and new numerical procedures that allow analysis and modeling of spatial data. These technologies have been embraced in a variety of disciplines ranging from mining engineering to biomedical research but one field where these tools are being rapidly applied is forestry. Typically, forest management entails making decisions on land use over large, heterogeneous landscapes. This decision making typically involves the integration of multiple data themes (such as vegetation, topography, hydrology) over large geographical areas and is therefore a prime candidate for application of GIS.

The U.S. Forest Service is currently implementing a national GIS plan that will integrate GIS and other spatial analysis technologies into many aspects of forest management. This technology is similarly being applied by state and private forest management organizations around the world. In 1990 the Computer Sciences and Telecommunication staff of the US Forest Service headquarters realized that during the implemention of this plan, there was a need to bring together university and Forest Service scientists from a variety of disciplines to discuss accomplishments and future needs in spatial analysis.

In early 1991 a team of scientists working in the field of forest insect and disease management and research began to organize a workshop that would address accomplishments and future needs in the spatial analysis of forest pest problems. This group included Andrew Liebhold, Northeastern Forest Experiment Station, Donald Jameson, Computer Sciences and Telecommunications, Ross Pywell, Forest Pest Management, Patrice Janiga, Forest Pest Management, J. Robert Bridges, Forest Insect and Disease Research, Brian Geils, Rocky Mountain Forest and Range Experiment Station, Jesse Logan, Virginia Polytechnic and State University, and Lukas Schaub, Virginia Polytechnic and State University. The objectives of the workshop that they organized were:

1. Exchange information on current and near-future needs and opportunities for application of spatial analysis to describe and predict the dynamics of insects and pathogens as well as their affects on forest ecosystems.

2. Identify critical gaps in our understanding of ecosystem properties or processes that require spatial analysis to describe, maintain, and improve forest health.

3. Develop a strategic plan whereby emerging concepts and technologies using spatial relationships could be better incorporated into forest planning, monitoring, and research.

The workshop was held April 27-30, 1992 at Mountain Lakes, Virginia. The first two days of the meeting were used by the participants to make presentations on current accomplishments in spatial analysis. The last day was spent in break-out groups, discussing gaps in our current knowledge and setting priorities for future research and development.

These proceedings contain papers authored by workshop participants and a final report at the end of this volume summarizes the conclusions made by the participants in the break-out groups. The purpose of publishing these proceedings was to allow individuals who were not at the workshop to learn about what research and development is underway in the area of spatial analysis of forest pests and to communicate the participants' conclusions about future research and development needs.

SPATIAL ANALYSIS AND FOREST PEST MANAGEMENT
April 27-30, 1992
Mountain Lakes, Virginia

CONTENTS

HISTORIC, CURRENT AND POSSIBLE FUTURE ANALYTICAL CAPABILITIES OF GEOGRAPHIC INFORMATION SYSTEMS (GIS)

DONALD A. JAMESON
USDA Forest Service, Computer Science and Telecommunications Staff, 201 14th St., SW, Washington, DC 20250

Abstract. In Forest Service use of GIS, we continue to emphasize that we are concerned about spatial analyses, rather than just mapping. Pursuit of object-oriented software technology should lead to better understanding of an "objects-in- space" approach to resource analysis and enhanced applications to questions like watershed (hydrologic), wildlife, pest and recreation management that are treated with difficulty with current procedures. We can expect that GIS software will move toward object-orientation, and it would be well to have our analyses concepts moving in a direction that would allow us to capitalize on the software. Additional developments in spatial statistics, Kriging, dynamics and fractal analysis coupled directly to GIS can also be anticipated.

HISTORIC AND CURRENT ANALYTICAL CAPABILITIES IN GIS

Recent developments in computer processing speed and color graphic displays have brought GIS to the forefront, but the cartographic and analytical concepts behind GIS are much older. Historic precedents of GIS include mapping and cartography, processing of remote sensing imagery, and spatially-oriented site and corridor analysis. Although image processing has maintained a more-or-less separate identity, the other historical precedents have had a definite impact on the subject matter of current GIS.

Among geographers, cartography and mapping are commonly seen as the dominant influence of GIS, but for natural resource managers independent developments in site and corridor analysis may assume more importance. Development of techniques by McHarg (1969) in the use of transparent overlays to study location of environmentally sensitive activities has had a major impact. At that time there was sufficient computer capability to move from hand drawn transparencies to computer manipulations with a few primitives, namely arithmetic, Boolean and set operators. An example "GIS" of the era was Harvard IMGRID, which could produce only gray maps with the line printers of the time. It is interesting that some current GIS's do little more than McHarg overlays (plus a computerized planimeter), but of course modern computers can make the process much faster and color graphics make the outputs more attractive.

Tomlinson et al. (1976) described the analytical subsystem of a GIS as including the following parts:

(1) Retrieval of data from storage.
(2) Measurement of areas or calculation of distance.
(3) Comparison of multiple data sets, i. e., a procedure to overlay one data set upon another and to determine the intersection or union of the variables.
(4) Statistical analyses appropriate for spatial data.
(5) Specific analytical procedures determined by the user.

Pages 1-7 *in* A.M. Liebhold and H.R. Barrett, editors. 1993. Proceedings: Spatial Analysis of Forest Pest Management. USDA Forest Service General Technical Report NE-175.

Part (1) is represented by attribute files (either flat files or relational databases) that are used or created by the analysis and display portions of the GIS. Parts (2) and (3) have evolved to current vector GIS (see USDA Forest Service 1991, Appendix C, for capabilities). Part (4) is expressed in continuing work in spatial statistics (e.g., Haining 1990, Cressie 1991).

Vector GIS has been very useful in mapping and inventories. In addition, most analyses of linear features, such as roads, trails and streams, can be well treated with vector GIS. However, many specific analyses of areas (Part 5 above) require a raster GIS.

Raster analysis was advanced with the Tomlin-Berry operators, which were first described by Dana Tomlin and Joe Berry (Tomlin and Berry 1979, Tomlin 1983), largely promoted by Berry (1987a, 1987b), and more fully described in Tomlin (1990). The MAP analysis package, implemented by 1980, included these operators as first described, and most commercial raster GIS's do the same. Authors of more recently coded commercial raster packages like to point out that they have implemented the operators described by Tomlin (1990), which has become the defacto commercial standard.

In addition to the primitives used by GIS circa 1970, the analytical GIS of the 1980's included local area descriptors (e.g., slope, aspect, diversity, variance); smoothers (e.g., majority membership, averages, polynomial smoothing); pattern analysis (e.g., clumps, connectivity, convexity, narrowness, and hole-ness or Euler numbers). Classification procedures (e.g., maximum likelihood, discriminant function multipliers, fuzzy classifiers) were generally reserved for separate packages known as image analysis software, but are included in some GIS's. Kriging, a more advanced smoothing procedure, and fractal dimensions, a more recently developed technique for pattern descriptions, are rarely included in standard GIS's and must be added as extensions if they are to be used.

Included in the Tomlin-Berry operators were habitat relationships RADIATE (for viewsheds), DRAIN (for watersheds), and SPREAD (over a friction or impedance surface). SPREAD operators are used for variable-width buffers and other analyses that are essential in habitat and landscape analyses. They have been included in better commercial raster packages, but are absent in others. Note that in vector GIS, only fixed-width buffers based on distance relationships are possible; variable width buffers of raster GIS depend on other relationships.

The Tomlin-Berry operators can lead to hypothesis statements. For example:

• Light travels in a straight line, but is interrupted by any opaque object (RADIATE). For the purposes of landscape/habitat analysis, this is appropriate (i.e., light bending is ignored), but the hypothesis hardly needs additional testing.

• Water follows the steepest descent pattern (DRAIN operators). This is somewhat shakier that the light hypothesis (i.e., the hypothesis ignores infiltration, evaporation, and movement along aquifers), but is still useful.

Marble (1990), in assessing the potential changes in views of the world that might result from applications of GIS, wrote:

> "I would submit that social scientists concerned with human spatial behavior ... have adopted a limited and myopic view of the subject, and that this myopia has been in large part the result of our inability to visualize, let alone model, the full scope of human spatial behavior ... we have lacked the tools which would permit us to organize and comprehend the data defining the real and extremely complex spatial environment in which human behavior actually takes place."

From an anthropocentric view, this statement seems appropriate. However, if we substitute "entomologists" or "pathologists" for "social scientists", and substitute "pest" for "human", the statement is patently inadequate because it ignores any consideration of explicit statements of pest behavior. For example, the SPREAD operator in raster GIS is one of the most powerful analytical tools available for studies of spatial behavior. However, it is incomplete because the only thing known for sure about the object to be spread is its location. Behavioral attributes of the moving object that control its spread are therefore imbedded in the description of the habitat (the friction or impedance layer), and relevant behavioral hypotheses are clouded. Development of the impedance layer often becomes contorted, and will require some kind of lineage tracking for documentation. This approach also commonly leads to the need for a reinventory when properties of the moving object are changed.

There has been some commentary about the need for dynamic GIS, but the application of a clear methodology to dynamics is practically unknown in GIS software. At a minimum, a dynamic GIS should have a simulation modeling aspect. It should also have the capability of including new observations as they become available, using a conditional probability procedure similar to or an improvement on the Kalman filter approaches adapted by Jameson (1985, 1986) to natural resource monitoring.

THE FUTURE - OBJECT-ORIENTED APPROACHES?

With the development of improved graphics and object-oriented computer languages, such as Smalltalk, C++, Object Pascal, and CLOS (an extension of Common LISP), software capability now seems to be catching up with many of the problems identified by proponents of adaptive resource management during the past two decades. Developments in these languages have led to specialities in software design, knowledge-based user interfaces, and database management (Khoshafian and Abnous 1990, Zdonik and Maier 1990). For information on object-oriented concepts in software design and programming, see Wirfs-Brock et al. (1990), Booch (1991), Smith (1991a), Taylor (1991), and others. Many current computer science topics in object-oriented approaches are published in the Journal of Object-Oriented Programming.

Use of object-oriented approaches to user interfaces is now so common that it can assumed to be the standard method for new developments (e.g., Dorfman 1990, Tello 1990, Smith 1991b, and many others). Much attention is also being given to object-oriented databases. A principal advantage of object-oriented database management is that the database can include functions (i.e., behavior) as well as state descriptions (Atwood 1991, Heintz 1991). In the general area of object-oriented database management, books and tutorial articles include Brown 1991, Gupta and Horowitz 1991, Hughes 1991, Joseph et al. 1991, Kim 1990, Kim and Lochovsky 1989, and Nahouraii and Petry 1991.

The application of object-oriented concepts to spatial data is currently in a rapid state of flux. Grosky and Mehrotra (1989) stated that relational databases are proving inadequate for spatial data, and have predicted that the relational approach will be supplanted by object-oriented databases in these cases. Kasturi, et al. (1989) have predicted that object/raster approaches will have more application than object-oriented vector systems, but this could change with further developments. There are several articles in the open literature on object-oriented spatial databases (e.g., Jagadish and O'Gorman 1989, Mohan and Kashyap 1988, Orenstein and Manola 1988, Oxborrow et al. 1991, Pizano et al. 1989, Robert et al. 1991, Worboys 1990).

Although at least two companies have long experience with object-oriented GIS, or at least a GIS that is written in an object-oriented language, commercial interest in object-oriented GIS is not as yet widespread. It appears likely that object-oriented CAD will appear as commonplace before object-oriented GIS. However, delays in industry-wide standards can be expected because there is not yet an ANSI C++, and there is no general agreement on standards for object-oriented spatial databases. In addition, most of the work on object-oriented databases has been done in academia or by small firms, so the forces for standardization have not yet focussed.

Much of the advanced development of an objects-in-space approach to spatial analysis has been spawned by a research group at Texas A&M University, with extension to cooperators at other institutions (e.g., Coulson et al. 1987, Saarenmaa et al. 1988, Folse et al. 1989, Folse et al. 1990, Mueller 1991, Roese et al. 1991). Their procedures feature individual or population models coded in a LISP-derived language (e.g., Keene 1989); these populations move through, modify, and learn from habitat features (points, lines and polygons) that are also coded with an object-oriented language. Work of this group has primarily been applied to wildlife and pest populations. Saunders et al. (1992) have summarized these approaches with a description of the union of knowledge based rules of animal behavior with object-oriented programming techniques to produce an intelligent GIS. Applications to hydrology have been presented by McKay et al. (1991) and Whittaker et al. (1990).

Fire behavior appears to be another promising area for an objects-in-space technique, but thus far there have been no published examples. However, the Advanced Resource Technology Lab (ART) at the University of Arizona is working on modeling of fuzzy moving objects in fuzzy space, using a GIS of their own design (George Ball, UA, personal communication), that could be helpful in fire applications. Because object-oriented approaches are an active research area, other applications will undoubtedly surface.

Extensions to the basic operators described earlier in this paper frequently are implemented through access to the source code of public domain computer programs such as GRASS. Developmental efforts involving open source codes are important and will continue to play a role not filled by commercial software. However, too often the results are obscure and contorted procedures that may be understood only by the programmers and difficult for less experienced users to explain.

Further development toward an elegant (in the mathematical sense) object- oriented GIS may be furthered as fundamental work in topology is advanced. For example, Egenhofer and Herring (1990) and Egenhofer and Franzosa (1991) have defined a set of topological spatial primitives that are independent of distance. The inheritance property of object-oriented languages should facilitate adaptation of these primitives to new situations. Inclusion of such primitives, much as the arithemetic, Boolean, and set operators are now part of GIS, should be helpful for the next generation of GIS to evolve on a broad scale.

DISCLAIMER

This paper is intended only to explore some historical developments of GIS. It is not an official policy statement of the USDA Forest Service, nor does it reflect in any way on any pending or future computer system procurement by the Forest Service.

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FOREST INSECT AND DISEASE RISK AND OCCURRENCE MAPS IN GIS: APPLICATION TO INTEGRATED RESOURCE ANALYSIS.

HELEN M. MAFFEI
Forest Pest Management, Pacific Northwest Region, U.S. Department of Agriculture, Forest Service, Bend, OR 97701

JOHN V. ARENA
Bureau of Indian Affairs, Warm Springs Indian Reservation, Warm Springs OR 97761

Abstract: Insect and disease (I&D) considerations impose important limitations on management options on the Warm Springs Indian Reservation. Difficulties have arisen, when evaluating the management implications of I&D from a big picture or landscape susceptibility perspective. Adding I&D occurrence and risk maps to the GIS data base will help to address landscape issues as well as incorporate forest I&D considerations into the overall integrated resource analysis process. Our approach to developing these layers in the face of time and budget constraints included: light surveys to answer specific I&D questions; use of aready existing information; and dividing up the reservation into several forest type strata. We found that needed I&D layers were either occurrence and risk maps. An example of each category is given using a 7,690 acre analysis area. Development of risk rating maps for western spruce budworm was also presented.

INTRODUCTION

Insect and disease (I&D) considerations impose important limitations on silvicultural management options on the Warm Springs Indian Reservation as they do on most of Central Oregon's forested lands. Difficulties have arisen, when evaluating the management implications of I&D in a context larger than the stand or cutting unit. Yet, these big picture or landscape susceptibility questions are commonly asked and the penalty of inadequate answers can be severe. For example, if the Tribal Council is not aware of the overall magnitude of I&D damage or threat to resource values (be they timber-, visual quality-, wildlife- or recreation values) they may not support silvicultural treatments required to deal with the problem. As a result, irretrievable losses multiply and future management options are lost.

In addition, previously collected I&D information is often lost, scattered, or in a form difficult to cross-reference with other resource information. Although analysis is still possible, it is time consuming to locate the information as well as interface it with other pieces of crucial information; if that is, the land manager is even aware of its existence. With limited time and personnel gathering together all the necessary I&D- and other types of information from these widely scattered sources is cumbersome and often doesn't take place. Instead the project is implemented without the information or the area is re-surveyed again wasting time and money.

Several years ago the Confederated Tribes of Warm Springs purchased a complete GIS system and hired two full time system's analysts. These employees have since been building a variety of resource information layers (36 in all) some of which include: registered ortho-quad maps; continuous forest inventory (CFI) plot summary information; plant associations; elk and deer habitat data; roads; rivers; sale area boundaries; harvest activity maps; and, rainfall maps.

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We believe that adding an insect and disease occurrence and risk layer to the existing GIS data base will better enable us to address insect and disease issues from a big picture or landscape perspective. In addition, when used together with the other layers, it will help us to look at how these agents may limit or affect other resources outputs. Thus, we believe it will be easier to evaluate the role of I&D in a true integrated resource management framework.

STRATEGY AND METHODS

While we can make a convincing argument in the long term for the usefulness of I&D information in the data base, we are still faced with the problem of limited personnel and the up front cost of getting the information into the data base. Our approach to these limitations may be summarized as:

1. **Streamline and work smart.** We wanted to collect additional I&D information using efficient, economical procedures. We also wanted this information to be sufficient not only to project landscape effects, but also to select a preferred alternative (this includes the ability to run the I&D model extensions), and develop a general treatment diagnosis for each stand. Thus, we chose surveys which were light and tailored to answer management questions associated with specific pest problems (see mistletoe example) commonly encountered on Warm Springs.

   At the time of project implementation, additional data for specific unit prescriptions can be gathered on an "as needed basis". We suspect that this additional information will not be needed most of the time.

2. **Use what you have.** If good information already exists (at the required level) we don't want to recollect it. Therefore, we plan to make use of any credible pre-existing pest surveys or risk maps. These can simply be added to the data base. Useful I&D information can also be derived from a wide variety of other sources including aerial surveys, biological evaluations and, forest inventory efforts.

3. **Compartmentalize the work.** The reservation contains a wide, and some may say, "bewildering" array of forest types and associated pest problems. We find switching back and forth from one forest type to another in course of a survey, usually results in confusion and inaccurate data, even from the best field crews. We are therefore compartmentalizing surveys by three general forest types (Figure 1); the pine, the mixed conifer, and, the true fir/hemlock. Not only do these forest type groupings improve the accuracy of the survey by making it easier on field crews, they also help us form a perspective on the size, cost, and scheduling of surveys needed to complete the I&D layers.

RESULTS

We found that needed I&D information was either: 1. **Occurrence and severity maps**, where the location of specific existing insect and disease populations are mapped along with the severity of damage or infection; 2. **Risk rating maps**, where the level of risk to a damaging outbreak of a specific insect or disease is mapped across the landscape. Although both types of maps are useful, some pests lend themselves more to one of these systems than the other. For example, many insect pests lend themselves better to risk rating than mapping because of their mobility. In the following paragraphs, we will illustrate examples of how these two types of I&D maps can be used in the pine forest type. We will then illustrate how risk ratings can be developed to predict western spruce budworm outbreaks in the mixed conifer and fir/hemlock forest types.

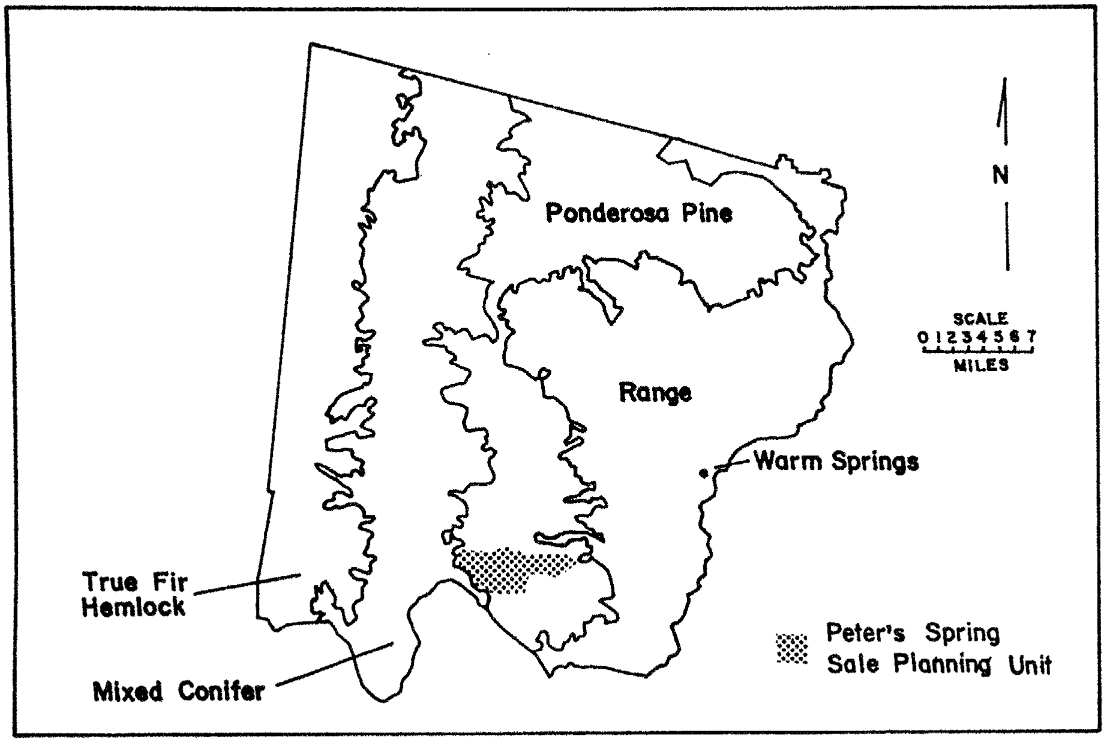

FIG. 1. Forested land on the Warm Springs Indian Reservation divided into 3 general forest types: 1. The pine type (177,000 acres); 2. The mixed conifer type (152,000 acres); 3. the true fir/hemlock type (119,000 acres). Location of Peter's Spring analysis area (7,690 acres) in the pine type forest.

Mapping dwarf mistletoe occurrence and severity

In order to develop an area based program to treat western pine dwarf mistletoe (*Arceuthobium campylopodum*) silviculturally, it is important to know it's distribution and severity with a reasonable degree of accuracy. Hence, we have developed a method of detection call the "mistletoe reconnaissance survey". This is a light survey which provides 100% forest area coverage while collecting general information with respect to species composition, size, stand structure, dwarf mistletoe infection incidence and severity (the dwarf mistletoe rating system (DMR) (Hawksworth 1977) was used). It is a visual reconnaissance, comparable to the roadside surveys done in the Southwest and Colorado in the 1980's (Maffei et al 1987a,b and c; Merrill et al 1985) except survey point centers were set up on a 5 by 5 chain grid system over the entire ponderosa pine type rather than surveying only along roads. The survey method assumes a 2.5 chain (165 ft.) line of sight in all directions from survey point center (approximately 2.5 acres).

To give you a general idea of how this survey can be used to evaluate the spatial attributes of dwarf mistletoe treatments we will use a project analysis area called Peter's Spring. A significant amount of this 7,690 acre ponderosa pine forest is infected with dwarf mistletoe(Figure 2).

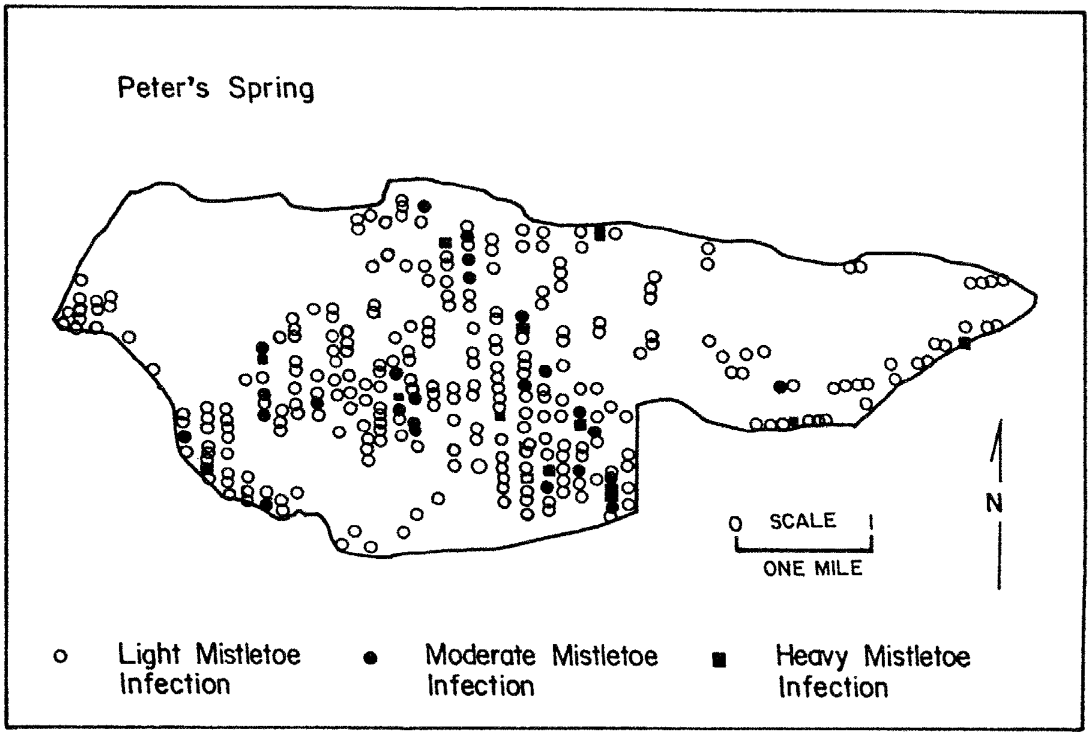

FIG. 2. Western pine dwarf mistletoe distribution by infection severity classes on the Peter's Spring Planning Unit. The total size of the unit is 7,690 acres. Each survey point square represents 2.5 acres (some of the irregular sized ones represent more). In areas with no survey point squares, trees are free of dwarf mistletoe.

By looking at the distribution of mistletoe and it's severity across the analysis area we can get a general idea of the treatment possibilities over the sale area as well as develop general priorities for treatment. For example, yield simulations done in conjunction with the roadside surveys in the Southwest (Hessburg and Beatty 1985) indicate that stands with moderate to heavy mistletoe cannot be managed to rotation without severe volume loss. Thus, if wood fiber production or growing big trees is your management emphasis, your options are probably limited to regenerating the stand. In the lightly infected areas however, an intermediate treatment (thinning, overstory removal etc.) can result in full rotation with little volume loss provided the stand is treated before it progresses to more severe infection levels (Hessburg and Beatty 1985). Besides the level of mistletoe infection and management objectives, priority and specific type of treatment can depend on size of the trees and location of adjacent areas of re-infection both of which can be determined from the dwarf mistletoe layer.

Integrating the mistletoe information with other resource layers such as the wildlife- and the harvest activity layer can also help with analysis and subsequent decision-making. For example, restrictions like wildlife cover requirements and maximum openings for watershed thresholds, can be analyzed and considered together with the need to treat dwarf mistletoe (Figure 2)

Mapping pine engraver risk

Pine engraver beetles (*Ips pini*) are not a problem everywhere on the Reservation. Usually, they only attack live trees where rainfall is 25 inches per year, or less. In these areas where risk is high, there is less flexibility in treatment scheduling and slash disposal. From where the Peter's Spring falls on the rainfall map (Figure 3), it appears we have to moderate our management activities to mitigate for pine engraver only on the eastern half of the sale (although this could change in a exceptionally dry or wet year).

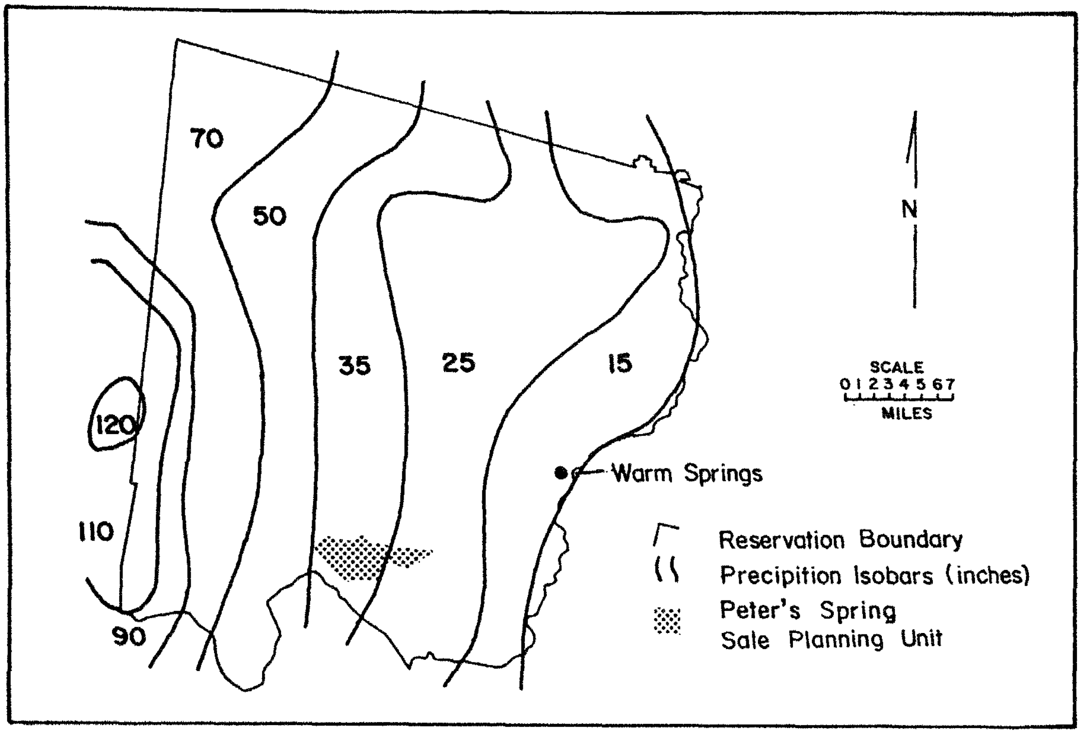

FIG. 3. Precipitation isobars (in./yr.) on the Warm Springs Indian Reservation and risk to pine engraver. Areas with 25 inches of rainfall per year, or less, are at high risk to fir engraver.

Mapping western spruce budworm risk

For another look at the application of risk ratings shift your attention to the mixed conifer and fir/hemlock forest types. Since western spruce budworm (*Choristoneura occidentalis*) defoliation has been a significant and re-occurring pest on the reservation, we developed a site specific defoliator risk map. Stands composed of greater than 30% host species, with high densities and southern exposures have been found to be high risk for western spruce budworm outbreaks on Warm Springs. These attributes are usually derived from the forest vegetation layer. Since this layer will not be installed until 1995 we are, for now, approximating the layer using the CFI plot summary information to predict general areas of high risk to western spruce budworm (Figure 4a). In comparing the risk layer in Figure 4a to present budworm activity (derived from the last two years of aerial survey) in Figure 4b, areas of high risk and budworm activity correspond well. Of course, if possible, the idea is to anticipate stand conditions of high risk; silviculturally treat them to lower the risk and <u>prevent</u> significant defoliator outbreaks!

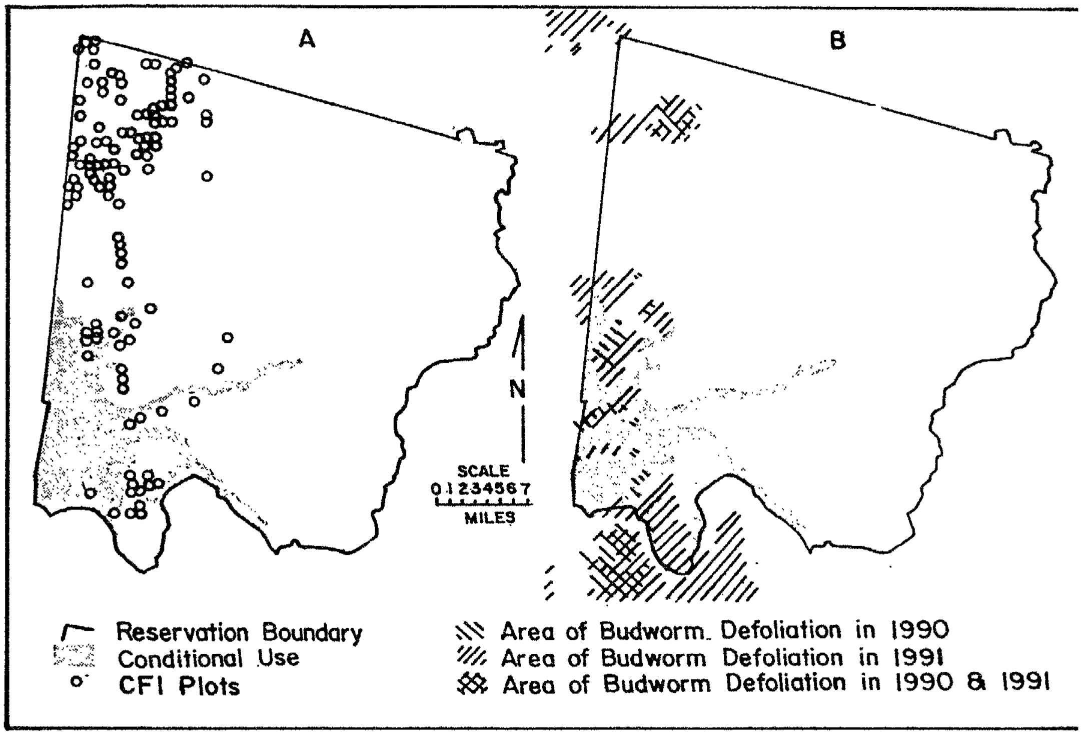

FIG. 4. a. Risk map for western spruce budworm outbreaks(developed using forest inventory plots, each square denotes high outbreak risk and represents about 250 acres); b. Distribution of western spruce budworm defoliation in 1990 and 1991 according to the aerial survey maps.

SUMMARY

In summary, we see the GIS system (complete with all resource layers, including the I&D maps) as a multiresource information system and an investment in the future. In order to perform the high level of integrated resource management required of us, we need tools which can deal with very complex analysis. GIS is such a tool and available to the Warm Springs Confederated Tribes. Once the pest layer is complete, the tribe will have an infinitely better picture of the the importance and role pests are playing in their forest, both at present and under various management scenarios. This will result in more informed land management decisions and a future which is much less likely to contain "unpleasant surprises".

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USE OF A GEOGRAPHIC INFORMATION SYSTEM IN SOUTHERN PINE BEETLE MANAGEMENT

Brian M. Spears and Wesley A. Nettleton
USDA Forest Service, Forest Pest Management, Region 8, 1720 Peachtree Road, N.W., Suite 925 North, Atlanta, Georgia 30367

Abstract. A geographic information system (GIS) is being used for southern pine beetle (SPB) management on the Oconee National Forest in Georgia and the Homochitto National Forest in Mississippi. Data were obtained from several sources including aerial photography, aerial detection surveys, the Southern Pine Beetle Information System, the Continous Inventory of Stand Conditions, and the Primary Base Series for the national forests. Maps were produced for proofing compartment and stand records, showing change in SPB hazard rating, and showing the threat of SPB outbreak to red-cockaded woodpecker colonies. Analysis included acreages of national forest affected within red-cockaded woodpecker zones of various radii, forest-type and age-class acreage calculations, and hazard rating susceptibility of stands to SPB attack. SPB is also one of the insect data layers in the Forest Health Atlas for the Southern Region.

Introduction

The southern pine beetle (SPB) is the insect most damaging to pine forests in the southeast. Numerous SPB outbreaks have occurred in the past 100 years causing widespread, often spectacular tree mortality for periods of two or more years. Such losses have upset management plans and reduced potential yields from managed forests.

In 1988, the USDA Forest Service established the SPB Demonstration Area Project on the 110,000 acre Oconee National Forest in Georgia and the 97,000 acre Homochitto National Forest in Mississippi. Both forests had experienced chronic SPB problems over the past twenty years. The project goal is to demonstrate how sound forest management practices and control strategies can minimize SPB and other pest-caused damage while still achieving overall management objectives (Nettleton, 1988). Emphasis is placed on utilizing available technology developed by research and integrating it into routine resource management.

Data Sources

Forest Pest Management personnel in the Southern Region integrated several major databases into a geographic information system (GIS) to assist in the management of the Oconee National Forest in Georgia and the Homochitto National Forest in Mississippi. We obtained information on the location of SPB spots from aerial photography and aerial detection surveys. The Southern Pine Beetle Information System (SPBIS) and the Continuous Inventory of Stand Conditions (CISC) are large relational databases which have been tied to the stand and compartment boundary information implemented in the GIS. Development of the national forest GIS for these demonstration forests was completed according to the Region 8, GIS Implementation Plan (Dull, et al., 1989). The national forest primary base series (PBS) data provide the background for resource management. They include ownership, lakes and streams, roads, and stands and compartments. These data are organized in map libraries in our GIS, and we use them to produce maps of various scales such as page size, 1:24,000 7 1/2 minute overlays, or forest-wide maps at 1 inch per mile or 1/2 inch per mile.

Pages 15-24 *in* A.M. Liebhold and H.R.Barrett, editors. 1993. Proceedings: Spatial Analysis and Forest Pest Management. USDA Forest Service General Technical Report NE-175.

DATA ANALYSIS AND PRODUCTS

An example of a page size map showing a forest compartment is shown in Figure 1. We produced similar maps for all compartments on both forests, and used them to proof compartment and stand records. They display both PBS and CISC data. We found it much easier to see errors when data were graphically displayed as compared to looking for errors in tabular information.

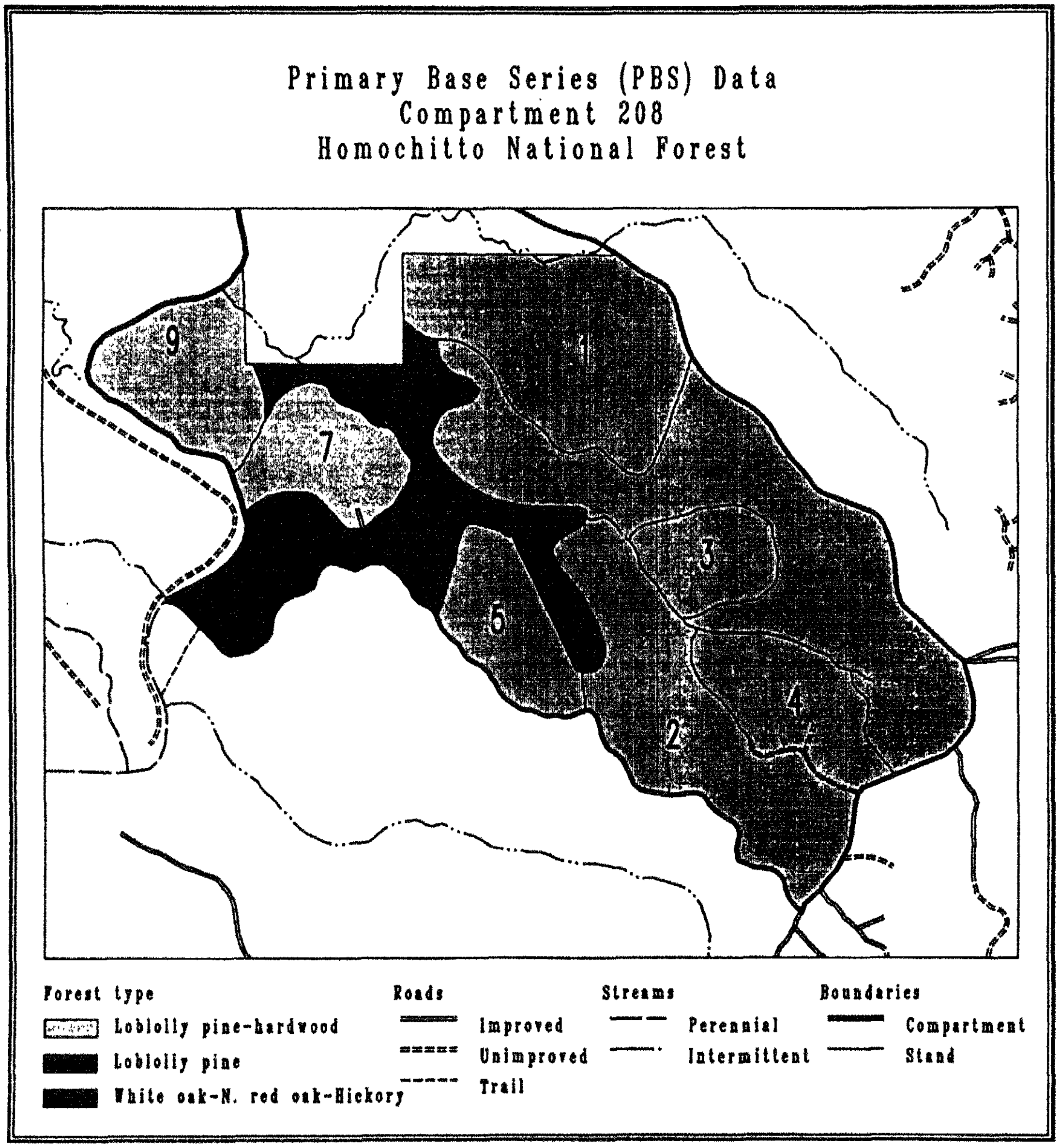

FIG. 1: Forest Types, Roads, Streams, and Stands for Compartment 208 of the Homochitto National Forest, Mississippi.

The GIS can be used to calculate acres or timber volume set aside for special uses much more quickly than conventional methods. Figure 2 shows one compartment from a ranger district map that was originally made at 1 inch per mile. We displayed SPB spots in relationship to red-cockaded woodpecker (RCW) colonies, and drew a 1/2 mile RCW foraging boundary around RCW colonies.

Understanding the relationship between SPB and RCW is important because the woodpecker nests in live pines which are susceptible to SPB attack. Figure 3 shows the acreage of national forest ownership affected if 1/4 mile, 1/2 mile, or 3/4 mile RCW foraging zones are allocated. Acreages for zones of other radii could be calculated in a matter of minutes if the above three were found to be inadequate for any reason.

Acres of general forest type (Figure 4), acres of each forest type (Figure 5), or acres of a forest type by age class (Figure 6) as well as other combinations can be quickly calculated. We used these types of analyses to hazard rate susceptibility of stands to SPB attack, and to map the hazard rating (Figures 7 and 8). Stand susceptibility was reduced after silvicultural treatments were applied. We mapped the changes in susceptibility following silvicultural treatments and updated the forest inventory data (Figures 9 and 10).

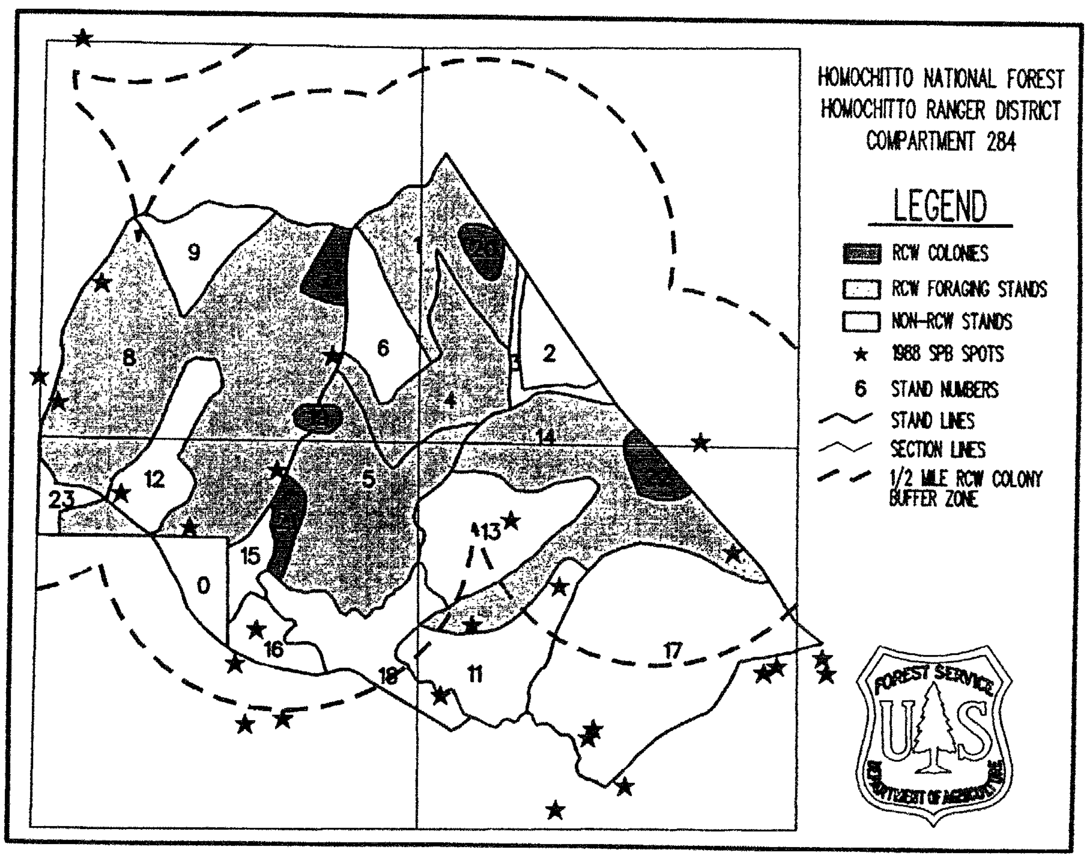

FIG. 2: Southern Pine Beetle Spots and Red-Cockaded Woodpecker Activity in Forest Compartment 284, Homochitto Ranger District, Homochitto National Forest.

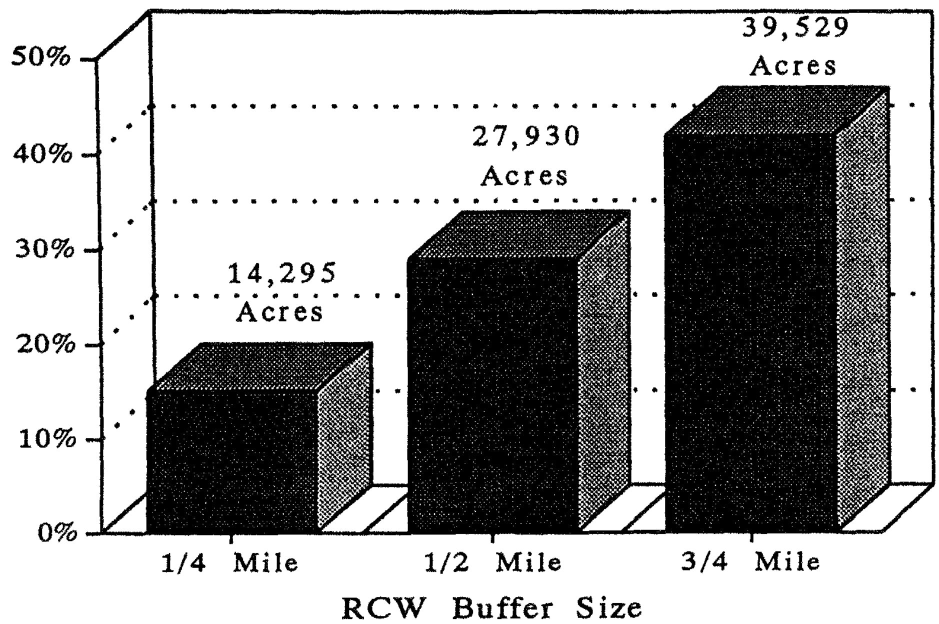

FIG. 3: Acreage of National Forest Ownership Affected on the Homochitto Ranger District, Homochitto National Forest, Mississippi, within 1/4, 1/2, and 3/4 Mile Red-Cockaded Woodpecker Buffer Zones.

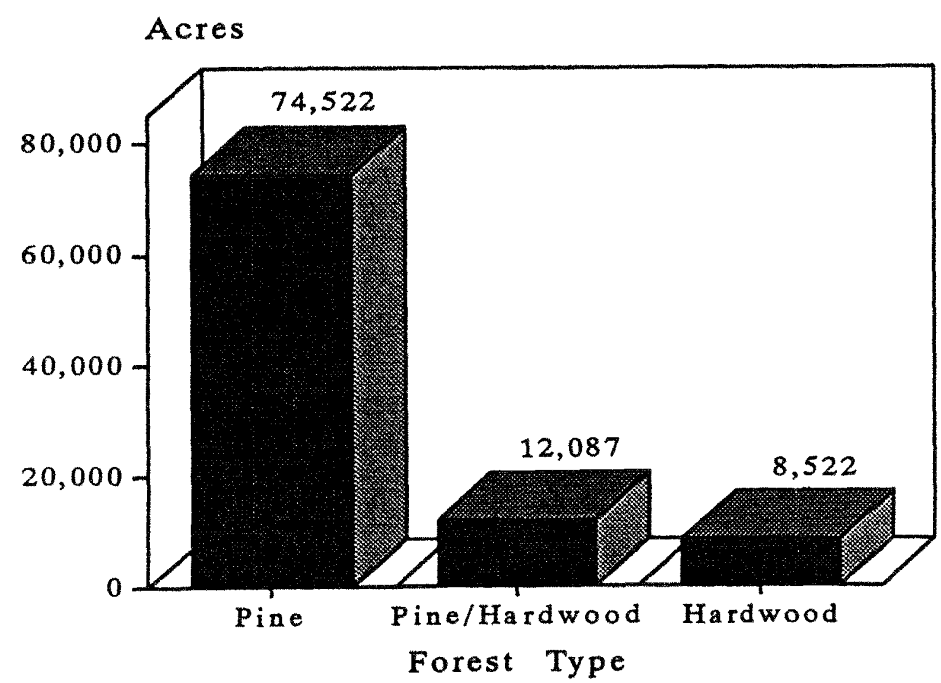

FIG. 4: Acres of General Forest Type on the Homochitto Ranger District, Homochitto National Forest, Mississippi.

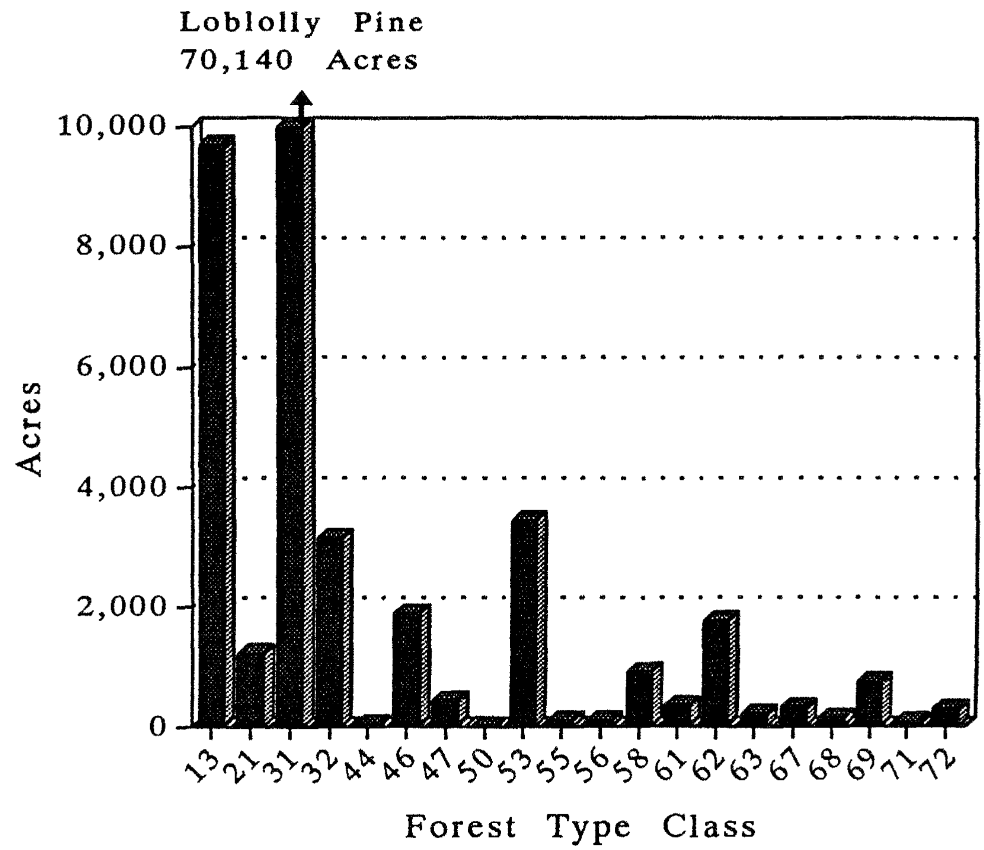

FIG. 5: Acres of Each Forest Type on the Homochitto Ranger District, Homochitto National Forest, Mississippi.

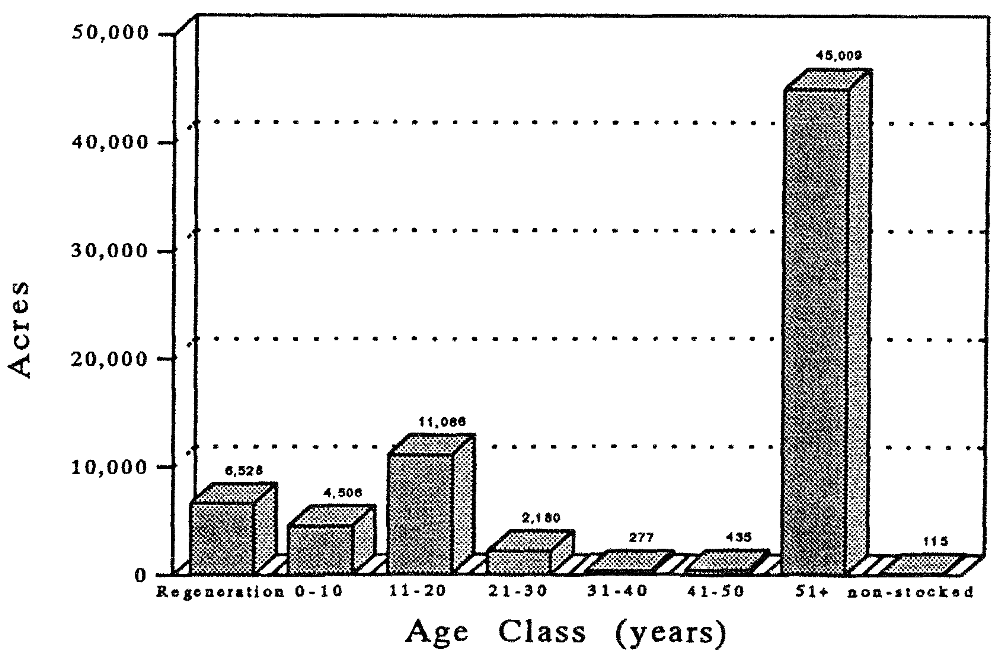

FIG. 6: Acres of Loblolly Pine by Age Class on the Homochitto Ranger District, Homochitto National Forest, Mississippi.

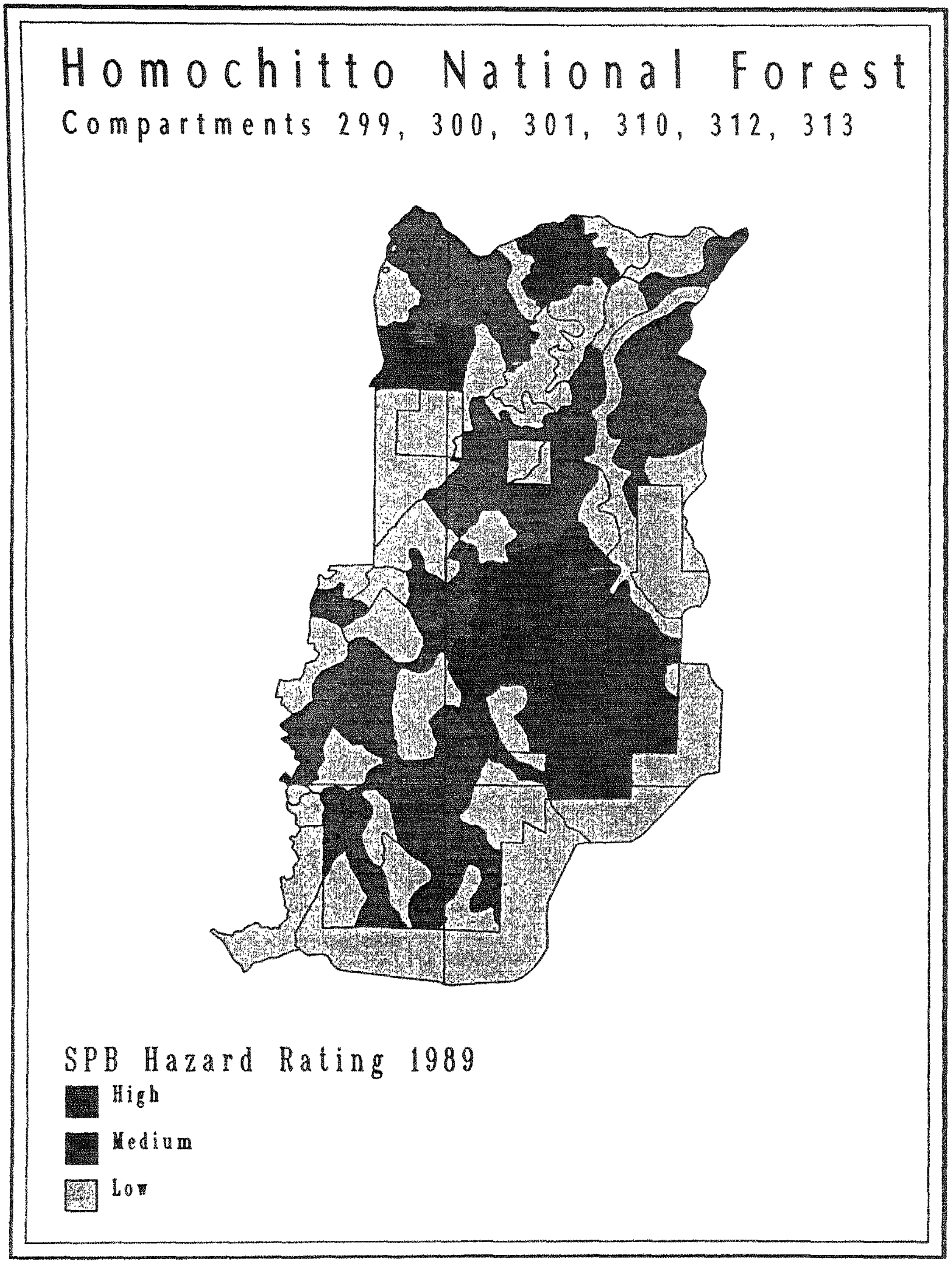

FIG. 7: 1989 Southern Pine Beetle Hazard Rating for Selected Forest Compartments on the Homochitto National Forest, Mississippi.

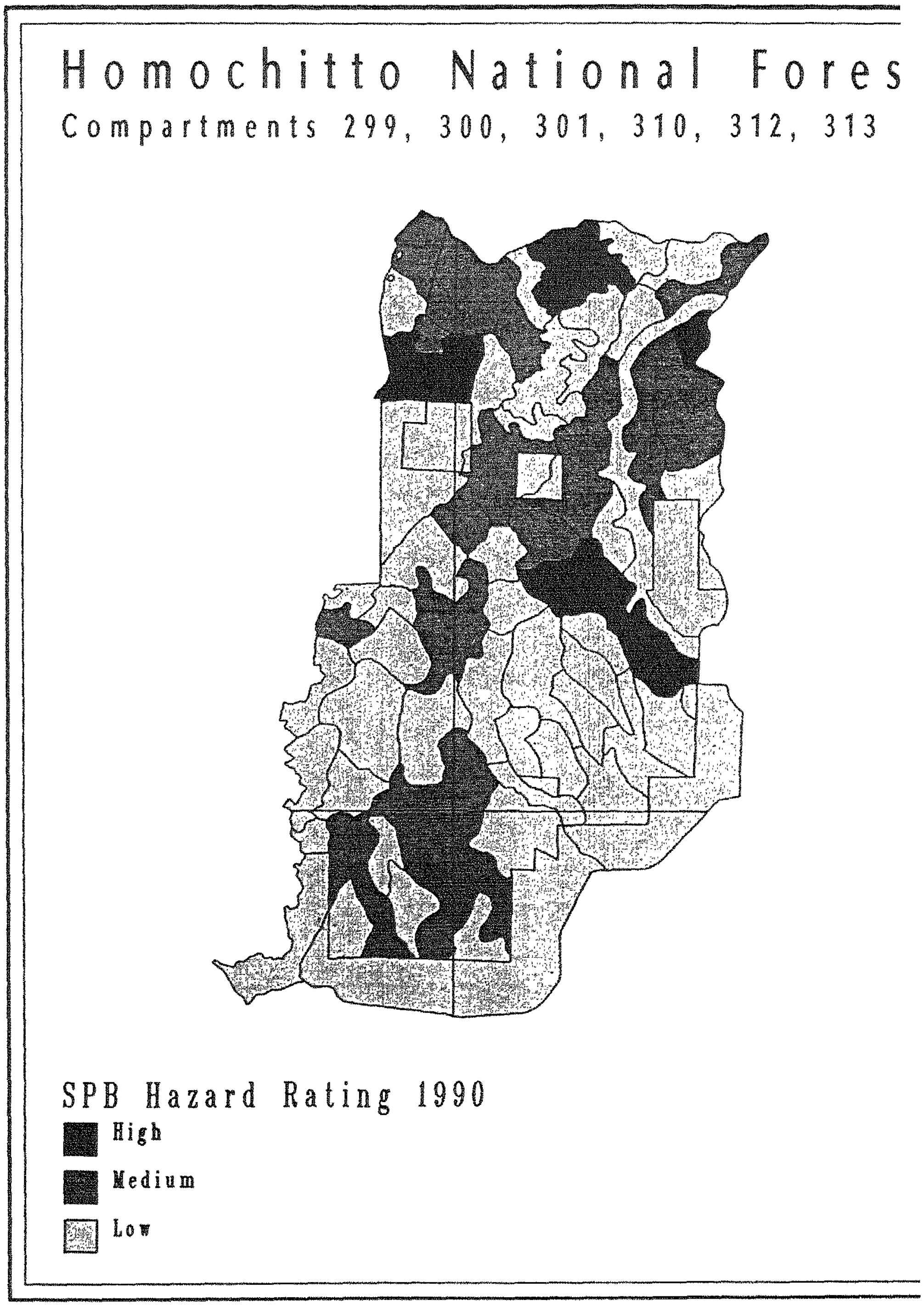

FIG. 8: 1990 Southern Pine Beetle Hazard Rating for Selected Forest Compartments on the Hom National Forest, Mississippi.

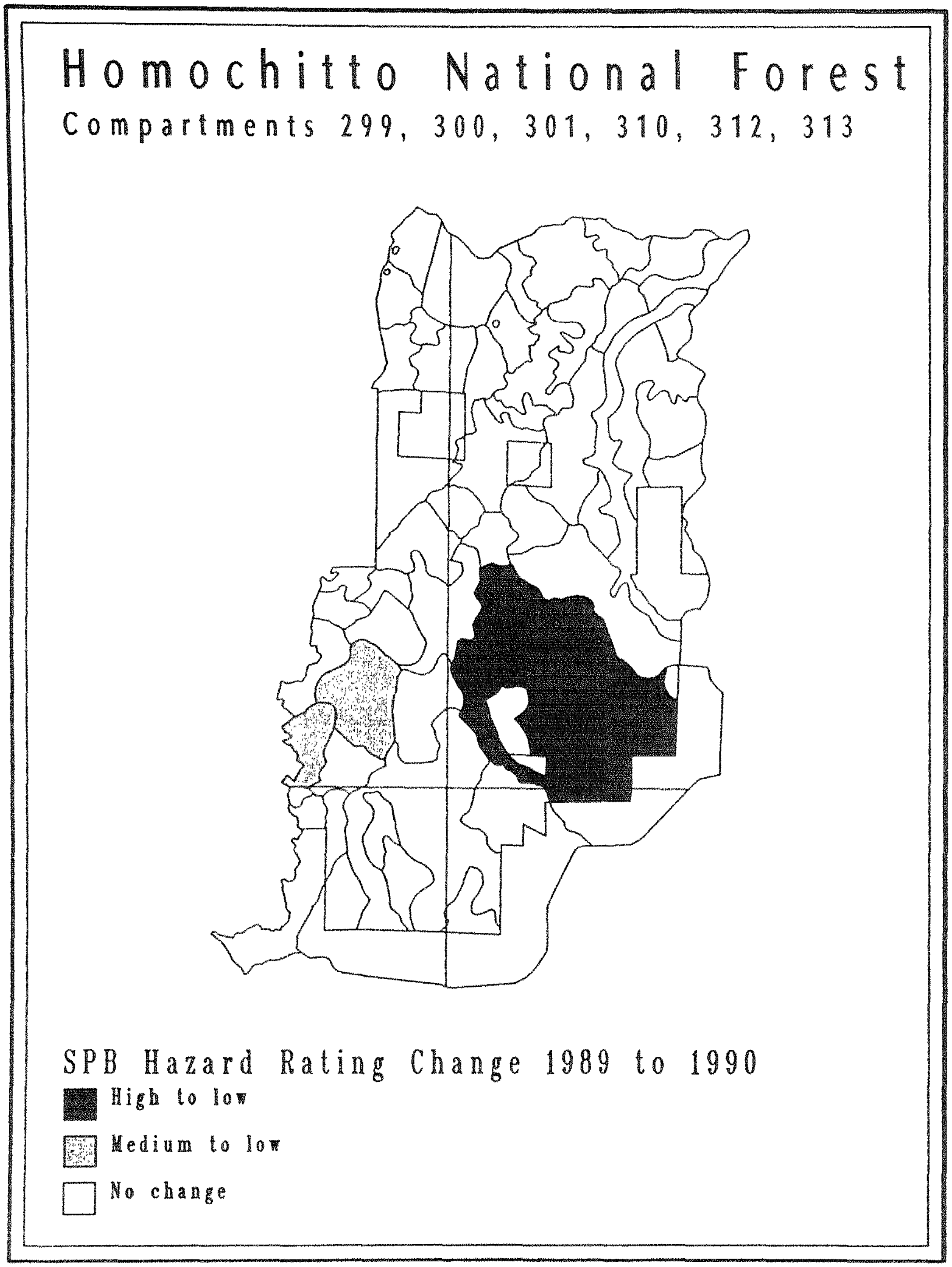

FIG. 9: Change in Southern Pine Beetle Hazard Rating Between 1989 and 1990 for Selected Forest Compartments on the Homochitto National Forest, Mississippi.

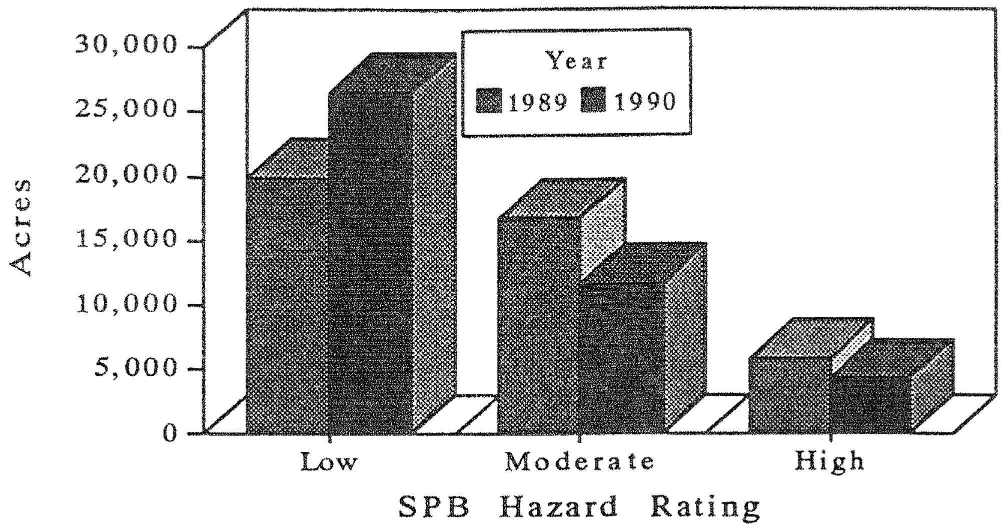

FIG. 10: Change in Southern Pine Beetle Hazard Rating Between 1989 and 1990 for the Homochitto National Forest, Mississippi.

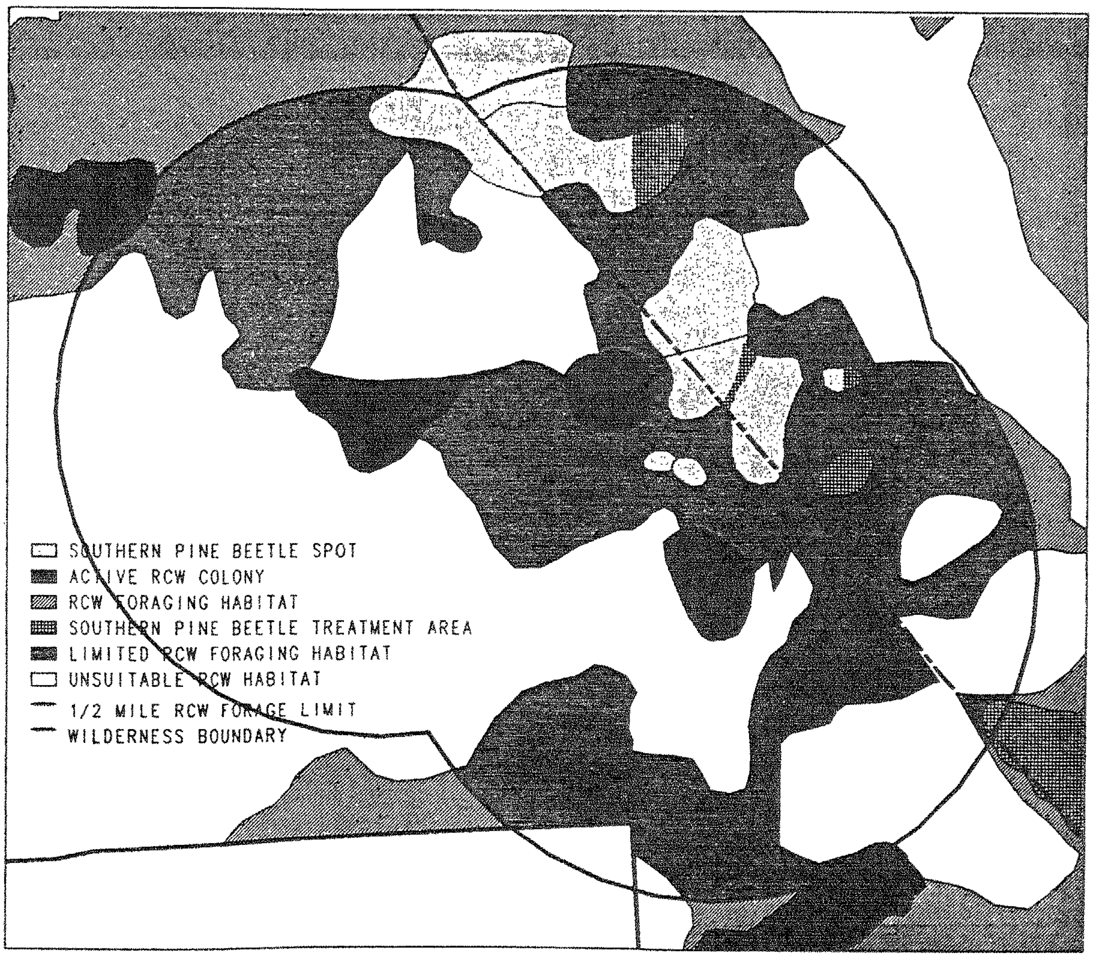

FIG. 11: Southern Pine Beetle Spots Threatening Red-Cockaded Woodpecker Colonies in the Little Lake Creek Wilderness in Texas.

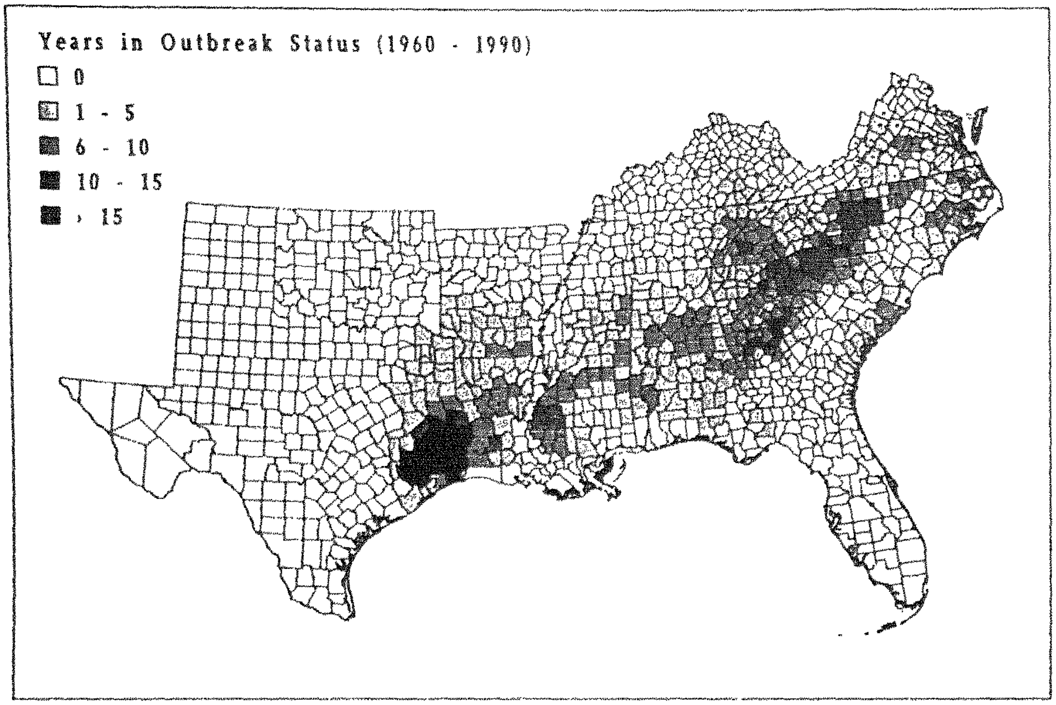

FIG. 12: Number of Years in Southern Pine Beetle Outbreak Status Between 1960 and 1990 for each County in the Thirteen Southeastern States.

One incidence illustrating the importance of analyzing data and producing graphics quickly was demonstrated when a SPB outbreak threatened RCW colonies within the Little Lake Creek Wilderness in Texas during 1990. The RCW must be protected according to the Endangered Species Act. The wilderness must be protected according to the Wilderness Act. We needed to cut SPB infested trees in the wilderness to protect the RCW so these two Acts would have been in conflict except thier is a provision in the Wilderness Act allowing treatment of pest outbreaks in wilderness areas. Therefore, the action chosen was to treat the SPB spots. We needed to treat the spots within a couple of weeks to keep them from spreading into RCW colony trees. Using the GIS, we quickly produced a map identifying which RCW colonies were threatened (Figure 11). The project resulted in successful treatment of SPB spots in the wilderness area and protected of the RCW colonies. We could not have produced the map in time to protect the colonies without the GIS.

We also have insect layers in the Forest Health Atlas for the Southern Region. Figure 12 shows southern pine beetle occurrence by county in the southern region. Tree stressors such as ozone, drought, fire, etc. which are in the Atlas can be analyzed in relation to SPB outbreaks.

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AIPM: A PROJECT DEMONSTRATING A GIS-BASED MONITORING SYSTEM FOR GYPSY MOTH

E. A. ROBERTS AND F. W. RAVLIN
Department of Entomology, VPI&SU, Blacksburg, VA. 24061

BRIAN M. SPEARS
USDA Forest Service, 1720 Peachtree Road, N.W., Suite 925 North,, Atlanta, GA. 30367

ABSTRACT. The Appalachian Integrated Pest Management Demonstration Project, a large gypsy moth pest management program, is survey intensive. Among the uses of GIS in the project is providing support for collection of male moth and egg mass data. In pheromone trap surveys for male moths, the GIS assists with management of trapping personnel as well as with quality control of survey data. Maps of male moth data are used to assist in determination of areas to survey for egg masses while maps of egg mass densities are used in delineation of potential intervention areas. Many aspects of the GIS are production-oriented and highly automated. The GIS/DBMS is centralized and future projects of this magnitude should consider a distributed system.

INTRODUCTION

Gypsy moth is a serious defoliator of oaks and other hardwoods in forested and residential areas of the northeastern and, more recently, eastern United States. Since its accidental release from Medford, Massachusetts in 1869, the insect has continued its inexorable spread south and west at a rate of several miles per year. The Appalachian Gypsy Moth Integrated Pest Management (AIPM) Demonstration Project is a large 5-year program begun in 1988 designed to use novel and existing management strategies to deal with this insect within 12.8 million acres in Virginia and West Virginia (Fig. 1). It is funded through the US Forest Service and involves several federal, state, and county agencies. Among the objectives of the program are: 1) minimize the spread and adverse impacts of gypsy moth within the project area, 2) develop a prototype integrated pest management program which can be implemented in areas outside the project, and 3) evaluate intervention methods for management of isolated and low-level populations. Over the lifetime of AIPM, a geographic information system (GIS) has proven to be a useful tool in many of the various program activities which comprise the workings of the project.

As a rule, population monitoring is a crucial component of IPM programs, and AIPM is no exception. Surveys for male moths and for egg masses account for a large portion of program resources and form the basis for most management decisions. This paper will discuss the use of GIS in providing support for the monitoring component of AIPM. We will discuss the use of GIS in a variety of aspects of the routine monitoring process, how the GIS has proven to be an effective tool for personnel management during periods of intense field activity, and how GIS assists in developing management strategies for areas of low-level populations.

AIPM GIS STRUCTURE

The AIPM GIS consists of Arc/Info software installed at four separate locations: USFS regional offices in Morgantown, WV; the Department of Geography and Geology at West Virginia University in Morgantown; USFS offices in Atlanta, GA; and the Department of Entomology at Virginia Polytechnic Institute and State University (VPI&SU) in Blacksburg, VA. Although each regional location assumes different responsibilities, activities typically are coordinated among the four groups. Because the AIPM data base is managed at VPI&SU, we at that institution have coordinated GIS efforts aimed at monitoring and data representation for management decisions.

Pages 25-36 *in* A.M. Liebhold and H.R. Barrett, editors. 1993. Proceedings: Spatial Analysis and Forest Pest Management. USDA Forest Service General Technical Report NE-175.

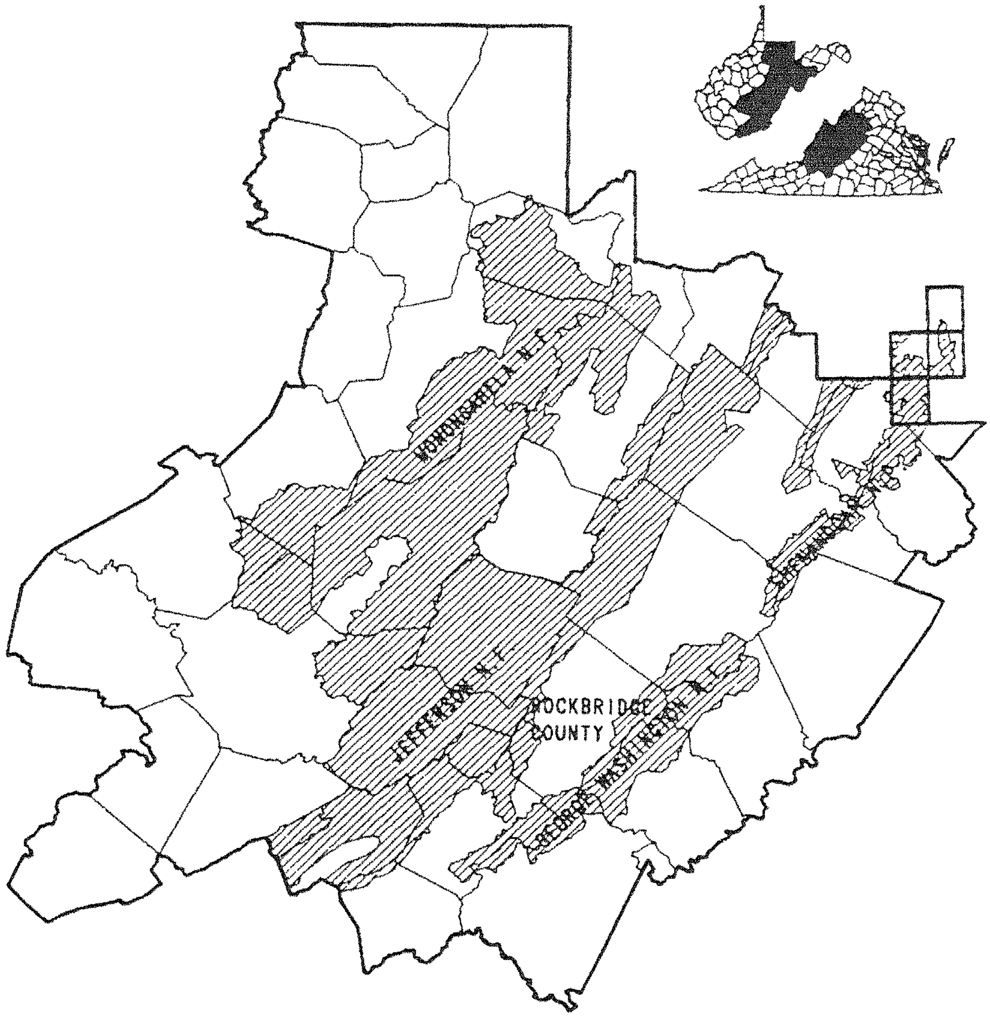

FIG. 1. The AIPM Project area. From Young, et al. 1991.

The emphasis of the AIPM GIS in support of monitoring activities has largely been on simplicity, and most maps involve no true GIS modelling. The philosophy associated with map production during the sampling phase of the program is to provide managers with information on what is happening on the ground and to let them make decisions based on that information. Many maps simply are depictions of point locations (sample sites) and their associated information, which is the type of information field personnel require most during the time when a survey is in progress. An advantage of these typse of maps is they are relatively easy and quick to produce and to interpret, which is important in rapid turnaround of data.

DATA FLOW AND AUTOMATION

Gypsy moth data are collected in the field on mark-sense forms and are mailed to VPI&SU. Each week the data are optically-scanned into the AIPM data base which is written in SPIRES data base management language on a large IBM mainframe computer. Positional data are recorded on the forms as UTM coordinates. After each weekly update flat files are created from the data base and transferred to a MicroVax 2000 which houses the GIS.

Essentially all operations which are performed more than once during the field season are automated with computer programs written in Arc/Info's macro language (AML). These include weekly creation of the point coverages and of the many types of maps produced over the season.

Map production at VPI&SU is limited by a lack of access to plotting devices suitable to production of large numbers of hardcopy maps. While maps produced on the available pen plotter are of good quality, it is not feasible to generate many copies of maps on this device. Thus, maps produced at VPI&SU are those requiring few copies (1 to 5) or are in a format which can be photocopied and distributed. Applications requiring production of tens or hundreds of maps are managed by sending digital files on tape to GIS operations in Atlanta, GA where they are plotted on an electrostatic plotter.

MALE MOTH SURVEY

Monitoring of male gypsy moths is accomplished through the use of pheromone-baited traps placed in the field prior to moth flight. Traps are placed on a regular grid in late spring and early summer. In West Virginia, traps are placed three kilometers apart while in Virginia traps are spaced every two kilometers. Traps in some areas are more closely spaced when higher resolution is needed to delimit populations or to assess treatment efficacy.

As a result of trapping on a regular grid, male moth data are essentially evenly-spaced across the entire project area. This uniform spatial distribution helps to make interpretation, analysis, and representation fairly straightforward.

PERSONNEL MANAGEMENT

Each year, approximately 175 field personnel, including trappers and supervisors, are involved in placing approximately 12,000 male moth traps within the AIPM region. These traps are placed within 38 counties in two states on federal, state, and private lands. The logistics of managing such an enormous field effort is compounded by the fact that different political jurisdictions have different management structures for field efforts. Often it is difficult for supervisors to maintain sufficient awareness of the spatial characteristics of trap placement, a situation which can lead to omission of traps in some areas or duplication of effort in others.

In attempts to prevent some of these problems, weekly data base updates include production of simple maps which depict locations of traps placed or monitored as the season progresses. Figure 2 depicts a map which provides trap location information relative to particular USGS quadrangles within a portion of the AIPM area. The project area is divided into seven regions which provide managers with more detail of their areas. Maps are made on 8.5 by 11 inch paper which facilitates handling. Figure 3 illustrates a series of small scale maps for the period of trap monitoring and removal for the entire project area. Managers readily notice those areas which have not been monitored and can investigate the causes of such neglect. Similar maps are produced during the time when traps are being placed in the field. Computer programs in Arc/Info are used to generate plot files of these maps which can then be either screen-dumped individually or plotted together on one large sheet of paper.

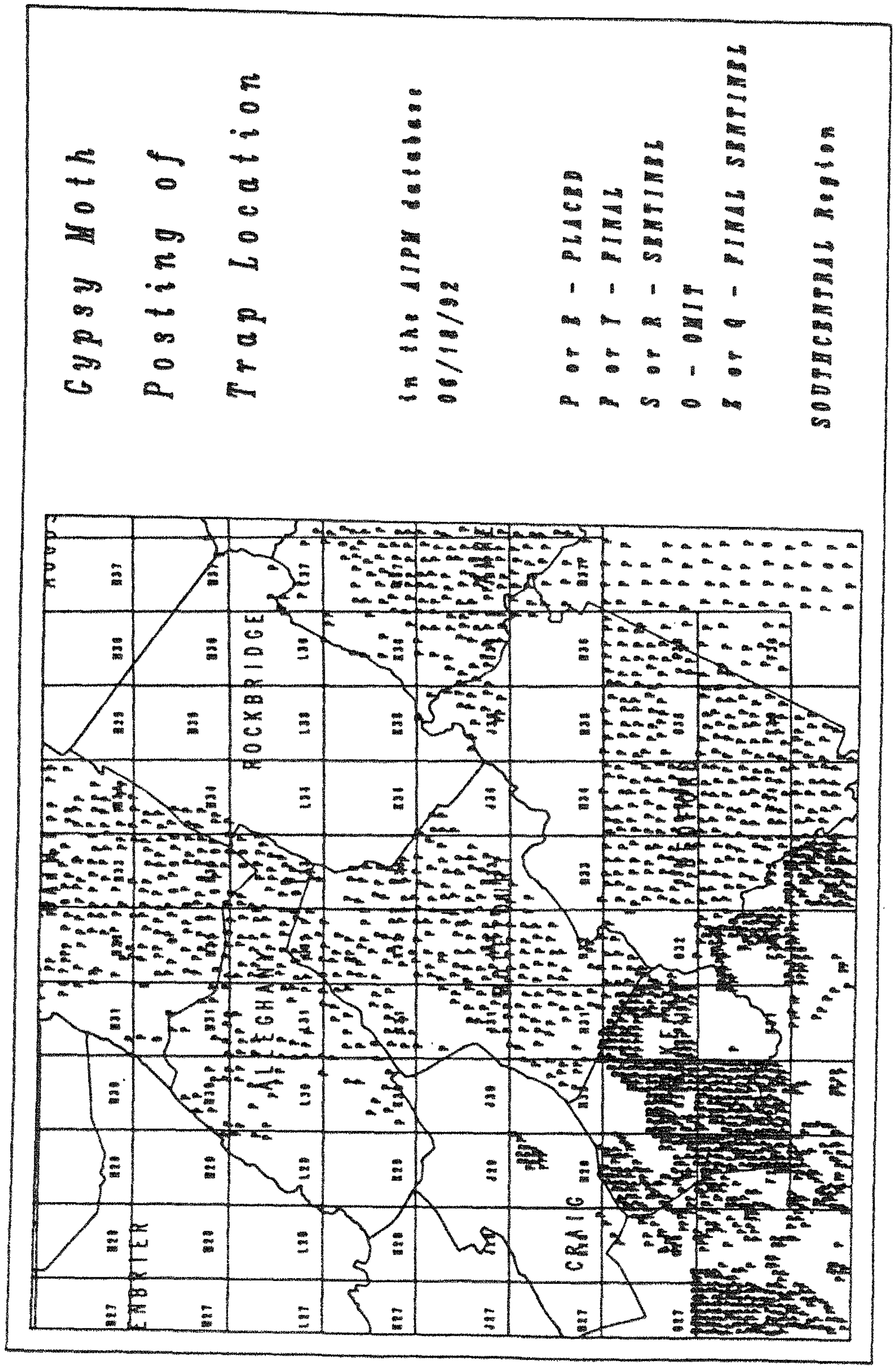

FIG. 2. Map of pheromone traps placed in early summer. Seven such maps are produced which represent the entire area.

FIG. 3. Map of pheromone trap and removal within the entire project area from August 28, 1989 through September 28, 1989.

Whenever possible, the GIS is used to respond to special situations which arise in the field and have a spatial component. For example, in 1990 there were a few areas in which traps were placed later in the season than desired. This precipitated concern that traps in these areas would not adequately represent moth populations because of the chance that first flight had occurred prior to placement. In response to this, we produced a simple map of trap placement sites with colored symbols corresponding to placement date. Field supervisors used this map as a subjective guide when interpreting moth catch at these sites.

MAPS OF MALE MOTH DATA

Logistically, nearly all monitoring activities in AIPM are associated with USGS 1:24,000 scale quadrangles. Maps of male moth survey data are created at this scale and used to assist in determining those areas in need of egg mass surveys (Fig. 4). At each pheromone trap site, catch values are posted along with information about trap monitoring procedures at that site. An interpolated surface of moth catch is represented as contour lines, often referred to as "isomoths". As a general guideline, any 1 km^2 cell wholly or partly within a 500 moth or greater contour interval is a candidate for egg mass surveys. Data themes which provide additional information include the previous year's egg mass survey locations with presence/absence of egg masses and a measure of yearly change in male moth catch values. Yearly change in pheromone trap catch is derived by associating the current year's catch with an interpolated catch at that same location from the previous year. A simple proportional increase or decrease is calculated and depicted on the map as a surface where each 1 km^2 contains a value for yearly change. Because maps are at 1:24,000 scale, field supervisors often overlay these maps onto USGS quad sheets on a light table.

Because of the large number (ca. 150) of maps produced during each field season, it is not feasible to plot them at VPI&SU. The computer programs which generate the digital map files were constructed to produce files compatible with the electrostatic plotter used by USFS operations in Atlanta. Digital maps are created at VPI&SU, written to tape, and mailed to Atlanta for hardcopy production and distribution.

Project-wide maps of moth catch are produced from interpolated surfaces of pheromone trap catch. These surfaces, termed lattice-polygons, are derived by first creating a triangulated irregular network (TIN) from the point data and then generating a raster surface of cells each having a categorical value for moth catch. Cell size is 500 meters and categories corresponded to management action thresholds. Whereas the 1:24,000 scale maps are designed to assist in survey and treatment decisions at the field level, these small scale maps are used most often to illustrate general population patterns within and among years (Fig. 5). Those interested should see Roberts *et al.* (1993) for more detailed discussion of surface representations of AIPM data.

EGG MASS SURVEY

Unlike monitoring for male moths where traps are placed on a predetermined grid over the entire project, surveys for egg masses are conducted only in areas which meet specific criteria. These are areas determined as a result of male moth data, landowner reports, intervention activities or some other method of prioritization. Egg mass samples are collected using a sequential sampling method devised by Fleischer et al. (1991). In areas selected for sampling, four to ten samples are taken in each 1 km^2 cell. Egg mass samples thus have a very clumped spatial distribution (Fig. 6) which makes some types of map representations involving interpolation more problematic than those for the evenly distributed male moth data (Fig. 3).

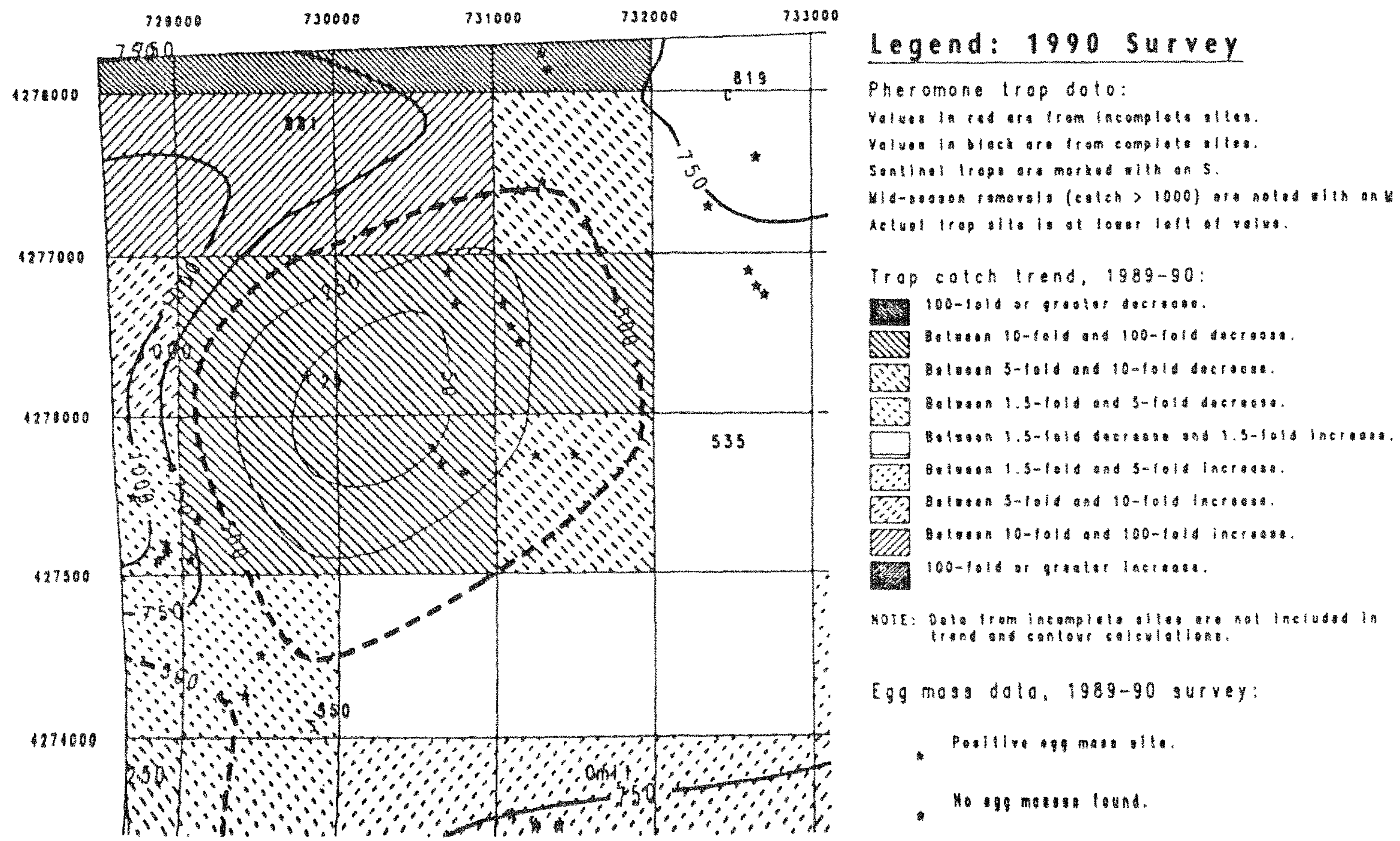

FIG. 4. A portion of a 1:24,000 scale map of male moth trap catch. Data layers include catch values, contours of catch, a measure of yearly change, and previous egg mass sample sites. The actual maps are in color.

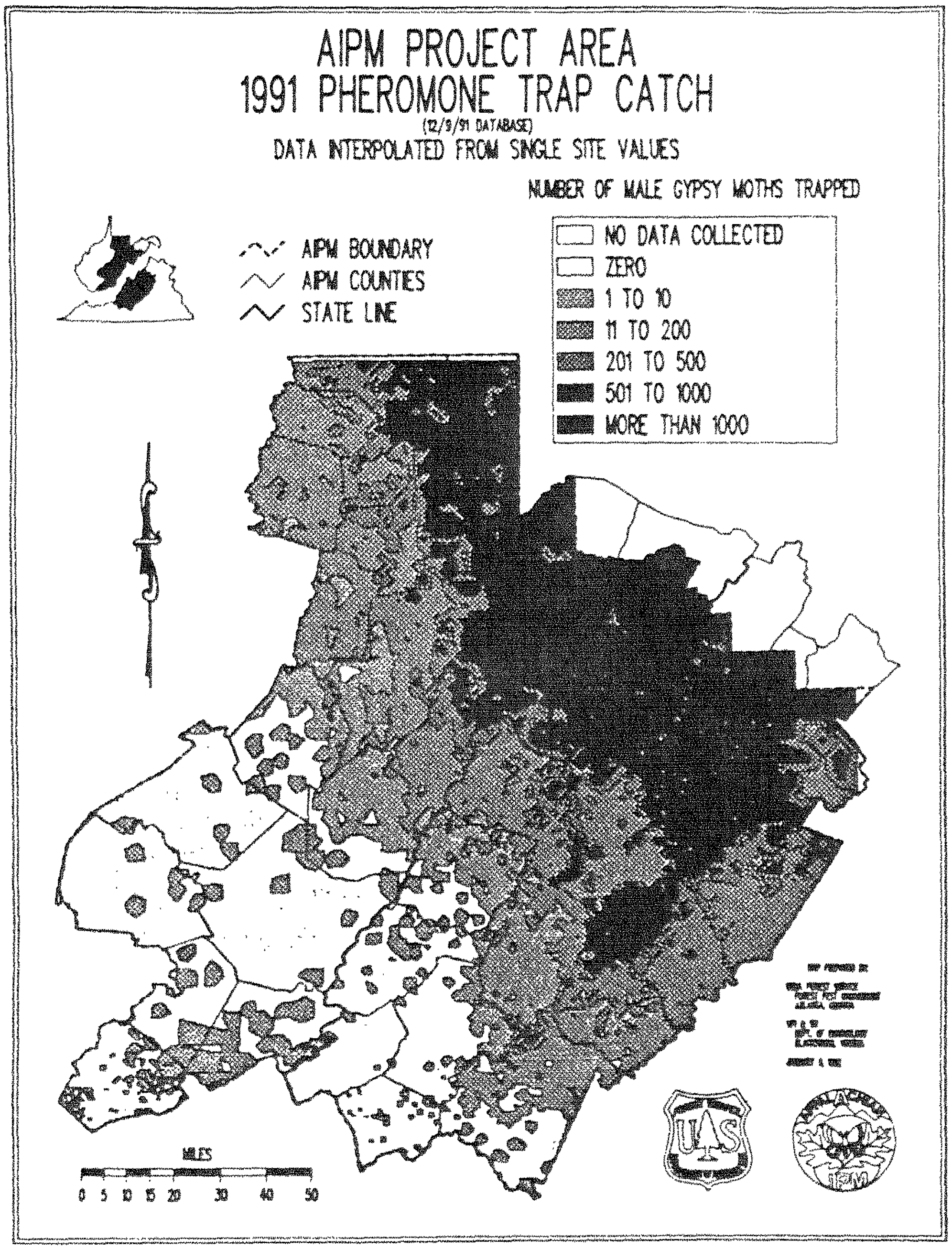

FIG. 5. Male moth catch over the entire project area. The representation is a lattice-polygon surface interpolated from a TIN of the sample data.

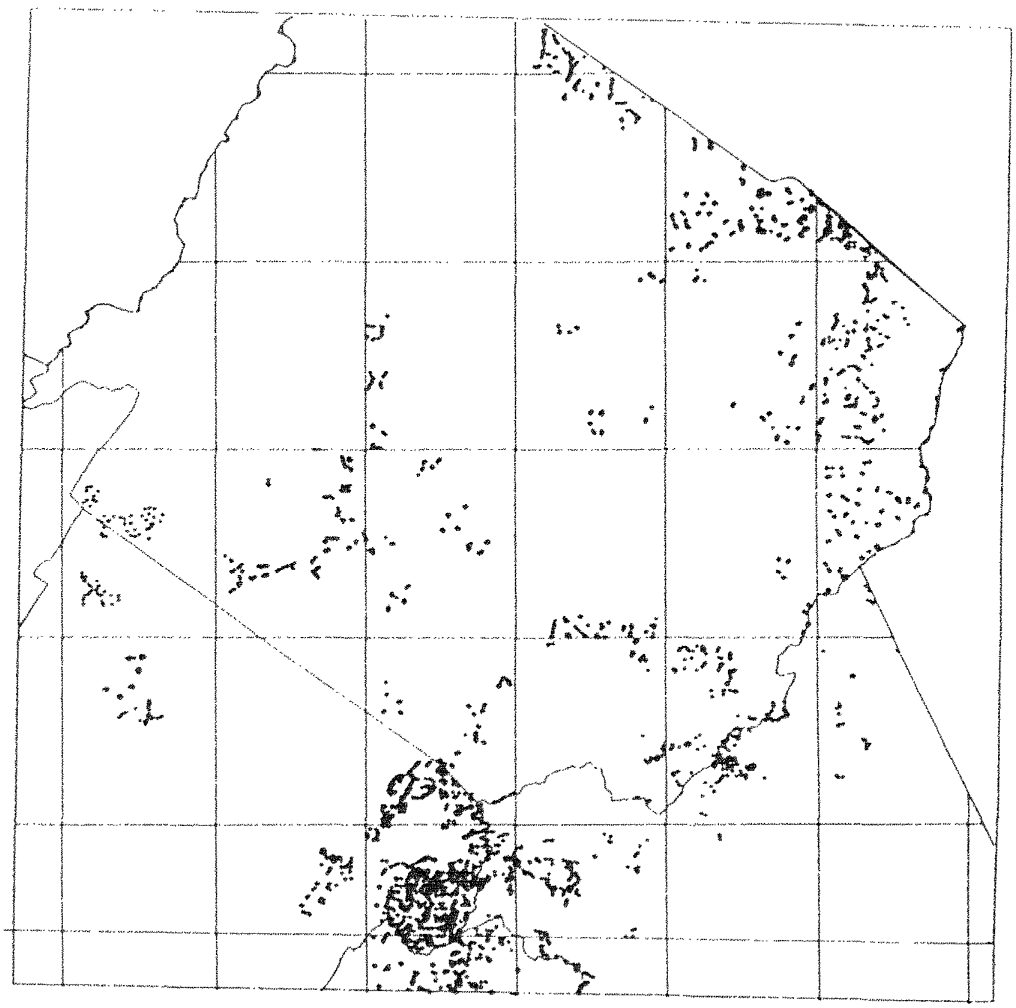

FIG. 6. Portions of Augusta, Rockbridge, and Nelson Counties in Virginia showing the clumped nature of egg mass sample sites. Data are from the 1991-92 egg mass survey.

Initial attempts at producing 1:24,000 scale maps of egg mass data analogous with the male moth maps proved frustrating. We felt uncomfortable interpolating across large unsampled areas, which occurred when interpolating from the TIN of the egg mass data. The displays of both the yearly change and egg mass sample surfaces were restricted to areas within 500 m of a sample site, but the resultant maps proved too complex to be easily interpreted. For this reason, as well as the long computation time (over 2 hours per map) and suggestions from the field, we opted for a simpler map showing only egg mass sample data and the most recent defoliation and treatment polygons. The lesson was one which anyone doing GIS will find familiar: just because you **can** do something in a GIS it doesn't mean that you necessarily **should** do it.

Unlike for the male moth survey, data base managers at VPI&SU have no means of knowing when a quadrangle is complete in terms of egg mass surveys and thus ready to map. For this reason, production of 1:24,000 egg mass maps is initiated upon the request of the field supervisor responsible for the area considered.

During the egg mass surveys, it often is necessary to provide maps to the field before the 1:24,000 scale maps are distributed. These "quick and dirty" maps depict political and USGS quadrangle boundaries, defoliation and treatment polygons, and egg mass sample values. They are produced at VPI&SU on a pen plotter and provide managers with relatively quick access to their data.

Like the display of the male moth data, the project-wide representation of egg mass data is a lattice-polygon of 500 m cells categorized into management action thresholds. The difference is that the egg mass display is restricted to only those cells which are within 1 km of a sample site (Fig. 7). This reduces risks associated with generalizing about egg mass densities in large unsampled areas.

Special Projects

The applications discussed above were components of the standard monitoring program for AIPM operations and were in place for most or all of the duration of the project. In addition to these applications, the GIS has been used to assist in development of new approaches to gypsy moth management which involve monitoring and interpretation of survey results using unorthodox methodologies. One example of this is the work which has been done in areas of low population levels. Recent trends in gypsy moth management have focused attention on slowing the spread of gypsy moth into uninfested areas. Whereas intervention activities traditionally are based upon egg mass survey results, populations in areas under management to slow the spread of gypsy moth are too low to find egg masses; thus, population estimates used in decision-making must be made solely on the basis of male moth captures. This translates into trapping in intensive grids, pinpointing locations of low trap catches (1 to 25), and scrutinizing the spatial relation among positive traps and those which caught no moths. GIS has been used extensively in guiding management activities in these areas of low moth catch. Some of the most useful applications in this area involved using the GIS to play out a series of "what-if" scenarios. By constructing theoretical treatment or monitoring areas around locations of traps within certain catch categories it was possible to estimate the resource needs for different management scenarios.

Decentralization of the GIS/DBMS

While the GIS proved to be crucial to many AIPM management activities, there were instances where it was obvious that improvements were needed in the structure of information flow. Because of the centralization of the GIS/DBMS the time lag between data capture and its availability to field supervisors was too great for some applications. Indeed, some supervisors were copying egg mass data from data forms onto their own 1:24,000 scale maps before the forms were mailed to VPI&SU for entry into the data base. Although production of 1:24,000 scale maps is streamlined as much as possible, the delay caused by mailing of paper products (data forms, maps) and computer tapes is sufficient to hinder management decisions. This is particularly true for egg mass data which must be collected and processed quickly while managers are scrambling to meet time demands in proposal of treatment blocks.

It became clear that a centralized DBMS/GIS was inefficient in attending to many needs of the managers. In an attempt to provide managers with access to survey data in a decentralized system, Young, et al. (1991) began development of a county-based map display and analysis system which is composed of an interface to PC Arc/Info. The goal is to provide managers with the tools to manipulate a variety of spatial data themes in a GIS environment oriented toward gypsy moth management. While this system, called GypMap, was initially designed as dependent upon the mainframe DBMS/GIS at VPI&SU, ongoing efforts are to make the system autonomous within a county or USFS ranger district. This has been accomplished by incorporating data input and management capabilities. GypMap is in place in Rockbridge County, VA and the Glenwood Ranger District in the Jefferson National Forest. A system for Albemarle County, VA is under development. Hopefully, this approach will supplant the need for a centralized system and expedite management decisions.

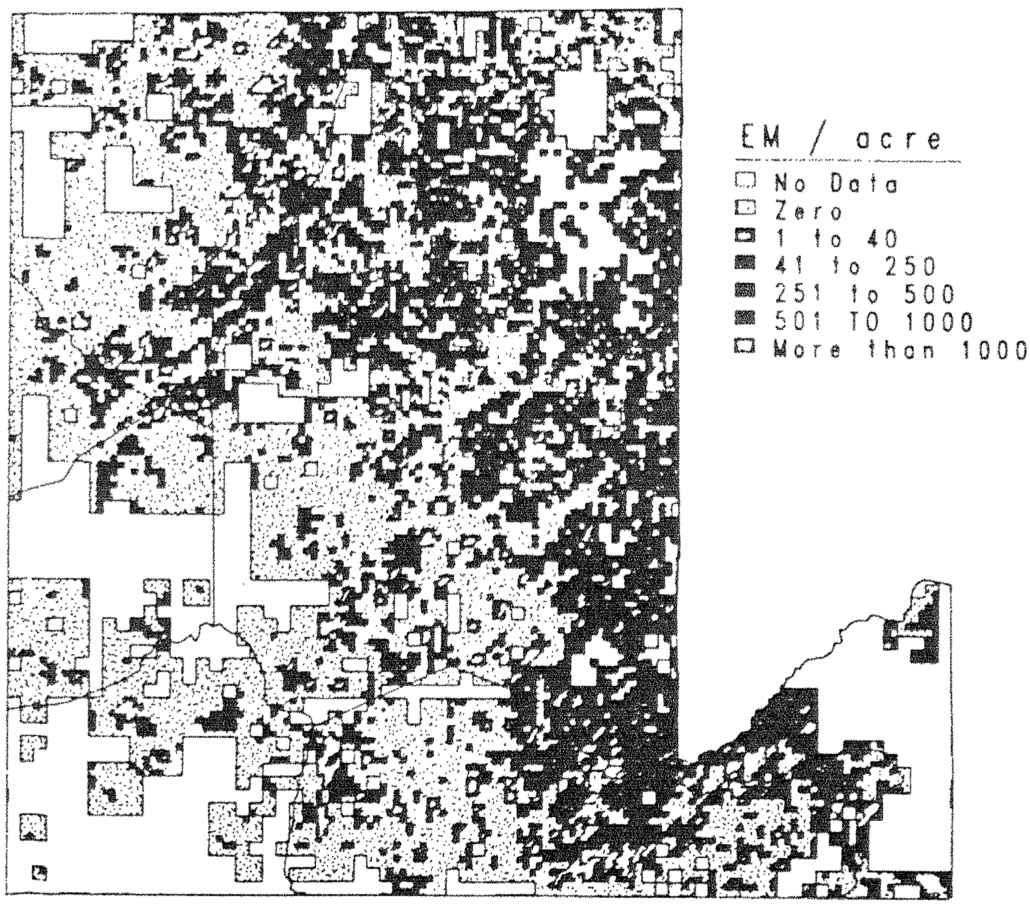

FIG. 7. A portion of the egg mass lattice-polygon surface in a several-county area of West Virginia. Cell size is 500 meters. Actual map is in color.

Conclusions

The AIPM Project has provided the opportunity to illustrate the role of GIS in a large pest management program. Although the AIPM GIS is involved in many more activities than just the monitoring program, the monitoring and survey component has developed into one of the most active uses of GIS in the project. With emphasis on simplicity and automation, the AIPM GIS has proven valuable in assisting in the management of project tasks such as personnel management which are not normally associated with GIS functions. Areas where the centralized GIS failed to meet project needs were addressed through development of a decentralized autonomous system for county-level management.

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THE NORTH AMERICAN SPRUCE BUDWORM PHEROMONE TRAPPING NETWORK

D. BARRY LYONS AND CHRIS J. SANDERS

Forestry Canada, Ontario Region, P.O. Box 490, Sault Ste. Marie, Ontario, Canada P6A 5M7

Abstract. The North American spruce budworm pheromone trapping network and its sampling protocols are described. Historical pheromone trap capture data, dating back to 1984, are used to illustrate techniques for mapping and performing simple modeling of georeferenced point data. Geostatistics are then utilized to interpolate between data points to convert capture data to contour maps with complete spatial coverage. The resultant maps can be imported into GIS software packages for spatial analysis. Suggestions for incorporating these maps into early warning and predictive models are outlined. Problems resulting from year-to-year variation in lure potency and moth migration make the development of predictive models difficult, but future research to overcome these obstacles is discussed.

INTRODUCTION

The spruce budworm, *Choristoneura fumiferana* (Clemens), is a serious defoliator of spruces (*Picea* spp.) and balsam fir (*Abies balsamea* (L.) Mill.) in northeastern North America. Literature on the spruce budworm is extensive and has been reviewed by Mattson et al. (1988) and Sanders (1991). The insect occurs over a wide geographic area and undergoes periodic outbreaks. The period between outbreaks has ranged from 17 to 100 years and has been shorter during the current century (Blais 1983). The budworm is a threat to more than 60 million ha of susceptible forest in North America and during outbreaks causes growth loss, top kill, cone and seed damage and mortality to host trees. During the last three outbreaks, this defoliator attacked 10, 25 and 55 million ha (Mattson et al. 1988). To make management decisions concerning the spruce budworm, temporal and spatial population data on the this pest must be obtained.

Collection of population data for the spruce budworm is currently very labor intensive and costly. Current survey methodologies include branch sampling for various life history stages (see reviews by Sanders 1980, Dorais and Kettela 1982). Eggs of the spruce budworm are deposited in clusters on the needles of the host plant, which makes them a useful sampling unit for population estimates. Collection of branches from the mid-crown of host trees, using pole pruners, is one method of sampling for egg masses. Branch samples are collected from a representative number of trees and are returned to the laboratory, where they are intensively examined. The budworm overwinters as a second instar in a hibernaculum on the host plant, and another sampling method to assess population densities involves the soaking of sample branches in a NaOH solution to remove these overwintering larvae (Trial 1985). These overwintering larvae are available in the field for a considerable period of time, which makes the timing of sampling less critical.

At the end of the feeding period, reddish brown needles, severed from the twigs but still attached by silken webbing, are visible from the air. In some regions, aerial defoliation surveys are conducted to detect this discoloration, but these surveys only detect populations above some threshold level at which defoliation is observable and are costly in terms of aircraft time. At this stage, outbreaks are usually well established. These surveys do, however, produce population indices that have complete spatial coverage.

The use of pheromone traps to monitor spruce budworm populations should alleviate some of these sampling problems. The traps require less resources to deploy, recover and evaluate than do more traditional sampling methods. They also provide an early warning system for incipient outbreaks. Ideally,

Pages 37-48 *in* A.M. Liebhold and H.R. Barrett, editors. 1993. Proceedings: Spatial Analysis and Forest Pest Management. USDA Forest Service General Technical Report NE-175.

the catch data could be used to predict future population levels with some degree of confidence and perhaps even future levels of defoliation or loss of wood supply. Some progress in predicting an index of defoliation level or a threshold, based on pheromone trap catch, has been made for other forest defoliators (Sartwell et al. 1985, Shepherd et al. 1985). Gage et al. (1990) had considerable success in predicting future gypsy moth populations based on pheromone trap catches, but the predictability was limited to an expanding population.

The purpose of this paper is to discuss the trapping network and protocols for spruce budworm, software tools for analyzing spatial patterns in the data, a preliminary analysis of the data, problems and future directions. Preliminary objectives are to develop techniques for constructing contour maps of the trapping data. Longer term objectives are to overlay successive years of data and detect changes, to overlay trap catch data on weather and forest type and to optimize trap distribution. From these analyses we intend to develop an early warning and predictive system for outbreaks and defoliation. This report describes the use of geostatistical techniques in spruce budworm research and their utility for converting data to a form suitable for geographical information system (GIS) analysis. The results are preliminary and are discussed for illustrative purposes.

Pheromone Trapping Network

Mating of the spruce budworm occurs shortly after the moths eclose from pupae in late June to late July. Females of the spruce budworm produce a potent sex pheromone, which has proven to have multiple components (Silk et al. 1980). A synthetic pheromone lure, when combined with an efficient trap design (Sanders 1986), results in a low-cost, efficient system for monitoring populations of male spruce budworm moths.

Trapping System and Protocols

The network employs high-capacity non-saturating Multi-Pher® traps (Jobin 1985). The trap consists of a funnel leading into a collecting chamber with a lid covering the funnel. Initially, the pheromone was incorporated into a polyvinyl-chloride (PVC) lure, but after 1989 Biolures® (Consep Membrane Inc., Bend, OR) were used in the program. The lure is pinned to the lid of the trap and a strip of dichlorvos killing agent is placed in the chamber. At each trapping location, three traps are deployed 2 m above the ground and about 0.5 m from foliage (Allen et al. 1986). The three traps are placed in a triangle with about 40 m between traps and each trap is placed at least 40 m from the edge of an opening in the forest. The correlation among catches in the three traps at each location, as indicated by the Ontario data for 1984, 1986, 1987, 1988, 1989 and 1990, is very high (Table 1). Data from 1985 were not used in the analysis because of problems with the killing agents in the traps. The use of three traps at each location guarantees a sample in the event that individual traps are damaged or lost. Samples collected at a given location are therefore the average of three or fewer traps. Traps are deployed from the beginning of pupation in June throughout the 3- to 4-week flight period of the moth.

TABLE 1. Correlation coefficients for spruce budworm moth captures from the sets of three pheromone traps at the same locations in Ontario.

	Trap 2	Trap 3
Trap 1	0.92 (n = 479)	0.878 (n = 447)
Trap 2	-	0.879 (n = 447)

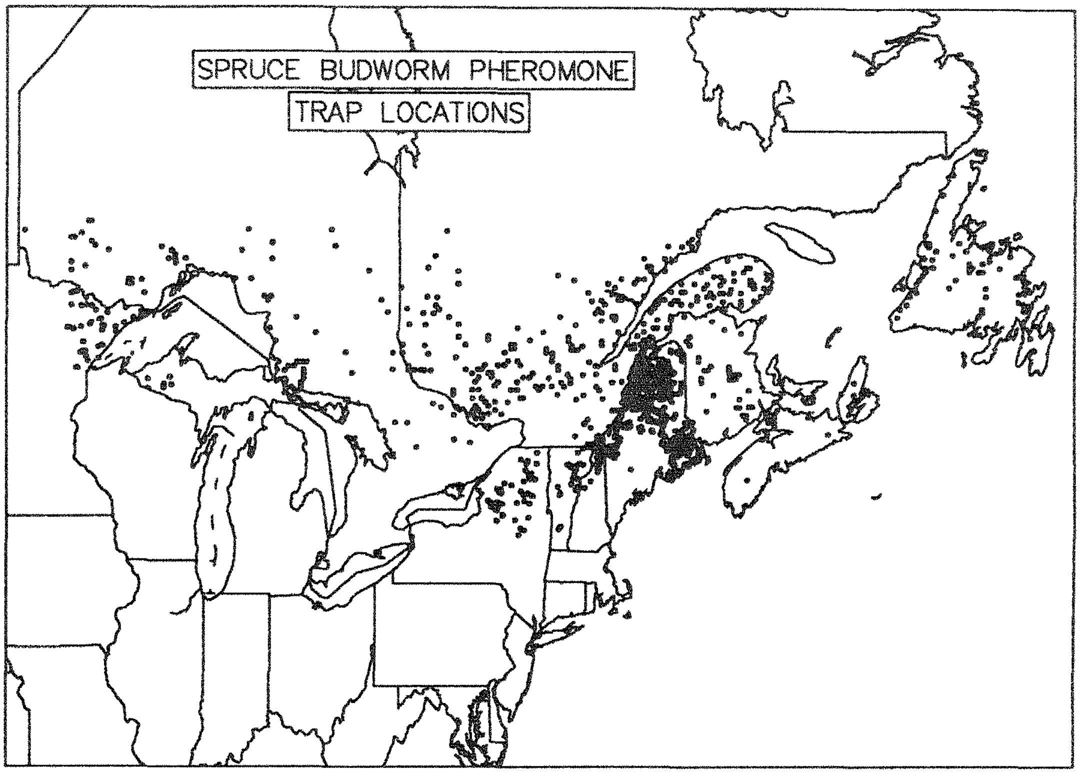

FIG. 1. Spruce budworm pheromone trapping locations in northeastern North America from 1984 to 1990.

HISTORICAL DATA

Figure 1 shows the distribution of trap locations in northeastern North America from 1984 to 1990. A few traps are also deployed in the three Canadian prairie provinces. Not all trap locations are sampled every year; the number of locations (Table 2) has varied considerably over the course of the project, depending in part on available resources. Staff of the Forest Insect and Disease Survey (FIDS) of Forestry Canada deploy and collect traps in the Maritimes, Newfoundland, Ontario and Northern Regions, while Forestry Canada researchers also place traps in Ontario and New Brunswick. In the Maritimes, these have been supplemented by traps deployed by the Nova Scotia Department of Lands and Forests and the New Brunswick Department of Natural Resources and Energy. In Quebec, trapping is carried out by the Ministère de l'Énergie et des Ressources. In the United States, traps are deployed by the states of Maine, Michigan, Minnesota, New Hampshire, New York and Vermont under the coordination of the USDA Forest Service. Private companies (J. D. Irving Ltd. and International Paper Co.) have also cooperated in trap placement. Table 2 shows the years for which data are available. The locations of the traps are stored as Universal Transverse Mercator (UTM) projection coordinates consisting of a zone number, a two-digit easting and a three-digit northing. Thus, the UTM coordinates denote the southwestern corner of a 10-km by 10-km grid square in a specific zone that contains the trap. By appending the digit "five" to the end of each coordinate, the reference point becomes the center of the square.

At some locations, associated population data are collected. Defoliation estimates are made in the Maritimes and Ontario regions; egg samples are collected in the Northern and Ontario regions; overwintering second instars (L2) are collected in the Maritimes, Newfoundland, Ontario and Quebec regions; and older larvae (L3-L4) are collected in the Maritimes, Newfoundland and Ontario regions. These associated data allow for comparisons to be made between trap catches and other estimates and indices of population density.

TABLE 2. The number of spruce budworm pheromone traps deployed in each region from 1984 to 1991.

Region	Year							
	1984	1985	1986	1987	1988	1989	1990	1991
Maritimes	0	40	39	39	34	13	23	21
Newfoundland	0	15	40	47	50	50	49	50
Northern	0	0	0	31	31	0	13	0
Ontario	25	30	51	78	75	55	74	85
Quebec	0	166	317	287	264	270	250	272
United States	0	242	300	369	427	248	121	92

SPATIAL ANALYSIS

Spruce budworm population data can be classified into two types: maps derived from aerial surveys, which represent complete spatial coverage, or point data from samples collected from a fixed location in space. Pheromone trap data, like branch sampling data, are represented by points in space.

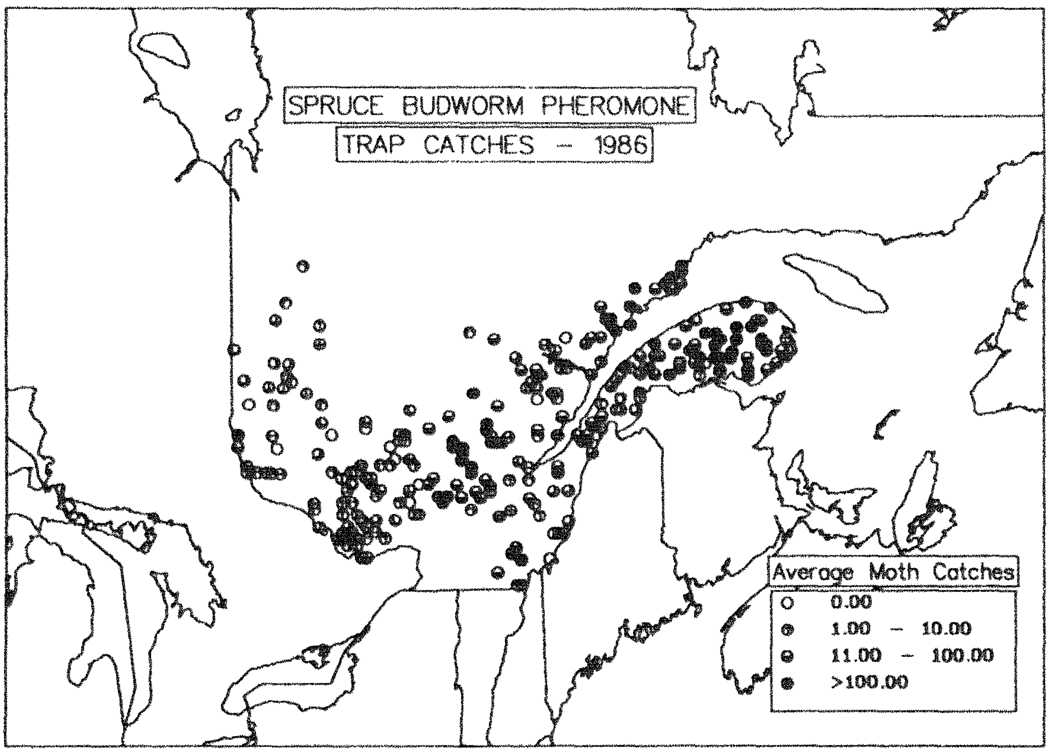

FIG. 2. Pheromone trap captures of male spruce budworm moths for Quebec in 1986, in four categories based on the number of moths caught.

The map in Figure 1 is an example of point data mapped using a software package called inFOcus® (Earth & Ocean Research Limited, Dartmouth, Nova Scotia). This is a simple GIS package that integrates QUIKMap® (Axys Software Ltd., Sidney, British Columbia) mapping software and FoxPro® (Fox Software Inc., Perrysburg, Ohio) relational database management software. In this example, the points are georeferenced (i.e., have map coordinates) but do not have attributes associated with the points. UTM coordinates for the original data were transformed to latitudes and longitudes using SPANS® (Intera Tydac, Ottawa, Ontario) software for use in inFOcus. However, not only are the map coordinates for the trap stored in the database, but also the number of male moths that were captured at that location each year. The database can thus be queried and the attributes (i.e., moth numbers) incorporated in the map. The attributes can be categorized with different symbols to indicate their magnitudes. Figure 2 shows the spruce budworm pheromone trap locations in Quebec in 1986 with the capture category indicated by different symbol types.

TABLE 3. Simple expert model for predicting the number (N) of spruce budworm moths captured in the current year (t) from captures in the two previous years (t-1 and t-2).

	$N_{(t-1)}$		
$N_{(t-2)}$	None	Low	High*
None	None	Low	Low
Low	None	Low	High
High	None	Low	Low

* High means > 100 moths

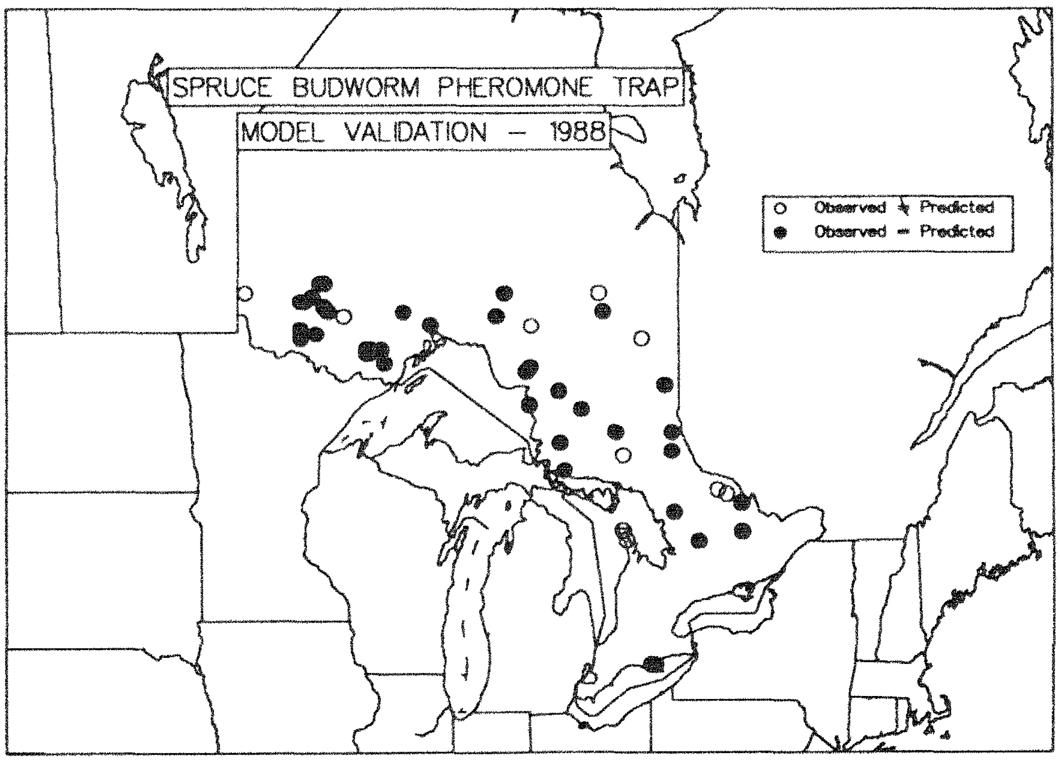

FIG. 3. Locations of correct and incorrect predictions of spruce budworm moth captures in Ontario in 1988 based on a simple expert model using moth captures in the two previous years as input.

Not only is this software useful for illustrative purposes and the visual detection of spatial patterns, but we can also do some simple modeling with point data. Table 3 indicates a simple expert model that predicts moth captures in the current year based on trap catches in the two previous years. For example, the model predicts low moth captures (i.e., < 100 moths) if moth captures were low in the two previous years. This is an intuitive model based on pheromone trapping experience. The inFOcus software can be used to generate predicted moth captures at each location and then to compare the predicted moth captures with actual moth captures at the same location. Figure 3 shows the distribution of correct and incorrect predictions of the model for Ontario in 1988. As indicated by the preponderance of black dots (i.e., correct predictions), the model predicted future moth captures fairly accurately. This simple model, however, probably behaves differently for increasing and declining populations. The representation of the data in the form of a map allows us to visualize areas in which the simple model performed well. If incorrect predictions were concentrated in a particular area, then failure of the model might have resulted from a spatial event such as an unusual weather pattern or moth migration. In the example provided (Fig. 3), however, the incorrect predictions are distributed evenly across the map.

The problem with point mapping is that the data represent points in space and we have no idea about what is happening in areas not represented by the data. To take full advantage of the analytical capabilities of GIS software, the data must provide complete spatial coverage. What we need is a means to interpolate between points, in a meaningful way, so that we have complete spatial coverage. Geostatistics provides us with the appropriate tools and GS+ (Gamma Design Software, Plainwell, Michigan) is an appropriate software package to perform geostatistical analysis of point data. The characterization of the spatial dependence for other insects using geostatistics has been effectively demonstrated (Kemp et al. 1989, Schotzko and O'Keeffe 1989, Liebhold et al. 1991).

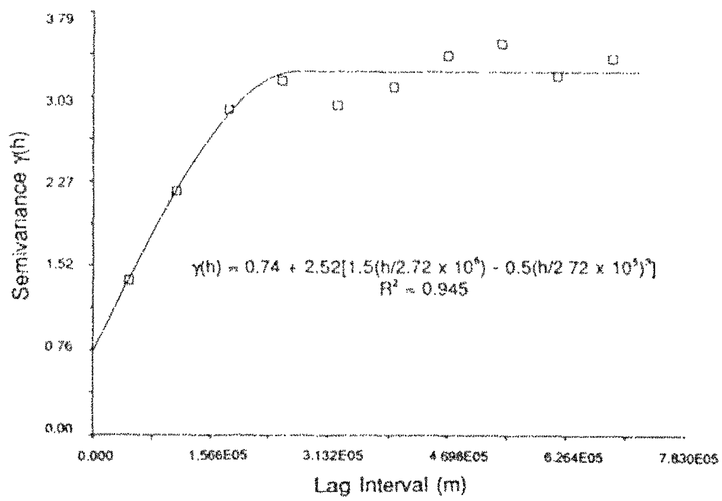

FIG. 4. Spherical semivariogram model for spruce budworm moth captures in Quebec in 1986.

The point interpolation routine used by GS+ is known as "ordinary kriging". Latitudes and longitudes for the Quebec data set were converted to x and y coordinates in metres, with 71.18°W and 47.34°N as the true origin, using an equidistant cylindrical projection in SPANS. The first step in the interpolation process is the construction of an autocorrelation model or semivariogram. The moth capture data for 1986 were transformed using $\ln(z + 1)$ to normalize the skewed distribution. Prior to mapping, the estimates were backtransformed using Haan's method (Gamma Design Software 1992). The semivariogram is essentially a plot of the variance between neighboring cells as a function of the distance between points. The software allows for the construction of either an omnidirectional (i.e., isotropic) or a unidirectional (i.e., anisotropic) semivariogram. Five different functions can be fitted to the scatter plot of lag distances using least-squares regression. The active lag used in the calculations was half the maximum lag, and the active step was one tenth the active lag (Liebhold et al. 1991). The isotropic semivariogram model for the pheromone trap data for Quebec in 1986 is shown in Figure 4. The curve is a spherical model, $\gamma(h) = C_0 + C[1.5(h/A_0) - 0.5(h/A_0)^3]$ where γ is the semivariance for distance h. C_0 is the "nugget" variance where the curve intersects the vertical axis and represents the variance attributable to local discontinuity

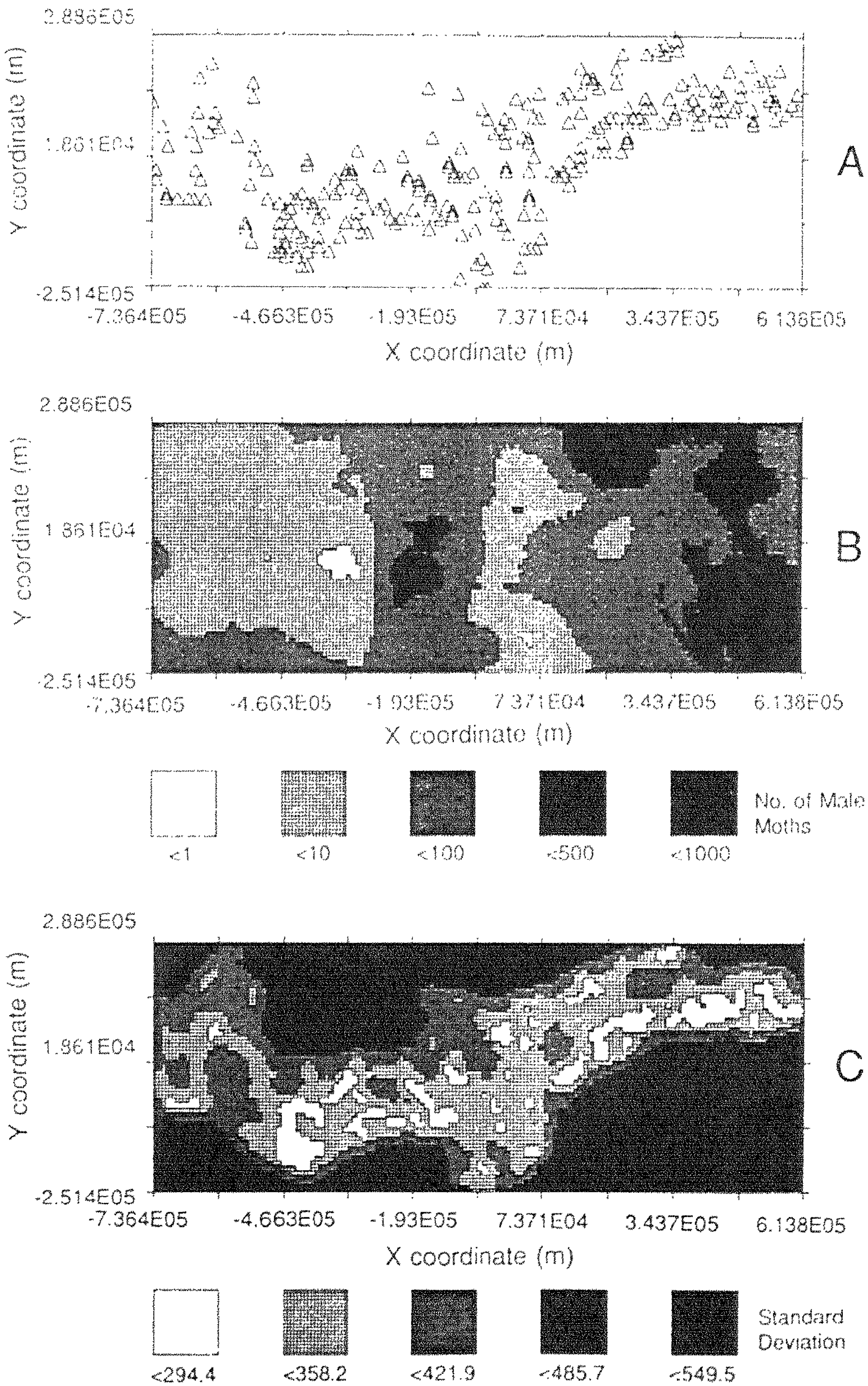

FIG. 5. Sample posting of spruce budworm pheromone trap locations (A); contour map of spruce budworm pheromone trap captures (B); and contour map of estimated standard deviations for spruce budworm pheromone trap data (C) in Quebec in 1986 using GS+ software.

or sampling error. The "sill" is where the semivariance reaches a plateau and is equal to the sum of C, the structural variance, and C_0. A_0 is the range of spatial dependence and its upper limit is where the curve reaches the sill. For the Quebec data, $C_0 = 0.74$, $C = 2.52$ and $A_0 = 2.72 \times 10^5$ m or 272 km ($R^2 = 0.945$). Once a semivariogram model has been calculated, the next step in the process of producing an isopleth of moth captures is interpolating between the point data using kriging. Kriging utilizes the weights determined from the semivariogram and the locations of the data points. Figure 5A is a sample posting of the point locations for traps, and Figure 5B illustrates the contour map of interpolated pheromone trap catches in the province of Quebec for 1986. GS+ also produces a contour map of estimated standard deviations (Fig. 5C). The distribution of sample points (Fig. 5A) reflects the distribution of the landmass of southern Quebec and the limit of the provincial border. The area in the southeast of the map is ocean and the southwestern part of the map is in the United States. The northern limit of the traps represents the limit of economically important budworm distribution. The smaller standard deviations (Fig. 5C) clearly delineate the outer limit of the sampling points.

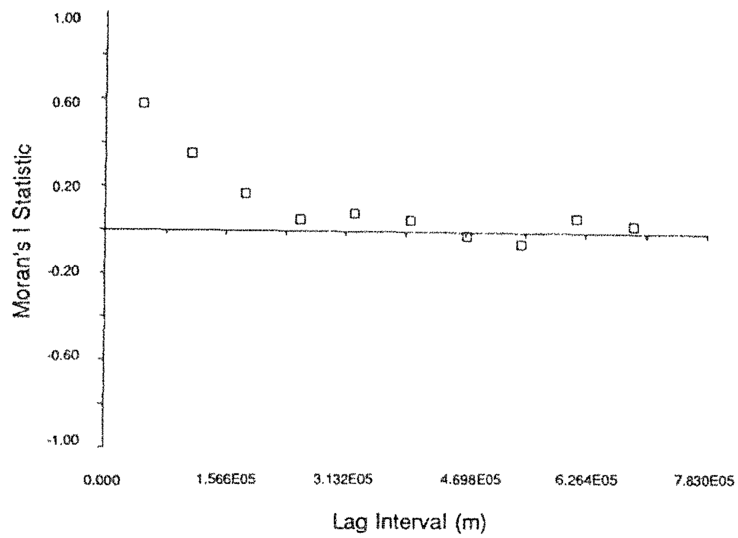

FIG. 6. Autocorrelogram of spruce budworm pheromone trap data for Quebec in 1986 using Moran's I statistic.

There are other methods for examining the spatial dependence of insect distributional data. Autocorrelations using Moran's I statistic is another technique provided in GS+ (Fig. 6). Parameters gleaned from autocorrelation analysis can also be utilized in a SPANS interpolation routine known as potmapping. These techniques have been used to evaluate grasshopper distributions in Alberta (Johnson and Worobec 1988).

Once contour maps of moth captures have been created they can be imported into GIS software packages. Areas that do not provide suitable habitat, such as bodies of water, can be stamped out of the maps. More complex GIS analysis, such as overlays, boolean algebra operations and modeling using maps as variates, are being undertaken using SPANS and IDRISI® (Clark University, Worcester, Massachusetts).

Table 4 shows a model of the empirical probabilities of defoliation derived from the Ontario data. Defoliation levels greater than 30% resulting from spruce budworm feeding are classified as equivalent to moderate-to-severe defoliation observed during an aerial survey. Contoured isopleths of moth catches can be converted to contours of defoliation probabilities using Table 4. Using SPANS, predicted maps can then be validated using digitized defoliation maps produced by FIDS from aerial sketch maps.

TABLE 4. The proportion of sites that will have defoliation levels greater than 30% in the current year for each category of trap capture of moths (N) in the previous two years (t-1 and t-2).

	$N_{(t-1)}$			
$N_{(t-2)}$	0	1 - 10	11 - 100	> 100
0	0.00 (n = 16)	0.00 (n = 23)	0.00 (n = 2)	- (n = 0)
1 - 10	0.00 (n = 18)	0.02 (n = 63)	0.05 (n = 20)	1.00 (n = 3)
11 - 100	0.00 (n = 8)	0.00 (n = 24)	0.30 (n = 27)	0.50 (n = 16)
> 100	0.00 (n = 1)	0.17 (n = 6)	0.45 (n = 31)	0.24 (n = 21)

PROBLEMS AND FUTURE DIRECTIONS

GIS and geostatistics allow us to visualize, manipulate and analyze spruce budworm pheromone trap catches in a spatial context. We have demonstrated the use of geostatistics to make meaningful contour maps of pheromone trap catches of male spruce budworm moths. One objective of the network is to provide an early warning for spruce budworm outbreaks based on trap catches. There is good evidence that this approach will be fruitful (Sanders 1988) and that we can do it spatially. However, an additional goal of the network is to predict future population levels or damage levels from the number of moths captured in traps in previous years. If we can develop predictive models of future population events, we can place these predictions in a spatial context using the techniques outlined. However, the relationships between moth capture and future events are not simple. Figure 7 shows the percent defoliation for sites in Ontario as a function of the logarithm of the number of male moths captured in pheromone traps in the previous year at the same location. The scatter of points suggests a weak relationship. When a Weibull function of the form $Y = 100(1-e^{-(X/A)^{**}B})$ was fitted to the observed points using nonlinear regression analysis, the regression only explained approximately 34% of the variability. However, if we insert a vertical line at the point where we start to get defoliation above 30%, the result is a threshold for the number of moths that are sometimes associated with moderate-to-severe defoliation. This sort of threshold approach has worked for the Douglas-fir tussock moth, *Orgyia pseudotsuga* (McDunnough) (Shepherd et al. 1985).

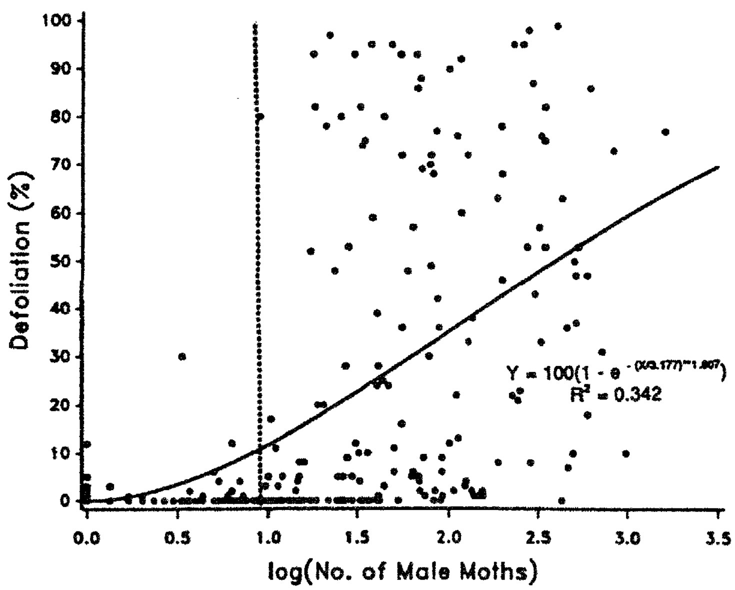

FIG. 7. Percentage defoliation as a function of log-transformed pheromone trap captures in the previous year. Dashed line indicates a threshold number of male moths greater than which is sometimes associated with moderate-to-severe defoliation (> 30%).

As previously stated, the utility of the network lies in its predictive ability. However, experiments conducted by one of us (CJS) indicate that there is considerable year-to-year variation in lure potency. Comparison of trap catches for 1989 and 1990 lures in 1990 at 12 locations indicated no significant difference ($R^2 = 0.948$, slope = 0.861) using linear regression analysis (Fig. 8). However, comparisons of 1989, 1990 and 1991 lures in 1991 caused some serious concerns. Significant and large differences among potency of lures was detected between the 1991 lures and those from the other two years (Table 5). Although we are not going to speculate on the cause of these differences here, the implication of this problem for a system that depends on year-to-year comparisons is catastrophic. Solutions to this problem currently being incorporated in the network include a bulk purchase of pheromone to help eliminate quality differences and continuous year-to-year comparisons of bait potency.

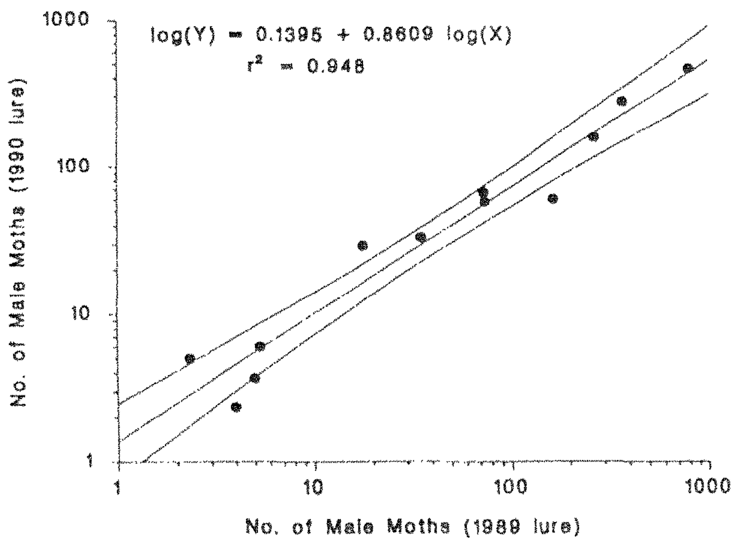

FIG. 8. Relationship between the numbers of male spruce budworm moths captured in pheromone traps using 1989 lures and 1990 lures in 1990. The lines are the linear regression and its 95% confidence limits.

TABLE 5. Mean number of spruce budworm moths captured in 1991 in traps (n=5) baited with lures from 1989, 1990 and 1991, and from unbaited traps at Black Sturgeon Lake, Ontario.

Lure	Mean number (SD) of moths
1989	57.0b (14.1)
1990	43.2b (13.6)
1991	289.8a (87.4)
Unbaited	15.0c (6.0)

Means followed by the same letter are not significantly different (Tukey's studentized range test; $P > 0.05$).

Moths often emigrate from heavily defoliated stands but probably do not disperse from sparsely or moderately defoliated stands. Distances traveled can be up to 600 km between origins and landing locations (Greenbank et al. 1980). Mass flights might initiate outbreaks in areas without previous high moth captures. Mass migrations of moths make correlations with other population indices difficult. Perhaps these observations can be assimilated into predictive models.

We would also like to know the level of trap density that provides us with the optimum amount of information to analyze trap catches spatially. Various grid sizes are being compared to address this question. These and other questions will direct future research.

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COOPERS ROCK DEMOSTRATION PROJECT
A DECISION SUPPORT SYSTEM FOR GYPSY MOTH MANAGERS

JAY HUTCHISON
Dept. of Geology and Geography, West Virginia University, Morgantown, WV 26507

SUSAN DELOST
USDA Forest Service, State and Private Forestry, Appalachian Integrated Pest Management Project, Morgantown, WV 26505

ABSTRACT. Gyspy moth managers are required to assess many factors when making the time-critical decisions about gypsy moth treatments. The Cooper's Rock Project was designed to demonstrate the capability of a GIS to automate some of the decision processes used by a gypsy moth manager. ARC/INFO GIS software and the ARC macro language were used to automate the decision protocols and generate suggestions for treatment type, location, and extent. A prototype of a graphical user interface was developed as part of the project.

INTRODUCTION

Geographic Information Systems are quickly becoming the technology by which spatial data is stored and manipulated and landscape decisions are made. In the management of forest pests such as the gypsy moth, treatment decisions are made considering the following spatial data: land cover (forest type); land use; management objectives; pest population densities; previous year's defoliation; previous years' treatments; topography (slope, aspect and elevation); infrastructure (roads, airports, etc.) and other information as applies to each unique situation. For example, surficial geology or soils information may be needed. The areas which are involved in such landscape scale management and analysis can be immense, easily covering hundreds if not thousands of 1:24,000 scale, 7.5-minute U.S. Geological Survey (USGS) topographic quadrangles, the traditional media for storing and analyzing this type of information. A GIS can efficiently store this information so that it is easily referenced and accessible, minimizing the time and frustration of sorting through thousands of maps and file folders. A GIS can be used to expand the types and depth of analysis that can be done by using only the traditional methods and materials such as hard copy maps and transparent overlays.

OBJECTIVES

In the first stage of the diffusion and acceptance of GIS technology, the GIS at first is often primarily used for storing map data and making customized maps. Only after the users are comfortable with the computer map environment and good spatial data in digital format is secured, do they use the analysis tools of the GIS. The Coopers Rock Project was designed to demonstrate how a GIS could be used in a gypsy moth management program to manage spatial information and to display the related data themes in a user-friendly environment. By using the GIS analysis tools, the land manager responsible for managing the gypsy moth infestations in his/her area would be able to access and use all available information in making the critical decisions concerning treatments to be used against the gypsy moth pest. The data needs for specific decision tasks and their analysis components in the GIS environment were formalized. Preliminary work to determine how a graphical user interface (GUI) could be implemented and used by the land manager was done. The use of a GUI would allow the land manager to concentrate on the decisions at hand, rather than learning the intricacies of the particular GIS software

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(Note: at the inception of this project, the GIS software used was still in the "toolbox" stage, requiring the user to be familiar with the hundreds of individual commands and their interrelationships in order to perform even the most basic functions). By using the graphical user interface menuing system, the land manager can concentrate on the decisions that need to be made concerning gypsy moth treatment alternatives.

STUDY AREA

The study area for this project encompasses the Lake Lynn, West Virginia 7.5-minute topographic quadrangle and parts of four adjacent quadrangles. This area was chosen for a number of factors. A primary factor in the site selection were the locations of two managed forests in this area, the Coopers Rock State Forest and the adjacent West Virginia University Research Forest. An assumption was made that the land managers on these two forests would have good land use and forest cover information, which is often difficult to obtain. This area also gives a good representation of various management objectives and mitigating factors, from the existence of a threatened and endangered species in the area, the presence of recreation areas, open water and forested residential neighborhoods to public forests and private woodlots. Finally, the area has a broad variation in gypsy moth population densities, from fairly low levels to highly defoliating populations.

METHODOLOGY

The GIS software used in this project was ARC/INFO, developed by the Environmental Systems Research Institute of Redlands, California. The computer platform used was a Digital Equipment Corporation VAX minicomputer. The basic decision guidelines, which were formalized within the framework of the GIS, were those used by the project sponsor, the Appalachian Integrated Pest Management Project (Table 1, AIPM 1991). These protocols provide alternatives for intervention activities for differing management objectives. In the AIPM project area, a zone concept was initiated, which helped define possible alternatives based on the extent (from generally infested to isolated occurrences) of gypsy moth infestation within a delineated zone. The proposed treatment alternative is the manager's decision, after taking certain factors into consideration. One such factor is the federal Environmental Protection Agency's (EPA) restrictions for use of certain pesticides. As an example, the pesticide Dimilin can not be used near open water. This consideration forces the gypsy moth manager to consider alternative treatments, including the option of no treatment. Other factors must be considered by the manager in proposing the type, if any, of treatment, including landowner's concerns, special use of the land in question, and the presence of a threatened and endangered species.

By using the AIPM protocols as a guide and interviewing the AIPM Project Manager for clarification and refinement, the needed data layers were determined (Data Layers, Table 2 at end of paper). Because forest composition data is needed in most hazard rating models, the Coopers Rock area was chosen, assuming that this data was available. However, this was not the case, except in specific research plots, where the best classification available was the delineation of oak/hickory, yellow poplar and a few pine and hemlock stands. These data were supplemented outside of the West Virginia University and Coopers Rock State Forest by updating the forest and non-forest areas as shown on the topographic quadrangles with 1988-era NAPP (National Aerial Photography Program) infrared photography. This made up the forest cover layer. An egg mass density surface layer was created using the Fall 1990 egg mass survey data collected by the AIPM project. This data was interpolated using the Triangulated Irregular Network (TIN) function contained in the ARC/INFO GIS software. The surface was then classified into ranges corresponding to the AIPM protocol thresholds. Because of limitations of some of the treatments around water, open water areas and open canopy streams were buffered to 500 feet to limit the types of treatment around them. To obtain the management layer, areas were classified into forest production, forest research areas, recreation areas, scenic areas, and residential. Because the threatened and endangered species areas overlap many of these management areas, it was developed as a separate layer. A layer of elevation ranges was also produced to represent differing phenology but has not been used to date.

Using the vector GIS model implemented in ARC/INFO, all layers were combined using the UNION operation (Figure 1, Burroughs 1986). This produced what we chose to call minimum separable units, the smallest unit of area which has discrete values associated with it and which would be used in further processing. Each of these polygons (unit areas) has discrete values associated with it, corresponding to values associated with each input data layer.

The many sub-decisions about treatment possibilities were encoded in a macro of more than 1000 lines which takes into account the various thresholds for treatment, management objectives and restrictions. Some decisions were chosen just as a manager might choose some preferred treatments. A choice was made to limit treatment in the threatened and endangered species areas (Triodopsis platysayoides - snail) to either Gypchek or no treatment. After the model was tuned, it was run and a map of suggested treatment alternatives was produced. This was then compared to the manual decisions made by the gypsy moth manager.

TABLE 1. Decision protocols for use of intervention activities within the AIPM Project Area in 1991.

If management Objective is:	Egg Mass/Acre	Intervention Available
Zone I (Generally Infested Portion of Project Area) Minimize damage (defoliation impacts, tree mortality)		
Timber or mast production areas, uninhabited woodlots	Greater than 1,000	No action, Bt (1 or 2 appl.), Dimilin, Gypchek
Forested residential communities	Greater than 500	No action, Bt (1 or 2 appl.), Dimilin, Gypchek
High use areas (e.g. recreation areas, parks, along scenic highways/streets)	Greater than 250	No action, Bt (1 or 2 appl.), Dimilin, Gypchek
Protect special values (e.g. trout streams, historic sites)	Greater than 250	No action, Bt (1 or 2 appl.), Dimilin, Gypchek
Zones II and III (Transition Portion of Project Area)		
Minimize population buildup	Greater than 250	No action, Bt (1 or 2 appl.), Dimilin, Gypchek
Minimize natural/artificial spread from high use areas, urban/suburban, etc. and protect special values	Greater than or equal to 50	No action, Bt (1 or 2 appl.), Dimilin, Gypchek
	Less than 10	Low level (pheromone flakes, inherited sterility, mass trap)
Zone IV (Isolated Portion of Project Area)		
Minimize natural/artificial spread from all areas: intensive detection		No action, Bt (2 appl.), Dimilin, Gypchek, Low leve (pheromone flakes, inherited sterility, mass trap)

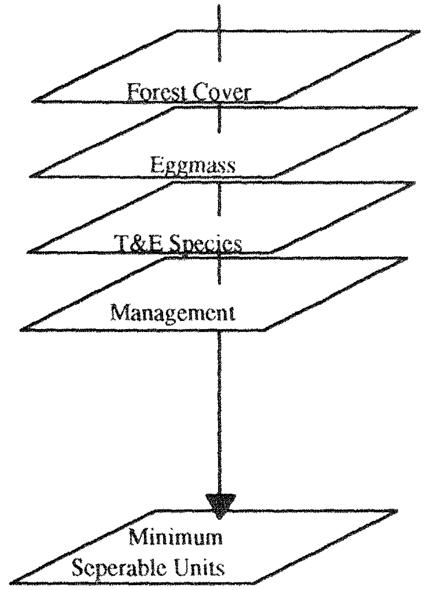

FIG. 1 The union operation

RESULTS

The areas suggested for treatment by the GIS and those of the gypsy moth managers corresponded very well. One area of disagreement was in the area near the research plots on the University Forest: in leaving a buffer around the forest research plots, the GIS used a discrete distance from the edge of the research plots as a delimiter, but in the decision made by the gypsy moth manager, subjective reasoning was used ("better not treat there, it looks too close to the research plots"). Another area of disagreement occurred where a single high count of egg masses forced the egg mass surface, produced by GIS operations, to skew the area into the high egg mass density range, indicating that a treatment was needed. The gypsy moth manager decided that the count was an anomaly (either wrong count or superficially high count on one tree) and decided against treatment. The exact boundaries of the suggested treatment areas differed frequently as the GIS is not predisposed to draw neat boxes or straight lines, however logistically for the type of treatment aircraft used by the state of West Virginia (DC-3), boxy areas are operationally more efficient.

For most of the forested areas of this part of the country there is minimal information on forest cover, so the model was run again using only a forest/non- forest delineation for the forest cover. The outcome of this operation added areas for treatment, but actually surprisingly little additional acreage compared to the originally suggested areas. The most common result was that suggested treatment areas increased in size and shapes became even less boxy and more nebulous.

Operationally, the vector model, used by the ARC/INFO GIS software, may not be the ideal method when faced with this type or other resource analysis type decisions which tend to incorporate many layers of information. In the vector model, the processes of unioning or intersecting these many layers to form the minimum separable units creates many very small polygons. These polygons may be spurious or may be smaller than the area of accuracy associated with the data. And, with each additional layer that is intersected, the number of small polygons increases exponentially. Ignoring the question of the value of the information in these small areas, the operational overhead occurring within the computer may slow the analysis to the point where manual analysis may be a better alternative. Therefore, in gypsy moth management as well as other resource analysis decisions, the raster model may be the more appropriate GIS approach. In the raster mode, the number of cells used to describe a particular phenomena are the same after a GIS operation as before the operation is performed. The number of cells making up the phenomena would be determined in advance by the manager as he/she deemed appropriate for the scale of that phenomena.

USER INTERFACE

One of the original ideas for the Coopers Rock project was to provide a "user-friendly" graphical user interface which would allow the gypsy moth manager to add or delete layers for the analysis and to change classification schemes, treatments and treatment thresholds without the need to learn the inner workings of a particular GIS. A rough conceptual prototype was programmed. However, during the course of this project, the need for this type of interface all across the GIS user community became glaringly apparent and the commercial suppliers of GIS software have now devoted vast amounts of resources to address this issue. By the time our prototype was operational, ESRI unveiled its Arcview product, which could, in the near future, become the core for a graphical user interface for gypsy moth and other resource managers. Further investigation of the Arcview product, which can be run on a high-powered microcomputer, is warranted.

CONCLUSIONS

It is clear that GIS technology can perform in more than a mapping capacity for the gypsy moth and resource manager. The analysis procedures used in this project are straight forward and follow closely those steps which a manager would normally use to make these types of decisions. The GIS is a more efficient means of storing map information, decreasing the chance that important information about an area is overlooked. The GIS is also a valuable tool, as relationships among data layers can be readily shown and incorporated as part of a decision matrix. The use of GIS points out where deficiencies in data occur, both in making it blatantly clear what is not available and what may be of poor quality or inappropriate. In this sense, the forest manager may be more comfortable doing business as usual. As the user interfaces to GIS software are more fully developed, become more user friendly and are adapted to specific purposes such as gypsy moth management, resource managers will have more opportunities to use a GIS to assist them in their decision-making.

TABLE 2. Coopers Rock Project Data Layers. **Bold Lettering** indicates layers which were unioned to make the minimum separable units layer. Underlining indicates layers used only as cartographic reference.

Layer	Description	Possible Values	Source
Forest Cover	Gross cover type aggregated from various sources	OH: Oak/Hickory, YP: Yellow Poplar H: Hemlock, P: Pine, F: Forested	Combined from WVU cover, Coopers Rock cover and Forested
WVU Cover	Cover type for the WVU experimental forest	Percent composition, Predominant species or no data	WVU Forestry via the GYPSES project
Coopers Rock Cover	Predominate species by stand	OH: Oak/Hickory, YP: Yellow Poplar or no data	West Virginia Forestry
Forested	Forested and non forest classification	F: Forested, blank: Non-forested, P:pine stands	From USGS 7.5' Quads updated from 1988 NAPP IR photography
Buffered Water	Open water buffered to 500 feet; two swath widths	1 or 0 for inside or outside the area	Buffered from Hydrology
Hydrology	Streams, lakes, and ponds	1 or 0 for open canopy or closed	USGS DLG Improved to Quad scale, updated from 1988 NAPP Photography
Buffered Research	Research Plots buffered to 1/4 mile	1 or 0 for inside or outside the area	Collected by AIPM from various sources
Buffered Threatened and Endangered Species	T and E areas blocked and buffered as to confuse exact location	1 or 0 for inside or outside the area	Buffered from Endangered Species
Endangered Species	Point location of endangered species in the study area	Type of species (One in study area) Triodopsis platysayoides -snail	Data from WV Natural Heritage Program
Egg Mass Densities	Classified surface created from egg mass survey data	Classes: 0 - 10, 11 - 50, 51 -250, 251 - 500, 501 - 1000, and over 1000 egg masses per acre	Generated from AIPM egg mass surveys
Egg Mass survey points	Point data from AIPM egg mass surveys	Actual sample values from zero to over 1000 egg masses per acre	From AIPM egg mass surveys
Elevation Ranges	100 meter elevation ranges from USGS 7.5' Digital Elevation Models	Values 2 through 8, value describes range. ie. 253 meters is in class 2	Generated from USGS 7.5' Digital Elevation Models
Management	Various management categories	Res: Residential, Rec:Recreation, Sce: Scenic, F: Forest	From various sources. WV Forestry, WVU Forestry, County Tax Maps, 7.5' Quads., 1988 NAPP IR Photography
Roads	Roads, streets and trails	Coded for interstate, primary, secondary and other roads, and trails	From USGS DLG data updated from NAPP IR Photography, and county road maps
Public Boundaries	Various political and management boundaries	County, state, park and forest boundaries	From 7.5' Quads and county tax map

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U. S. Department of Agriculture, Forest Service - State and Private Forestry, Appalachian Integrated Pest Management Project. 1991. AIPM Project Area decision protocols. Morgantown, WV.

CREDITS:

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GYPSES:
A DECISION SUPPORT SYSTEM FOR GYPSY MOTH MANAGEMENT

M.J. TWERY
USDA Forest Service, Northeastern Forest Experiment Station, 180 Canfield St., Morgantown, WV 26505-3101

G.A. ELMES
Department of Geology and Geography, West Virginia University, Morgantown, WV 26506

L.P. SCHAUB
Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

M.A. FOSTER and M.C. SAUNDERS
Department of Entomology, The Pennsylvania State University, University Park, PA 16802

Abstract. GypsES is a decision support system for the management of gypsy moth using a knowledge-based geographic information system and multiple knowledge-based modules or 'advisors'. The advisors provide decision information on Forest Hazard Rating and Risk Assessment; Insect Monitoring and Prediction; and Intervention Decision and Implementation. System development is sponsored jointly by two branches of the USDA Forest Service: the Gypsy Moth Research and Development Program of the Northeastern Forest Experiment Station and the Forest Pest Management Technology Development Program through the Northeastern Area, State and Private Forestry. The basic objectives of GypsES are to model the sequence of evaluations necessary for gypsy moth management decisions and to provide active managers of the gypsy moth problem with a useful tool to make their work more efficient. This paper describes the knowledge bases included in GypsES and the state of the software development project which incorporates that knowledge.

INTRODUCTION

The gypsy moth is an insect that defoliates trees, often disturbing forest ecosystems and the people who inhabit or use the forest. When gypsy moth expands into new regions, as it is doing in the southeastern and midwestern United States now, the potential economic damage is extensive, compounding the existing substantial aesthetic damage and urban nuisance problems. To help forest managers deal with this threat we developed a computer program that can help managers determine how to set priorities for their forest lands according to relative risk from gypsy moth and how to improve the efficiency of their gypsy moth control efforts.

GypsES is a decision support system for the management of gypsy moth using a knowledge-based geographic information system and multiple knowledge-based modules or 'advisors'. The advisors provide decision information on: Forest Hazard Rating and Risk Assessment; Insect Monitoring and Prediction; and Intervention Decision and Implementation.

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THE KNOWLEDGE BASES

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 (Hedden and others 1981) and is generally regarded as a useful management tool. To be useful, however, a great deal of information is needed about the forest stand and the pest insect. In general terms, the necessary stand information includes species composition, stocking level, tree vigor, and stress levels. The population levels of the pest insect also are 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 the entire Northeast at times, the specific areas of forest where it may be found vary from year to year. Also, however, individual stands within the same major forest type and in the same geographic area may have very different potential hazards. 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 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 is present. Vulnerability is the probability that damage (mortality, growth loss, reduced scenic beauty, etc.) 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.

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 (Gansner and others 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 have been compiled for many species in Pennsylvania (Gansner and others 1987, Hicks and Fosbroke 1987) and are still being refined. Stand-level vulnerability, which is a more useful scale to the forest manager, can be compiled from individual tree data or from stand level surveys. The stand-level survey is easier to manipulate, but is somewhat more variable because of the information it necessarily omits.

Forests of 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 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 vulnerability 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 the 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 condition of individual trees. When such information is available, it is the best source from which to predict hazard to the 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.

Monitoring and Prediction of Insect Populations

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 usually is more intensive than techniques used by 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 have 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 prism points or fixed-radius plots and timed walks that provide only number of egg masses per acre and have not been a dependable predictor of defoliation. Factors such as forest site, foliar biomass, insect population vigor, and phenology are important components of predicting defoliation for purposes of initiating management action.

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 would reach damaging densities. Conversely, populations in stands that are rejected for treatment often irrupt to defoliating levels.

Several studies (Campbell and Standaert 1974, Gansner and Herrick 1985) have focused on predicting defoliation from gypsy moth egg mass density, estimated either from fixed-radius plots (Kolodny-Hirsch 1986) or fixed- and variable-radius plots (Wilson and Fontaine 1978). It is obvious that egg-mass density alone may not always accurately predict subsequent defoliation since gypsy moth dynamics, like that of most other insect species, is affected by a complex set of factors. Variability in fecundity, egg survival, first-instar dispersal, and larval survival may all contribute to variance in the relationship between egg mass density and defoliation (Campbell and Standaert 1974). More research is needed on the development of simple, yet precise, models that will forecast defoliation from variables that can be measured economically.

Intervention Decisionmaking and Implementation

Decisions regarding management of gypsy moth are always heavily influenced by political factors. The insect and the trees it attacks are highly visible to the public and draw much attention from the press.

Decisionmaking with regard to treatment involves three functions: decision, implementation, and evaluation. Treatment decision determines where to administer gypsy moth suppression activities. Implementation carries out the suppression process; that is, the details of aerial application and alternatives such as silvicultural options and natural enemies. Evaluation records the year's suppression program. This allows a comparison of the suppression program's efficacy with that of previous years. The goal of treatment decision is to determine which areas or polygons are to be treated. The logic flow can be divided into five main tasks: (a) determine which areas qualify for treatment, (b) split areas where justified by heterogeneity in risk or phenology (c) buffer or eliminate those areas with open water, objectors, aerial navigation hazards, or nontarget species, (d) assign treatment priorities to those that remain, and (e) identify the final set of treatment units that are affordable within the user's budget (in conjunction with state assistance).

The knowledge base for the treatment advisor is derived from two categories of government documents: Environmental Assessments and State Guidelines for gypsy moth cooperative suppression programs in Delaware, Maryland, Michigan, New Jersey, Ohio, Pennsylvania, Virginia, and West Virginia. The Environmental assessments describe gypsy moth suppression program objectives, biological criteria for areas to be included in a suppression program, alternative treatment options, and justification of recommended options. Guidelines describe the specific procedures to be followed by program staff in preparation and submittal of proposed treatments to the respective states.

Geographic Information Systems

Geographic information systems (GIS) enable gypsy moth management decisions to include, store, manipulate, and analyze geographical data in a spatial frame of reference. Although maps are the most commonly used product of GIS, the most important feature of a GIS is its ability to handle and analyze multiple layers of spatially referenced data. For example, map themes related to the determination of risk and hazard, the location of insect populations, and other data may be overlaid to produce measures of areal association. One of the most significant uses of GIS in GypsES is the creation of new data layers through reclassification or map overlay operations or both. In addition, the strength of influence of variables over distance may be calculated to provide otherwise unavailable information about a management unit from adjacent and surrounding areas.

Conceptually the intelligent functions of the GypsES GIS are separated into the graphical user interface and the spatial information management system. The graphical user interface guides an inexperienced user through the most efficient use of the system components according to their stated needs. More experienced users are provided with short cuts and tools to maximize system accessibility. The user interface also provides for concurrent access to different computer subsystems through multi-tasking and windowing. The spatial information management system is composed of several sub-systems for the management of: data error and lineage, cartographic output, and rules controlling spatial operations. Relevant knowledge of GIS experts and cartographers is being formalized to assist in: (1) geographic database maintenance, (2) map design, and (3) GIS operations. The knowledge bases feature the ability to obtain an explanation of the reasoning behind decisions that have been made; that is, the logic path is traced through the production rules to permit the user to determine the acceptability of the outcome provided by the expert system. An intelligent geographic information system (IGIS) comprises several interconnected components linked to knowledge bases in order to manipulate geographical data required for a given sequence of operations. A knowledge base has to be developed for each specialist area, embodying information that has been developed over many decades. In some instances, the knowledge required is on a research frontier and part of a research agenda and will be subject to revision.

A model approach to the development of the various IGIS knowledge bases falls into three categories: specification, design, and implementation. Understanding what knowledge is required is necessary before it is possible to determine how the knowledge should be represented in a formal or symbolic language structure. The principal issues are related to data quality and conveying such information to the user. Two major interrelated themes emerge as being central to the needs of users: lineage and error handling.

THE WORKING SYSTEM

Implementation of a fully functional system and its distribution to Ranger Districts and state gypsy moth control programs will significantly enhance the efficiency and efficacy of those programs. The current design of GypsES incorporates GIS capabilities compatible with those in the planned Forest Service GIS acquisition. It includes forest hazard rating and insect monitoring capabilities to focus on gypsy moth control efforts. It also incorporates the user's priorities in delineating recommended treatment areas. The algorithms and rule bases for use in the fully implemented system have been acquired from the literature and experts in the field, including the developers. These rule bases will continue to be refined during the ongoing development process.

The full GypsES system is being developed under the UNIX operating system. This system was chosen to use the Macintosh hardware already available to the developers and to prevent the end product from being obsolete before its release, which is currently planned for late 1993. The UNIX system allows use of the GIS program GRASS, which is a full-featured GIS in the public domain, a factor that helps minimize the cost to users. Hardware currently running GypsES includes Macintosh computers, Intel 80486 computers, Sun SPARC stations, and a DEC 5000 workstation, illustrating the portability of software developed in the X-Windows environment.

The Interface

The Graphical User Interface (GUI) is the part of the program seen by the user. It includes a system of windows, icons, menus, and pointers (WIMPs) that are designed to be easy to understand. The design of the GUI was complete by July 1990, and its basic programming has been accomplished since then. The individual modules within the GypsES system all use a set of four work windows in which different information can be displayed. Each opens with a simple flow chart to provide visual clues to the user about how the program's logic works and to simplify navigation through the program's many parts. Interactive use is guided by internal functions that simplify use and avoid excessive complexity to the user. An integrated help facility provides ready access both to information on how to use the system and on the knowledge bases behind it. Output to paper maps can be produced for any image that is visible on any screen in GypsES.

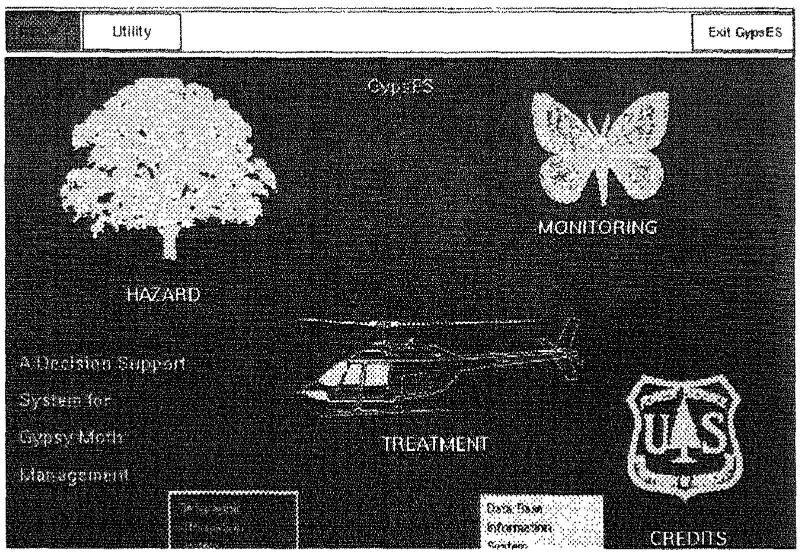

FIG. 1. The opening screen of GypsES showing the "point-and-click" interface with buttons and pull-down menus.

The Profile

Key elements in the system include the ability to store and recall information about the user and the areas under management. This function, known as the Administrative Profile, incorporates budgeting constraints, treatment priorities and preferences, and other individual characteristics, all of which are customized for or by each user.

Hazard Rating

The hazard rating module is designed to incorporate all the elements of the forest conditions and management considerations that are necessary as a precursor to any gypsy moth-related activity. This includes primarily information on the types of trees in the areas of concern, so that the system can determine the susceptibility to gypsy moth defoliation. Vulnerability to damage is then calculated based on the stocking, vigor, and prior disturbance history as described by the user. Management objectives are then incorporated to produce a hazard rating. This hazard rating can be used by the monitoring module to help determine sampling needs. In return, information from the defoliation prediction module is used within the hazard rating module to predict current risk of a gypsy moth infestation significant enough to need management intervention.

Monitoring and Prediction

Knowledge in the egg-mass sampling designer (EMSD) is derived from egg-mass sampling procedures applied in several county programs in Virginia and the Appalachian Integrated Pest Management (AIPM) Project and information available from other components in GypsES. The AIPM project developed sequential sampling plans for the forested areas in the AIPM project area (Fleischer and others 1991,.Rutherford and Fleischer 1989). The AIPM project implements a sequential sampling procedure for each 1-km cell. The EMSD adapts this approach to use sequential sampling procedures to estimate egg mass densities of management units. The parameters of sequential sampling are treatment (egg mass) threshold and acceptable error. The AIPM project leaves decisions on treatment thresholds and acceptable errors open to managers. The EMSD applies an average weighting scheme to combine input layers required to assign priorities to egg-mass sampling areas. The user chooses the weight she wants to associate with different input layers. Management units with a low Hazard Rating are associated with a high treatment threshold (1000 egg masses per acre) and management units with a high Hazard Rating receive a low treatment threshold (250 egg masses per acre). In an analogous fashion, acceptable errors between 15 and 35 percent are assigned to management units. The user has the ability to override the recommendations.

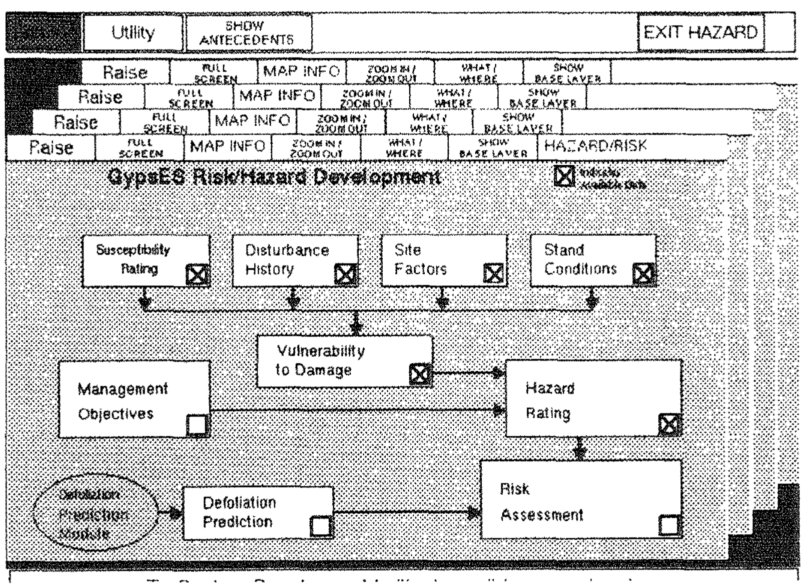

FIG. 2. The main Hazard Rating screen of GypsES showing the logic used to determine risk.

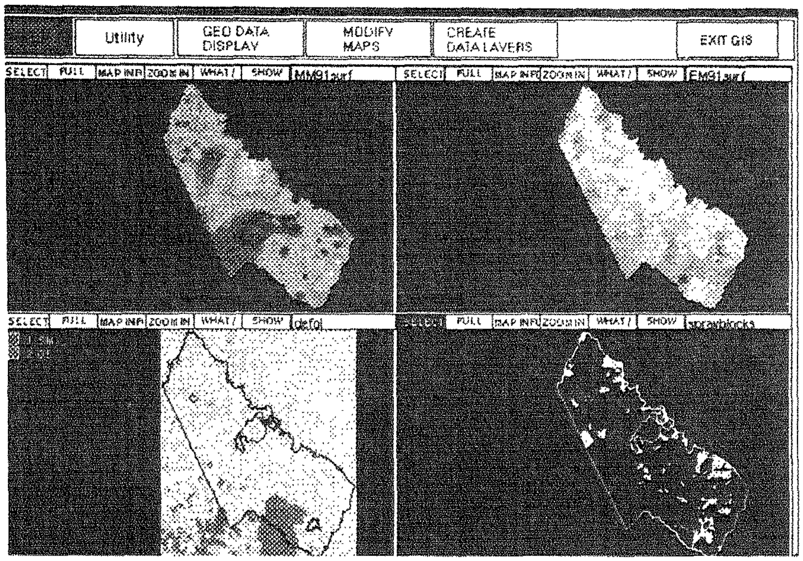

FIG. 3. Four input maps in tiled display as needed by the monitoring module.

The pheromone trapping system designer (PTSD) helps decide where and how many pheromone traps should be placed. These decisions are based on the monitoring priority resulting from the combination of the weighted input layers. Gypsy moth density estimates from pheromone traps have two purposes: (1) to provide the latest estimate of population densities in order to design egg-mass sampling and (2) to provide a low-cost, general survey of the population over a large area. The PTSD currently deals only with leading edge situations of gypsy moth populations.

The purpose of the phenology descriptor (PD) is to give the user a landscape-wide view of phenology (estimates of the timing of development of events such as gypsy moth egg hatch and larval development) and to provide information about phenology to the Treatment Component. Knowledge of phenology is important in planning spray operations and timing spray operations. To generate a map of phenology, the PD needs a map of elevation and temperature data from one location. The map of phenology is the basis for generating maps of expected phenology (mean and variability) of treatment blocks.

Treatment

The treatment module focuses on two functions in the treatment process: decision and implementation. Treatment decision assists a user in configuring potential treatment areas as suggested by the risk rating accomplished in the hazard rating module, assigning treatment priorities based on the risk assessment, and determining the final set of affordable treatment units. Treatment implementation advises on scheduling of aerial application activities, evaluation of aerial applicators' bids, and calibration of spray nozzles.

Potential treatment areas are identified through display of the risk rating generated in the Hazard module, and the user draws blocks on the screen to delineate areas of interest. The treatment module can then produce an estimate of the area to be treated. On the basis of cost estimates provided by the user, the module then assists in setting priorities for treatment that fit the fiscal constraints of the program.

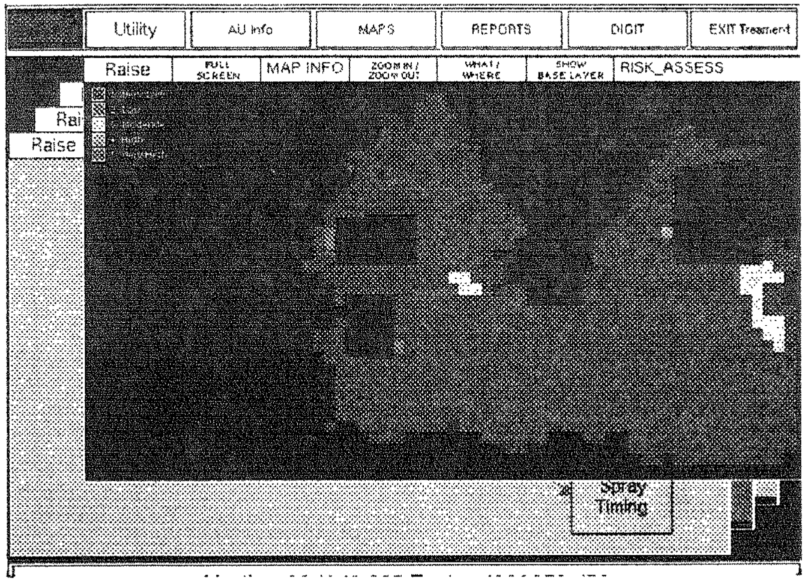

FIG. 4. Proposed treatment blocks drawn by a user on a sample area using the GypsES treatment module.

The scheduling of treatment blocks is based on information from the Phenology Descriptor. Predicted timing of larval development over each of the blocks produces an estimate of how much area needs to be treated during which time periods and how wide an effective window may be for each area and the overall program.

ACKNOWLEDGEMENTS

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MODEL AND DATA-DRIVEN VISUALIZATION OF FOREST HEALTH DYNAMICS

Brian Orland, J. Jay Obermark, Jeanine LaFontaine, Teresa Suter
Imaging Systems Laboratory, Department of Landscape Architecture, University of Illinois at Urbana-Champaign

Abstract. Natural systems change slowly and impacts on them become evident only with the passage of considerable time. The ability of scientists and managers to comprehend such systems can be aided by the use of computer modeling accompanied by visualization of the resulting predicted changes. Visualization tools range from strictly scientific tools enabling specialists to better understand complex resource interactions, to visual simulation tools enabling non-experts to judge the acceptability of expected changes. This paper describes the use of different visualization techniques in the context of large-scale forest management. Use of such techniques in contentious settings results in the necessity to demonstrate the validity and accuracy of resulting imagery, as well as represent the dynamics of changing systems and the uncertainties inherent in computer modeling. This paper describes a visualization system in development to address these issues.

Introduction

Typically, forest health or productivity impacts occur sporadically and proceed slowly, making the understanding of system dynamics by forest scientists difficult to assimilate, and the appropriate management responses difficult to promote and initiate. Computer data visualization offers opportunities to rapidly review developing impacts and alternative responses by animations of the outputs of models such as those for stand growth or insect spread.

Background

Data visualization has been recognized as an increasingly important aspect of the management of environmental resources (see Orland (ed) in press). Visualization tools have been used both by natural resource scientists seeking to better understand their science (e.g., Onstad, 1990; Larson et al., 1989; Cox, 1989), and by social scientists seeking to better understand human behaviors vis-a-vis those resources (e.g., Orland et al., 1990; Malm et al., 1980; Daniel et al., 1988). However, each group of users is willing to accept that their tools could bear considerable improvement, and that the wide range of tools in use would benefit from integration with comprehensive links between different modeling domains (Orland, in press). In addition, visualization users have identified several pressing needs in the development of new tools for environmental management. First, the reliability and validation of visualizations has been identified as an area needing attention (Daniel, in press) and, second, the necessity to support visualization at detailed as well as regional scales has been identified (Orland, in press).

Because of the complexity of their biology and their sensitivity to public opinion, the national forests have been the focus of extensive programs of modeling and visualization. There are comprehensive models of timber growth (e.g., Wykoff et al., 1986) and of pest damage (e.g., Stage et al., 1986) available for various parts of the forest system. Visualization tools have been developed to respond to those

Pages 65-72 *in* A. M. Liebhold and H. R. Barrett, editors. 1993. Proceedings: Spatial Analysis of Forest Pest Mangement. USDA Forest Service General Technical Report NE-175.

models (e.g., Heasley, 1990; Loh, 1990) and have been used in one or two pilot studies to assist public groups understand the forest dynamics at work in a management plan. Others (e.g., Daniel and Orland, 1991; Kruse et al., 1991; Orland, Vining and Ebreo, 1992) have used visualizations of forest conditions to elicit public reactions to forest policy issues and to alternative management plans.

CRITIQUE OF PREVIOUS VISUALIZATION TECHNIQUES

For each group there have been considerable drawbacks in the nature of the visualizations available. For example, the visualizations created by Heasley (1990) presented convincing perspective diagrams of forest conditions to facilitate understanding of forest growth, but were probably not sufficiently realistic to support valid evaluations of scenic quality. Moreover, they were based on timber stand data -- the common management unit for national forests. Since a timber stand is determined as a relatively homogeneous unit of variable size, there is no detailed information about the locations of individual trees -- Heasley's visualizations were probabilistic in their distribution of trees and thus not able to accurately depict detailed areas.

Modeling based on such coarse delineations lacks the ability to address detailed issues of forest management, failing to offer support for management actions which increasingly focus on tree-by-tree management, and failing to respond to current conceptions of forest ecosystem dynamics based on the behavior of individual stems. The opportunity to model and visualize forest systems in the desired detail has been missing for the lack of sufficiently detailed forest databases, and for the lack of visualization techniques able to handle the extremely large databases that would result.

In contrast, the visualizations created by Orland and collaborators (e.g., Orland, 1991) display high levels of detail and realism. However, their verifiable links to resource models have been weak, relying on expert appraisals rather than model output. This has mostly been an immediate consequence of there not being adequate models available (e.g., Orland et al., 1990), but the links of model to image would still present problems related to graphic system issues of geometry and perspective (see Orland and Kesler, 1991) as well as the data issue noted above -- that a stand map is too coarse to support detailed visualization.

Orland and Kesler (1991) suggested that the video-imaging technology being used for detail visualization was an intermediate technology -- precisely for the reasons noted above. The benefits of reliability and verifiability would accrue to the geometrically-modeled types of visualization if the necessity for sufficiently detailed databases could be met. The requirement for realism, while not as easily achieved, might be addressed through ever-improving graphic tools. Much of Orland's work for the last few years has focused on the development of image processing and sampling techniques able to create realistic images in response to calls from underlying forest system models (see Figure 1).

A SPATIALLY DEFENSIBLE VISUALIZATION SYSTEM

In the work reported here, an advanced graphically-oriented computer workstation has been used to develop a tree-by-tree visualization of forest databases. Computer capabilities have been evolving rapidly. When Heasley (see above) was developing his forest stand visualizations the graphics components of the computer system were limited by the US Forest Service Data General computer and associated Tektronix graphics displays. None of the devices was optimized, or even intended, for dynamic, shaded, three-dimensional displays. In addition to limited graphics capabilities, Heasley's visualizations were restricted by available computer power and time-sharing to image creation times of several to many minutes. Interaction with the screen image was impossible.

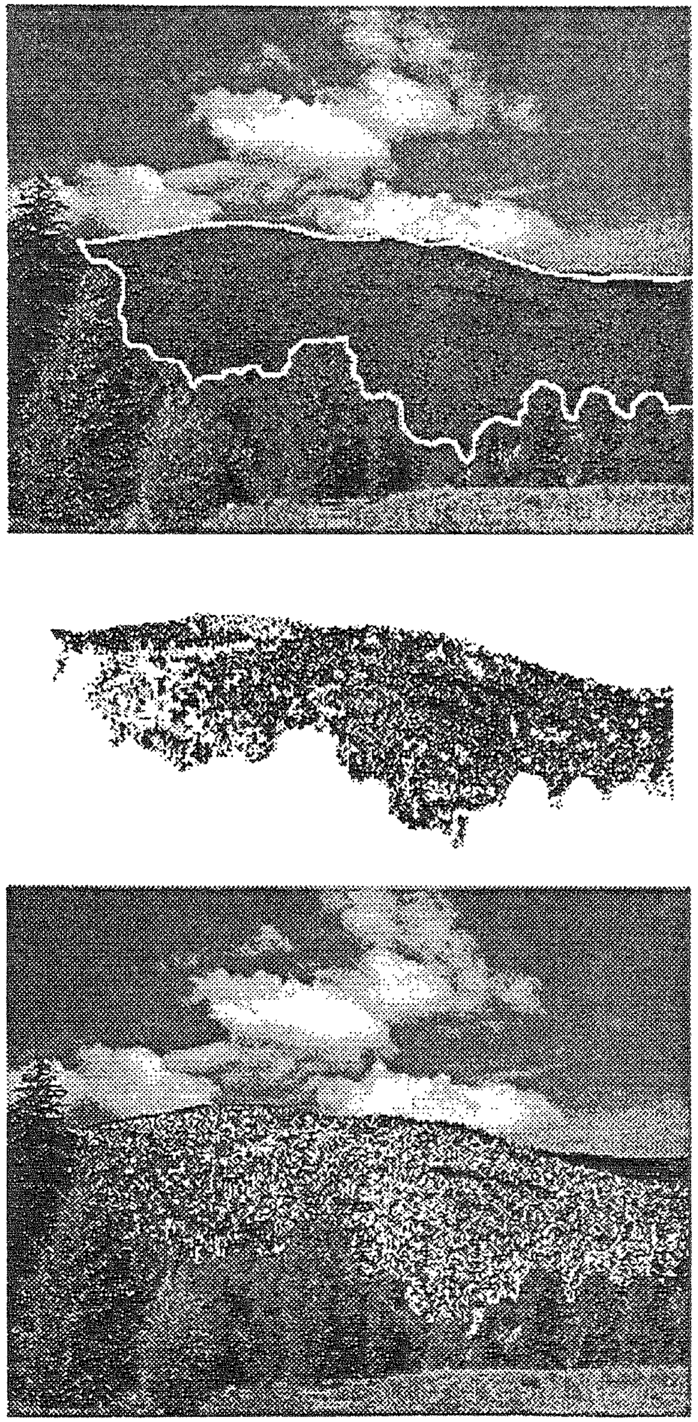

FIG. 1. Image processing was used to simulate the visual effects of Western Spruce Budworm damage on mixed conifer stands on the Carson National Forest, New Mexico. The first image shows the impacted stand delineated; the next image shows the digital filter used to manipulate the image; the third image shows the filter applied to the original image (changes greatly exaggerated for black and white reproduction)

These earlier visualizations were developed to display the data in forest stand tables. While that strategy was fitting to the agency's field operators the outcome must inevitably be an approximation to on-ground conditions. Stand data based on sampled data lack the spatial differentiation vital to many aspects of forest modeling. On-ground management of the resource results in decisions to thin particularly dense tree groupings -- or to preserve the resulting wildlife habitat -- but those decisions cannot be made based on the data held in the forest inventory. At the same time, the increasing burden of public accountability suggests new demands for detailed and concrete forest resource information to be used in management. Orland (in press) has described the emerging need for highly detailed and defensible data visualizations in forest management.

Three goals were identified for the visualization system described here:

1. To achieve sufficient speed in the modeling system to allow users to use the visualization as a decision support tool, rather than just to display decisions already made.

2. To develop forest visualizations where individual trees are represented and to take advantage of the most detailed single tree growth models and population dynamics models available.

3. To develop an interface which enables a user to import data tables from a variety of sources, to deal with data bases of differing resolution and abstraction, and to manipulate model parameters and instantly view the results.

SYSTEM DESIGN

To achieve the above goals demanded the identification of a suitable computer platform. The Imaging Systems Laboratory at the University of Illinois was mostly built around the use of personal computer equipment -- both IBM-PC and Apple Macintosh formats. The machines had been frequently up-graded and remain adequate for their main task -- image processing of single frame images. However, the equipment did not have sufficient processing speed or adequate memory for the rapid graphic modeling proposed here. A high-performance workstation, the Silicon Graphics Indigo, was acquired. This machine was a recently introduced, and inexpensive, dedicated graphics workstation. The computer uses the UNIX operating system, has 16Mb of memory and a 420Mb hard disk. The dedicated graphic processor of this particular machine is designed for 3-D visual modeling at speeds many times faster that with PC-DOS or Macintosh machines.

The modeling and visualization techniques adopted had been widely used and tested (e.g., Cox, 1990). However, much previous work in the area of resource management had focused on visualization tasks with relatively simple spatial characteristics. For example, growth models and pest population models had assumed flat terrain and evenly spaced host species. In addition, with interest focused on scientific visualization, the visual icons and techniques in use could be quite abstract.

In contrast, in the instances reported here the realism of the resulting imagery was critical, so some elaboration of previous visualization models was necessary to deal with irregular terrain, and to create visual icons sufficient to represent tree-forms when seen in the context of the modeled stand.

Programming of the visual modeling system has used the C programming language and the GL graphics library (a Silicon Graphics Inc. proprietary system). To date visualization models have been developed to allow the rapid and easy manipulation of the display (e.g., zooming and panning) using keyboard or mouse. Simplified timber growth and harvesting models have been developed which allow the user to readily alter model parameter or harvest prescriptions using standard forestry nomenclature. (Figure 2)

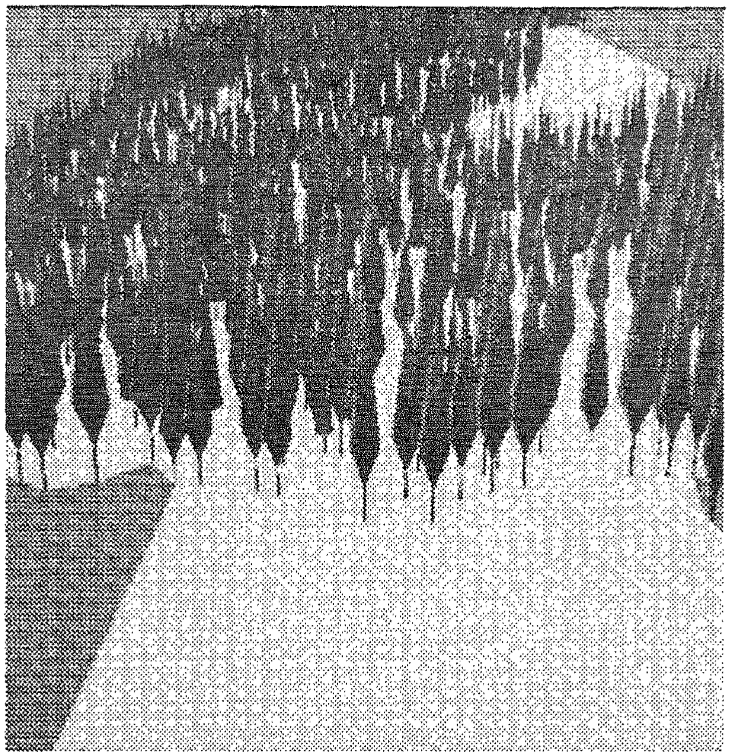

FIG. 2. A portion of a mixed spruce-fir stand on the Dixie National Forest, Utah. Image indicates the spatial distribution corresponding to locations from on-ground inventory data.

The implementation of these tools on two forest case studies is described below. The intention is to incorporate models for pest impact and stand recovery as resources become available, and to create animated visualizations that illustrate the changes expected in that stand over time, under a variety of different stand management prescriptions.

TWO CASE STUDIES

Chugach National Forest

In the course of other funded research two highly detailed forest inventories have been assembled. The first was an inventory of a Lutz spruce-white spruce-hardwood stand on the Kenai Peninsula in Alaska (Orland et al., 1990). The location is within an area which has suffered intense bark beetle attack in recent years, resulting in widespread tree mortality and offering ample opportunity for later validation of model outputs. Three years of research in the area has focussed on the application of computer visualization techniques to solicit public preferences for various public policy options facing the Kenai. The spatial data was collected using a laser range finder device, enabling the collection of accurate location (in x, y, and z dimensions), height, dbh, condition and species data.

We will conduct a validation study to measure the effectiveness of the visualizations by reference to existing conditions elsewhere on the Kenai peninsula. The area exhibits examples of forest stands of numerous different compositions and age structures, at different stages of insect attack and recovery. We will evaluate the utility of the visualization approach vis-a-vis the visual simulation approaches previously employed by Orland, (a) by expert panel scrutiny conducted by forest entomologists and silviculturists, and (b) by a pilot study comparison of preference judgements for graphic modeled vs. edited video visual simulations.

Dixie National Forest

The second case study is a mixed Engelmann spruce-subalpine fir stand on the Dixie Forest in southern Utah. The location is suffering an active outbreak of spruce beetle in large diameter trees, and is expected to lead to widespread mortality. Current visualization projects are focusing on the historic and long-term future effects of insect outbreaks on the forest. The spatial data were collected by stereoplotter using high resolution aerial photography of the stands.

In the absence of detailed ground data for this stand the validation issue becomes one of evaluating the relationship between estimated forest conditions represented by the visualization vs. on-ground conditions. As above, the evaluation will comprise both expert appraisals and preference judgements.

BENEFITS OF THE VISUALIZATION APPROACH

The principal applications benefits of the project were described above. In addition there are significant benefits to on-going research programs:

1. The visual simulation techniques employed previously have suffered from inadequate geometric control. While it has been possible to guide the image editing processes by overlaying wire-frame topographic grids, certain physical constraints of the computer display systems (e.g., the thickness of displayed vector lines) have restricted the accuracy that can be attained. The approach described in this paper offers much better geometric control, although at the expense of some realism in the final picture. The issue of when or whether that loss is sufficient to impact the usefulness of the imagery in decision-making is an important research question (see Daniel, in press). This pilot study will enable the investigation of such issues at a time when the direction of visualization of forest systems is in need of such information.

2. The systems previously addressed in scientific visualization, while complex in the number and interactions of variables portrayed, have focused on relatively simple data sets -- for example, individual corn plants on a flat field, evenly spaced, and all starting at the same age. This study offers the opportunity to add several levels of complexity -- the stand in question contains four species, unevenly spread on uneven topography, in numerous age classes, both healthy and insect-impacted. As a visualization exercise it offers many previously unaddressed complexities and will have important ramifications both for visualization and for modelers working in complex systems.

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ASSESSMENT OF POTENTIAL IMPACT OF GYPSY MOTHS ON GREAT SMOKY MOUNTAINS NATIONAL PARK

HOPE R. BARRETT
USDA Forest Service, 180 Canfield St., Morgantown WV 26505-3101

STEPHEN C. NODVIN
NPS-CPSU, 274 Ellington Plant Sci. Bldg, University of Tennessee, Knoxville TN 37901-1071

Abstract. In assessing the potential impact of gypsy moth on Great Smoky Mountains National Park (GRSM), forests in GRSM were rated for defoliation potential, sensitivity to environmental stress, and tree mortality potential. Maps of the GRSM vegetation cover, human access, elevation, slope, and aspect were obtained in digital format at 90-meter pixel resolution. These parameters were incorporated into a geographic information system modeling program.

Ratings of forest-type preference for defoliation by gypsy moth resulted in five major classes: most preferred (6% of GRSM, 11,551 hectares); highly preferred (15%, 32,030 hectares); moderately preferred (30%, 61,376 hectares);, less preferred (11%, 22,250 hectares); and least preferred (2%, 4,765 hectares). Twenty-three percent of GRSM (47,807 hectares) was sensitive to gypsy moth defoliation due to slope, aspect, and elevation. Combinations of forest preference with forest sensitivity produced estimates of potential forest mortality. Fifteen percent of GRSM (30,416 hectares) was predicted to be vulnerable to forest mortality within the first 2 of gypsy moth introduction.

Both forest and human management of GRSM may be influenced by the invasion of gypsy moth. Infestation in GRSM may prompt mitigation actions by the National Park Service should defoliation reach an unacceptable level and/or if resultant changes in forest composition are unacceptable or public safety is threatened by dying or falling trees in recreation or visitation areas.

INTRODUCTION

The gypsy moth, *Lymantria dispar*, is one of the most significant forest pests in North America. Larvae of this species can feed on the foliage of more than 300 tree species, and gypsy moth often causes extensive defoliation of forests that can result in tree mortality. Migrating gypsy moths are present in Tennessee, southwest Virginia, and North Carolina, but their populations are not dense in the Great Smoky Mountains National Park (GRSM). Since 1984, GRSM personnel have used pheromone traps to monitor the park for the presence of male gypsy moths. To date, only a few male moths have been caught annually (Leonard 1991), so gypsy moth does not yet pose a threat to the park.

This study was the first attempt to assess the forests of GRSM for potential impacts from the inevitable gypsy moth invasion. Three questions were addressed: What areas of GRSM are likely to become infested and thus defoliated by gypsy moth within 2 years of gypsy moth introduction? What forested areas would likely suffer mortality if defoliated by gypsy moth considering topographic features of the park? What specific park areas are both likely to be infested with gypsy moth and suffer forest mortality within 2 years of gypsy moth introduction into the park?

Pages 73-84 *in* A.M. Liebhold and H.R. Barrett, editors. 1993. Proceedings: Spatial Analysis and Forest Pest Management. USDA Forest Service General Technical Report NE-175.

METHODS

The following variables were evaluated: short-term susceptibility to defoliation, forest sensitivity to gypsy moth defoliation, and short-term vulnerability to forest mortality. The evaluations were completed using a geographical information system (GIS) and together provide a hazard assessment for GRSM forests likely to be affected by gypsy moth.

Short-Term Susceptibility Evaluation

Susceptibility of forests in GRSM was determined on the basis of ratings of feeding preference by gypsy moth larvae and proximity to sites of probable gypsy moth introduction. The degree of feeding preference was based on species composition within nine forest types in the park. In this paper, defoliation refers to 100% leaf loss from a tree that is infested with gypsy moth larvae. A GRSM vegetation cover map developed by MacKenzie (1991) categorized 90- by 90-meter (0.81 hectare) digital GIS picture elements (pixels) into various forest types.

Foliage Preference Index. - The susceptibility evaluation required the development of a foliage preference index to rank the nine forest types into preference categories. The term "preferred" in this study refers to forested areas favored by gypsy moth due to the high palatability of the tree leaves. The 63 tree species included in verifying the vegetation cover map were weighted according to foliage preference by gypsy moth. Each species was assigned a 0, 1, 2, or 3 with zero indicating that no information was available and 3 indicating the highest preference. Because food preferences by gypsy moth larvae may vary among geographic locations, the foliage preference weights assigned to tree species were unique to GRSM (Table 1). Preference weights were assigned to tree species following a review of the preference weights used in each of the following studies: Kegg (1971), Gansner and Herrick (1985), Houston and Valentine (1985), and Shumway and Bowersox (1987). Within each of the nine forest types, species weight was multiplied by the species mean basal area following MacKenzie (1991). The products were summed across species and forest types with similar sums were placed in the same preference class (highest, high, moderate, low, lowest) (Table 2).

Dispersal Zone. - The second step in determining GRSM susceptibility ratings entailed locating pixels that represented areas where gypsy moths were assumed to be introduced. Frequently, this pest invades uninfested areas by attaching itself to transportation vehicles. Developed campgrounds, environmental education centers, visitor centers, picnic areas, and heavy- or medium-duty roads were determined to be the sites of assumed gypsy moth introduction into the park. Point data (campgrounds, education and visitor centers, and picnic areas) were digitized using a 1:125,000 resolution topographic map, while vector data (roads) were transformed from a digitizer to a raster GIS at a 90-meter pixel resolution. An equal probability of gypsy moth introduction was assumed at each point and along each vector. A dispersal zone around all sides of all introduction locations was created and represented the assumed distance (5 km) in which gypsy moths were expected to disperse within 2 years of their introduction to GRSM. This linear dispersal distance was based on an assumed dispersal rate of 2.5 linear kilometers per year. This rate generally is used to represent the expansion of low-density gypsy moth populations (Doane and McManus 1981).

TABLE 1. Ratings of Individual tree species for gypsy moth preference in the Great Smoky Mountains National Park

Scientific name	Rating	Scientific name	Rating
Acer pensylvanicum	1	*Liquidambar styraciflua*	3
Acer rubrum	2	*Liriodendron tulipifera*	1
Acer saccharinum	1	*Magnolia acuminata*	2
Acer saccharum	1	*Magnolia fraseri*	2
Acer spicatum	1	*Morus rubra*	1
Amelanchier arborea	2	*Nyssa sylvatica*	2
Amelanchier laevis	2	*Ostrya virginiana*	2
Aralia spinosa	2	*Oxydendron arboreum*	2
Aesculus octandra	2	*Picea rubens*	2
Betula lenta	2	*Pinus echinata*	2
Betula lutea	2	*Pinus pungens*	2
Betula spp.	2	*Pinus rigida*	2
Carpinus caroliniana	2	*Pinus strobus*	2
Carya cordiformis	3	*Pinus virginiana*	2
Carya glabra	2	*Platanus occidentalis*	1
Carya ovalis	2	*Prunus pensylvanica*	2
Carya pillada	2	*Prunus serotina*	2
Carya spp.	2	*Quercus alba*	3
Carya tomentosa	2	*Quercus coccinea*	3
Castanea dentata	2	*Quercus falcata*	3
Cladrastris kentukea	0	*Quercus prinus*	3
Cornus florida	1	*Quercus rubra*	3
Fagus grandifolia	2	*Generic red oak*	3
Fraxinus spp.	1	*Quercus velutina*	3
Halesia carolina	0	*Rhododendron maximum*	2
Hamamelis virginia	3	*Rhododendron spp.*	1
Ilex montana	1	*Robinia psuedocacia*	1
Ilex opaca	1	*Sorbus americana*	2
Juglens cinerea	2	*Sassafras albidum*	2
Juglens nigra	1	*Tilia heterophylla*	2
Juniperus virginiana	1	*Tsuga canadensis*	1
Kalmia latifolia	1		

0 = no information 1 = low preference 2 = moderate preference 3 = high preference

TABLE 2. Forest-type preference ratings for the Great Smoky Mountains National Park

Preference	Forest Type
Highest	Mesic oak
High	Pine-oak
High	Pine
High	Xeric oak
Moderate	Northern hardwood
Moderate	Cove hardwood
Moderate	Spruce-fir
Low	Mixed mesic hardwood
Lowest	Tulip-poplar

Susceptibility Ratings. - The third step in determining gypsy moth susceptibility ratings entailed the development of a program to locate forest-type preference ratings of pixels within gypsy moth dispersal zones. Forests outside of the dispersal zone were assumed to be nonsusceptible to defoliation during the first 2 years after introduction of gypsy moth. The model predicted what forests within the dispersal zone were likely to be defoliated within 2 years of introduction, and assigned ratings of highest to lowest susceptibility to the pixels.

Forest Sensitivity Evaluation

Forest sensitivity in this study refers to the likelihood that forests exist under environmental stress based on pixel location within distributions of particular topographic factors. Stress was measured by the associations of a forest type with the topographic factors (GIS map layers) of elevation, slope, and aspect. The rationale for this approach was based on preliminary observations that each of the nine forest types were normally distributed over the gradients of each of the three topographic factors. The assumption was that the majority of trees in the pixels located toward the center of the Gaussian (normal) distributions were experiencing lower stress compared to trees located in pixels at the extremes of the distributions. Each topographic variable was cross tabulated with each of the nine forest types and data were plotted on an XY graph. The plotted distributions represented frequencies of the nine forest types over an elevation gradient, seven slope classes, and eight aspect directions. An iterative Marquardt-Levenberg nonlinear least-squares curve fitting algorithm was used to fit Gaussian curves to the distributions (MicroCal, Inc., 1991). Goodness of fit was calculated and a 95% confidence interval was estimated from each Gaussian distribution. Lower and upper limits of each confidence interval were used to determine the "optimal" and "suboptimal" growing range for each forest type. "Optimal" referred to pixels representing a forest type assumed to be experiencing lower amounts of stress; "suboptimal" pixels representing a forest type that was experiencing higher stress. A model was developed to determine suboptimal forest growing sites due to all or any of three map layers. The model was applied to all nine forest types and determined high, moderate, and low forest sensitivity for all possible combinations of elevation, slope, and aspect.

Vulnerability Evaluation

Vulnerability was defined in this study as the likelihood that forests in GRSM would suffer mortality (the death of all trees in a pixel) within 2 years of gypsy moth defoliation. The vulnerability evaluation was based on the assumption that defoliation will weaken the stands and would indirectly kill the trees. The predicted degree of mortality for the park was based on all possible scenarios of combined forest susceptibility and sensitivity ratings.

The vulnerability evaluation was completed in one modeling step that combined the susceptibility ratings and forest sensitivity ratings. A program was developed to choose all possible combinations of forest susceptibility and sensitivity by following the rules outlined in Table 3. Pixels in each combination represented a specific degree of potential mortality (vulnerability rating) that was predicted to occur within 2 years of gypsy moth defoliation.

RESULTS

Susceptibility Evaluation

Foliage Preference Index. - Individual tree species that were assigned a foliage preference weight of 1, 2, or 3 influenced the overall forest-type preference rank (the likelihood that a forest type will be defoliated by gypsy moth). *Hamamelis virginia*, *Liquidambar styraciflua*, and all species of *Quercus* were highly preferred by gypsy moths, so these species were assigned a 3 (Table 1). Species of *Amelanchier*, *Betula*, *Carya*,, *Magnolia*, *Pinus*, *Prunus*, and several individual species were assigned a 2, indicating a moderate foliage preference. During the application of the selection index, 17 species were considered low in foliage preference. Among these were *Fraxinus* spp., *Ilex* spp., *Juniperus virginiana*, *Liriodendron tulipifera*, *Morus rubra*, *Plantanus occidentalis*, *Robinia pseudoacacia*, and *Tsuga canadensis*.

A foliage preference value of zero, indicated that a species did not influence the rank of the forest type. Two of the 63 tree species (*Cladrastris kentukea and Halesia carolina*) weighted for foliage preference were assigned a of zero because they were not ranked in the following studies: Kegg (1971) Gansner and Herrick (1985) Houston and Valentine (1985) and Shumway and Bowersox (1987) (Table 1).

Susceptibility Ratings. - Sixty-four percent of GRSM (131,972 hectares) were sufficiently close to assumed introduction sites to be defoliated within 2 years of the arrival of gypsy moth (Table 4). Approximately one-quarter of that land area consisted of forest types that were ranked as highly preferred by gypsy moth; about half consisted of moderately preferred forest types.

TABLE 3. If/then rules that use susceptibility and sensitivity ratings to determine vulnerability ratings for pixels that represent forests of the Great Smoky Mountains National Park

If susceptibility rating is:	And if sensitivity rating is:	Then vulnerability rating is:
Highest	High	High
Highest	Moderate	High
Highest	Low	Moderate
High	High	High
High	Moderate	Moderate
High	Low	Moderate
Moderate	High	Moderate
Moderate	Moderate	Moderate
Moderate	Low	Low
Low	High	Moderate
Low	Moderate	Low
Low	Low	Low
Lowest	High	Low
Lowest	Moderate	Low
Lowest	Low	Low
None	None	None

TABLE 4. Area based on preference ratings and composition of the Great Smoky Mountains National Park

Preference rating	Hectares (no.)	Percentage of GRSM
Highest	11,551	5.56
High	32,030	15.4
Moderate	61,376	29.6
Low	22,250	10.7
Lowest	4,765	2.29
Total	131,972	63.6

Forest Sensitivity Evaluation

Twenty-four percent of GRSM (47,807 hectares) were sensitive to gypsy moth defoliation based on the distribution of forest types across elevation, slope, and aspect: 0.32% of (662 hectares) had high sensitivity, 4.26% (8,852 hectares) had moderate sensitivity, and 18.4% (38,293 hectares) had low sensitivity (Table 5). A rating of high meant that the pixel was found to be a suboptimal growing site in all three map layers. A rating of moderate meant that the pixel was a suboptimal growing site in any combination of two data layers. A rating of low meant that the pixel was a suboptimal growing site in only one of the three layers.

Distributions of forest type/elevation, forest type/slope, and forest type/aspect were accepted within the determined degrees of freedom and chi square values in all nine forest types (Figures 1, 2, and 3). Normality was determined by the goodness-of-fit tests calculated for each Gaussian distribution. Distributions of forest type/elevation for xeric oak, pine oak, and spruce-fir types were distributed in a non-normal manner as were the slope distributions for all forest types. With the available data it was difficult to visualize where the peak of the distributions of xeric oak, pine-oak, and spruce-fir elevation might lie beyond the extremes of the elevation range sampled. When the peak of a normal distribution is near or beyond the ends of the sampled range, it often is difficult to fit the data to a normal distribution from mathematical algorithms. In such cases, it can be assumed that the peaks are at the end of the sampled range of elevation. Given the nature of the curve-fitting program used, it was possible to assign a peak to the distributions and thus assume their normality.

TABLE 5. Area based on sensitivity ratings and composition of the Great Smoky Mountains National Park

Sensitivity rating	Hectares (no.)	Percentage of GRSM
High	662	0.32
Moderate	8,852	4.26
Low	38,293	18.4
Total	47,807	23.0

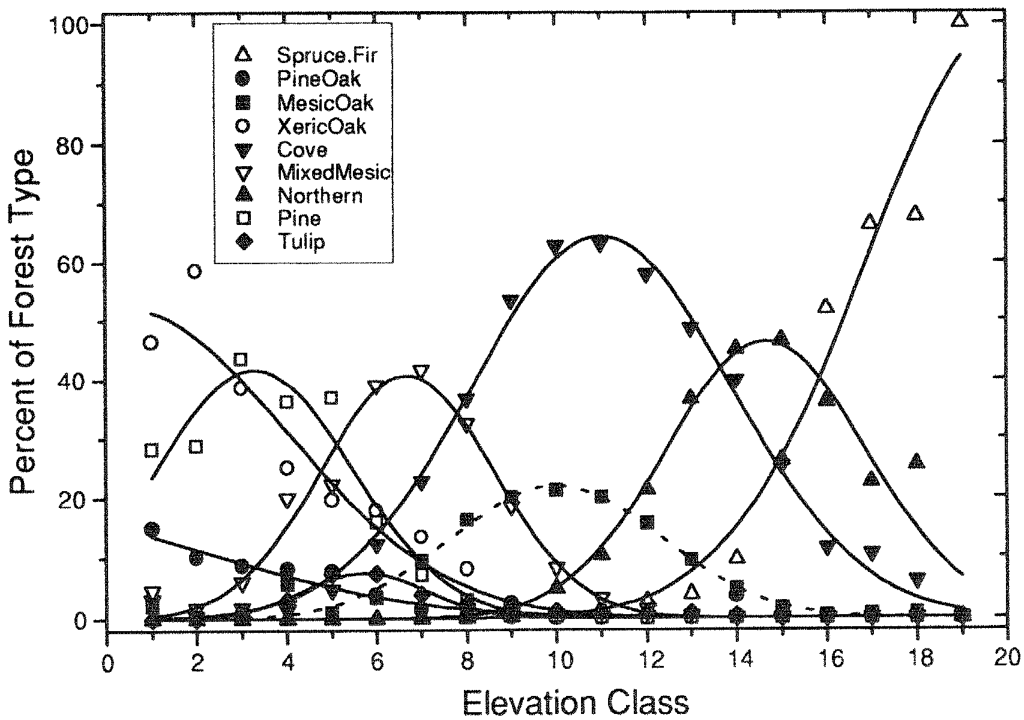

FIG. 1. GRSM Forest Type - Elevation Distributions

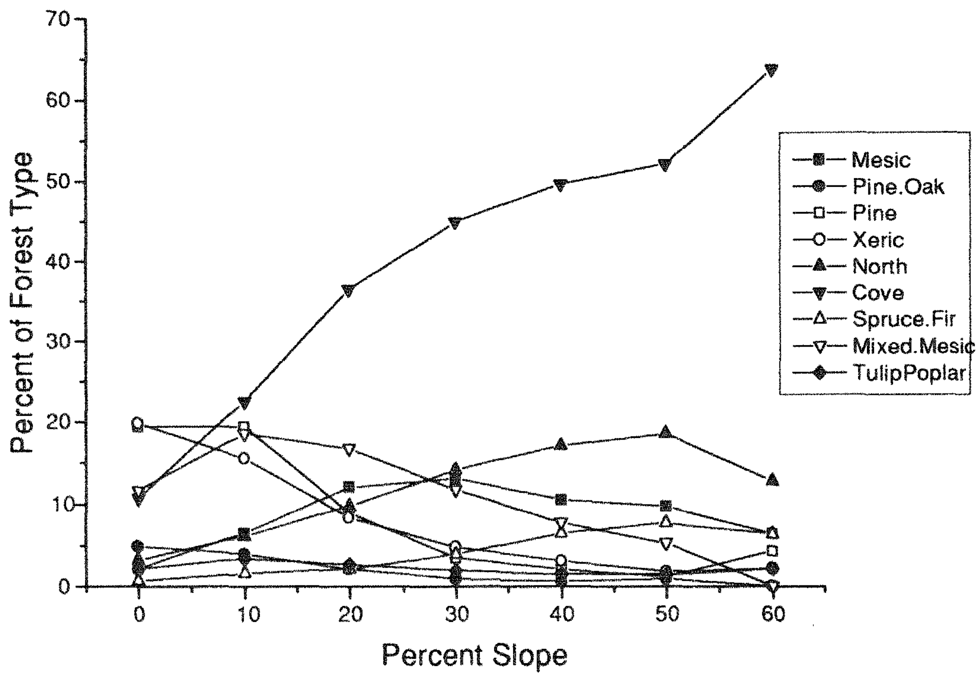

FIG. 2. GRSM Forest Type - Slope Distributions

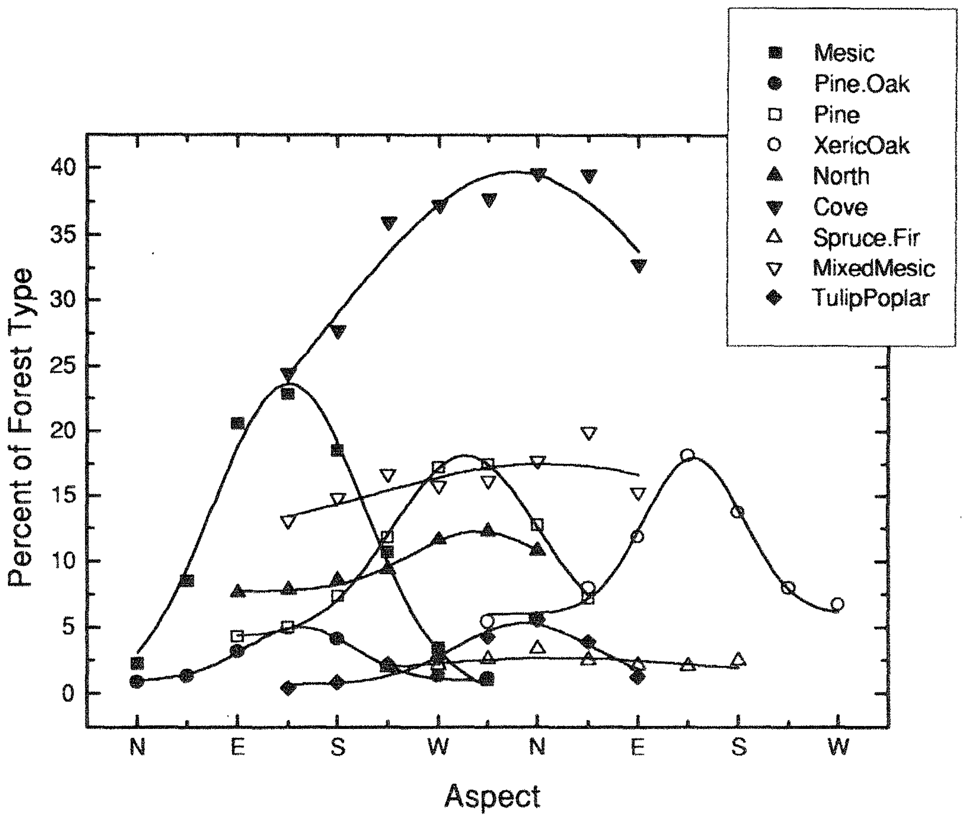

FIG. 3. GRSM Forest Type - Aspect Distributions

Vulnerability Evaluation

Fifteen percent of GRSM forests (30,416 hectares) were projected to be at some risk to forest mortality within 2 years of gypsy moth defoliation (Table 6, Figure 4). Most of this acreage was moderately vulnerable to mortality while less than 1% was highly vulnerable.

TABLE 6. Area and composition of forests that are high, moderate, or low in vulnerability to mortality within 2 years of gypsy moth introduction to the Great Smoky Mountains National Park

Vulnerability rating	Hectares (no.)	Percentage of GRSM
High	349	0.16
Moderate	18,279	8.80
Low	11,788	5.68
Total	30,416	14.7

CONCLUSION

The results of the present study have several management implications and can be used for initiating additional ecological research. Both forest and human management in the park can be influenced by results of the present study. Park managers could use the comparison to support management decisions such as the approval of the use of gypsy moth suppression techniques (*e.g.*, applications of Dimilin or Bt) in the old growth forests. The decision to alter the management of highly visited areas of the park may be influenced if defoliation occurs in those areas, and the results of the present study could be considered during the further development of visitor management in GRSM with respect to gypsy moth invasion. Interpreters and education specialists may develop an educational program in anticipation of gypsy moth invasion to explain that gypsy moth populations may indirectly cause forest mortality in the park. Such a program could also include rationale for the potential use of suppression techniques for reduction of gypsy moth population density.

There are five possible areas of research that might follow from this study: 1) ecological model development, 2) vegetation map development, 3) gypsy moth effects on wildlife of GRSM, 4) gypsy moth effects on GRSM forest types and understory, and 5) gypsy moth populations as affected by current GRSM Lepidoptera populations. Strategies that incorporate new computer technology in developing new gypsy moth modeling techniques could enhance those used in this study. The production of a finer scale GRSM vegetation map could be more useful as a basis for ecological research and forest management. The literature suggests that there are few interactions among gypsy moths, birds, and small mammals in North America; thus, there may be only minor indirect effects on plant and wildlife populations in the GRSM. Forest composition in the GRSM may be changed relative to both dominant species and understory structure if tree mortality follows gypsy moth defoliation. However, to date, no predictions have been developed to estimate specific effects of gypsy moths on GRSM plant or wildlife populations. Lepidoptera competition for available habitat and food may not be intense in areas that are newly infested with gypsy moths, yet there is no current investigation that might confirm this hypothesis.

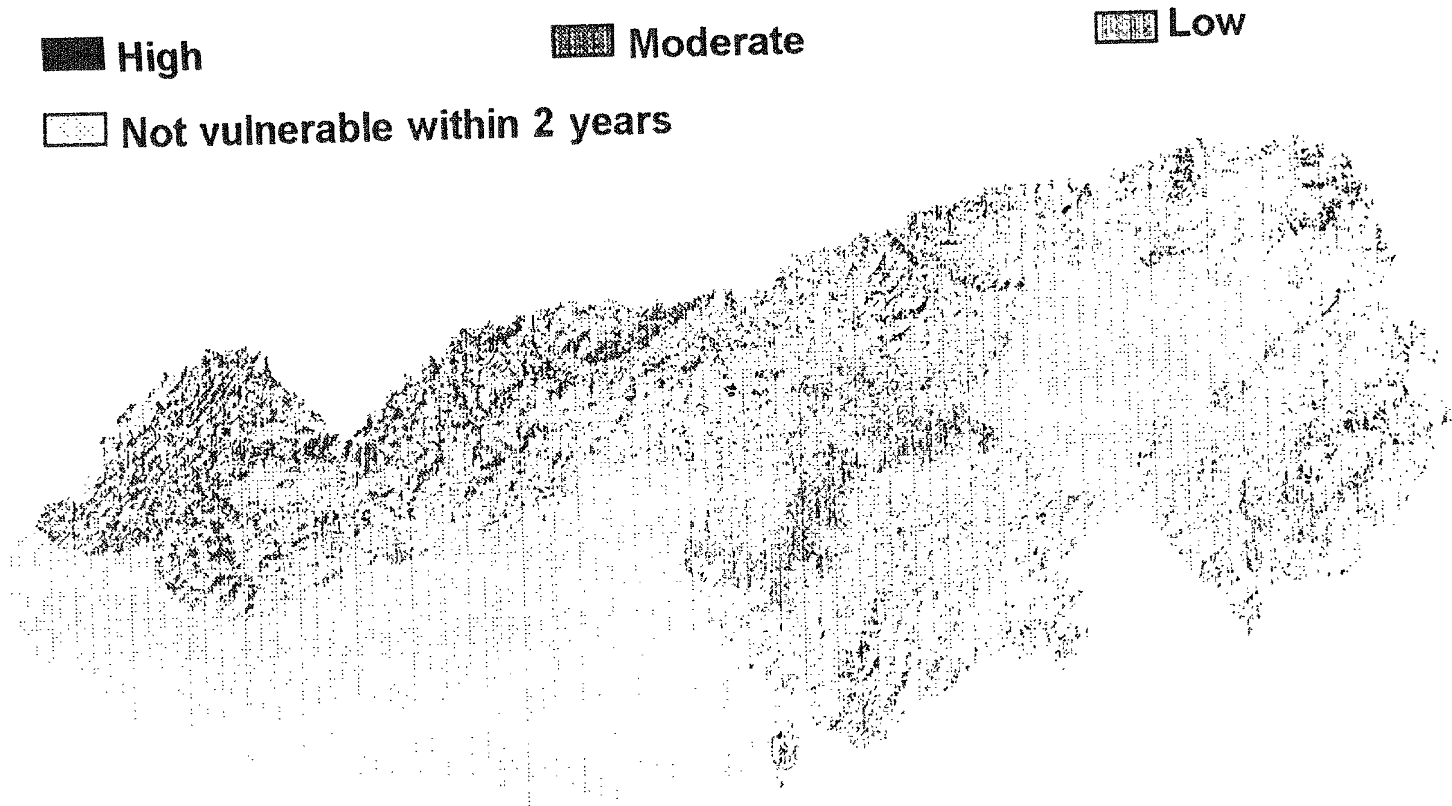

FIG. 4. High, moderate, and low ratings of forest vulnerability to mortality within 2 years of gypsy moth introduction to the Great Smoky Mountains National Park.

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INFORMS-TX OVERVIEW

STEPHEN B. WILLIAMS
USDA Forest Service, Forest Pest Management, Methods Application Group, 3825 East Mulberry Street, Fort Collins, Colorado 80524

Abstract. INFORMS-TX is an integrated software application which attempts to provide the forest resource manager with a powerful yet easy to use tool for assessing and solving complex resource management problems. INFORMS-TX, an acronym for Integrated Forest Resource Management System - Texas version, is based on the concept that the power and utility of several commercial and public domain software packages can be linked together through a user-friendly interface to provide the user with a set of commonly needed functions to perform specific tasks. In the case of INFORMS-TX, the components tied together for the benefit of the forest manager include a geographic information system (GIS), relational database management system (RDBMS), various forest resource models, and knowledge base (i.e., rulebase) software.

INFORMS HISTORY

A strategic goal of the U.S. Forest Service (USFS) Forest Pest Management (FPM) is to promote and improve integration of forest pest management with forest planning processes. To address this goal, FPM has been sponsoring the development of integrated technologies through the Integrated Forest Resource Management System (INFORMS) project (Andersen 1989a). INFORMS-TX is one of several integrated technology projects related to INFORMS objectives. FPM managers believe that the design concepts present in INFORMS-TX can help integrate forest pest considerations into forest resource decision processes. By incorporating pest models and pest knowledge into a software package that is easy to use and relevant to management tasks, it is more likely that forest resource managers will consider pest impacts when developing management alternatives.

FPM's early efforts in providing resource managers with a set of computer software tools for assessing the forest environment can be traced to the early 1980s. The first prototype was developed between 1980 and 1983 and was called the Integrated Pest Impact Assessment System (IPIAS) (McNamara et al. 1990). This effort came out of Virginia Polytechnic Institute and State University with support and cooperation from the U.S. Forest Service and the U.S. Fish and Wildlife Service. The system ran on an Apple II+ computer.

The concepts and ideas generated by IPIAS were moved to the Data General computing environment (i.e., the service wide computing environment of the Forest Service) in 1987. This software version was renamed INFORMS-DG. Work continues today on this version with support and development contracted through Management Assistance Corporation of America for the FPM Methods Application Group (MAG). INFORMS-DG contains a large amount of custom code, manipulates and displays MOSS-formatted spatial data, and contains the unique ability to display three-dimensional forest scenes as affected by various management alternatives. This software has been used to develop environmental assessments on the Deerlodge National Forest in Montana and on the Wallowa-Whitman National Forest in Oregon.

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In 1988, these integration concepts were tested on a microcomputer in a project called IRMAÑIntegrated Resource Management Automation (Loh et al. 1988). This demonstration project was conducted by the Nicolet National Forest in Wisconsin and Texas A&M with cooperation and support from FPM, USFS-Timber Management, USFS-Land Management Planning, the U.S. Fish and Wildlife Service, and the USDA-National Computer Center.

In many ways, the IRMA project spawned the INFORMS-TX project. Following the IRMA experience, the USFS recognized the need to integrate several commercial packages utilizing a workstation computing environment (Andersen 1989b). The workstation would allow multitasking as well as align this software for easy integration into the expected future computing environment of the USFS.

Based on these above ideas, FPM in 1990 sponsored a Technology Development Project in cooperation with the National Forests in Texas and Texas A&M's STARR Lab (Oliveria et al. 1991). The project remains active through March of1993. This project has resulted in the INFORMS prototype known as INFORMS-TX. INFORMS-TX integrates the ORACLE relational database management system, the ARC/INFO geographic information system, the CLIPS rulebase processing engine, various USFS models, and the OpenWindows interface on a SUN SparcStation. Texas A&M researchers have and continue to work very closely with the Neches Ranger District in Texas in integrating these products and providing key GIS, RDBMS, rulebase, and modelling functions necessary in performing project level planning on a ranger district.

INFORMS-TX: Specifics

INFORMS-TX is designed to facilitate project-level planning on National Forests. INFORMS-TX should simplify three important steps in this planning process. These include: developing management alternatives (e.g., thinning, prescribed burning, etc.), assessing the impact of management alternatives, and comparing the potential outcomes for a forested area in order to assist managers in selecting a preferred alternative.

INFORMS-TX was developed around the planning process used in the Neches Ranger District. The typical land unit under scrutiny in the planning process is a forest stand within a compartment of a ranger district. INFORMS-TX software provides the resource manager with an array of tools to isolate the planning area from a larger database, review descriptive spatial and non-spatial data for that area, and apply various models and rulebases to the area to evaluate and select management alternatives.

The value of the INFORMS-TX product is that the user does not need to be a power user of the ORACLE RDBMS, the ARC/INFO GIS, or other significant software products in order to utilize the functionality of these products in project level planning. INFORMS-TX provides a relatively friendly graphical user interface. The complexity of a RDBMS or GIS is hidden behind the interface. Yet the user still has access to search and manipulate large volumes of spatial and non-spatial data, perform various GIS functions, process these data through various resource models, and evaluate site data against established rulebases to derive potential management alternatives. The OpenLook graphical interface provided by INFORMS-TX is consistent throughout these functions, thus providing the user with an easily learned shell for performing a broad range of tasks. The foundations of INFORMS-TX design and functional requirements have been refined throughout the term of this project and many others (Loh and Chen 1991, Loh and Saarenmaa 1992, Loh et al. 1991, Loh and Rykiel 1992, Loh and Power 1992).

Most resource managers will follow a similar path in using INFORMS-TX. Upon entering the system, the manager will typically display the GIS layer associated with their land management area. In the prototype developed at the Neches Ranger District, this area is the district itself. The layers most commonly accessed depict the forest compartments and stands for the district. Other layers available can include geographic features such as streams, soils, road and trail networks, etc. Layers available to the user will vary depending on the needs of the implementation site and availability of data. Actual use of the available layers will vary by project goals.

With a view of the whole management area on screen, the manager then focuses on only the area involved by the given project. Using a mouse, the study area is isolated by drawing a boundary around the area and then "clipping" this area from the total management area (see Figure 1). Through the clipping process, the system creates the necessary spatial and non-spatial data files to represent the study area in a special directory created for that manager. This feature allows the manager to freely manipulate aspects of this study area. The manager can view just this smaller land area (see Figure 2), run data associated with just this area through various rulebases and models, and create various management alternatives to help reach final management decisions. The clipping process creates a subset of smaller databases from larger corporate databases, thus protecting these larger databases and allowing the tasks associated with the study area to be accomplished more quickly and efficiently.

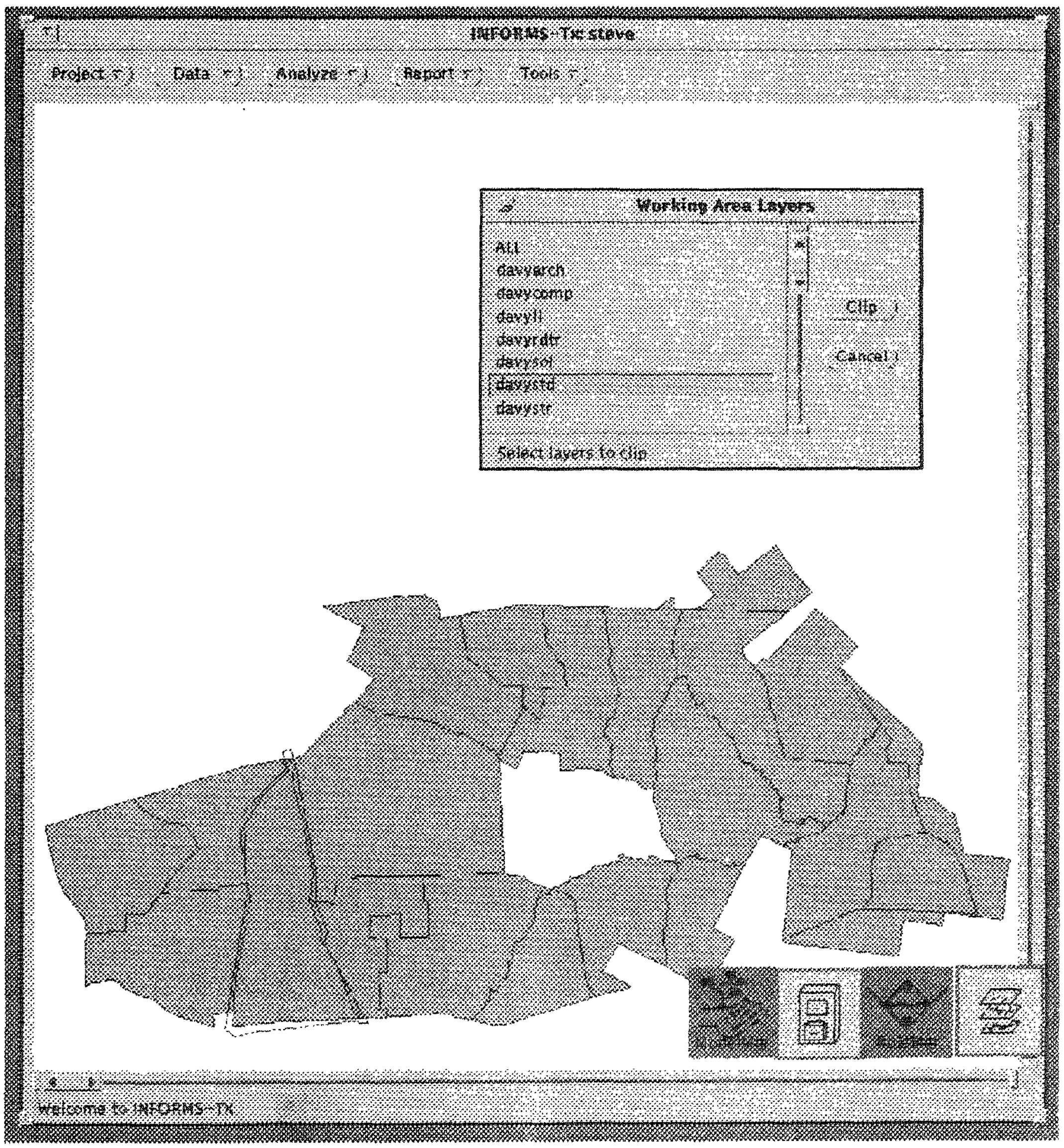

Fig. 1. A polygonally defined clipping area.

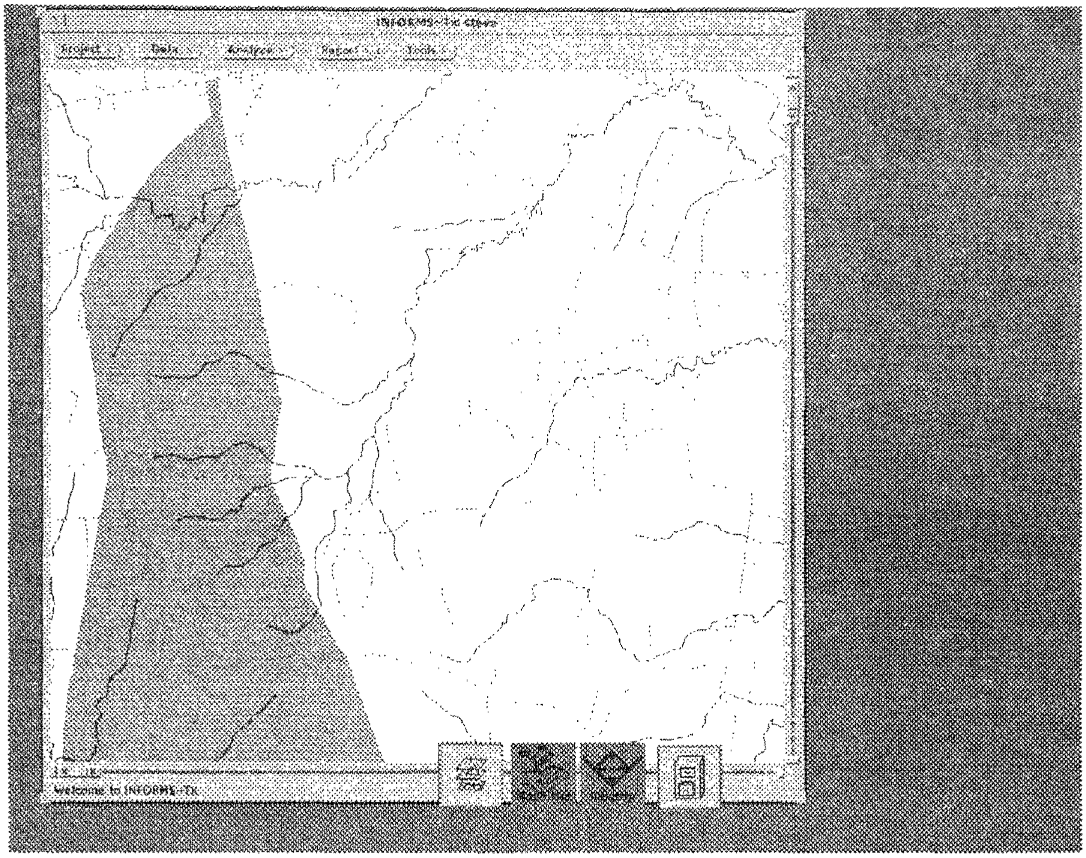

Figure 2. Display of the layers that were clipped.

Usually after clipping, the manager will then take advantage of the rulebases (i.e., knowledge bases) that are available through INFORMS-TX. The rulebases built into INFORMS-TX give an indication of the suitability of a particular prescription for stands in the clipped areaÑthe study area. Each stand can be evaluated against the rulebase to determine whether or not a particular prescription such as thinning is desirable. Stand data kept in the ORACLE database tables are accessed by the rulebase engine to determine suitability for treatment. The results of processing the stands of the study area through a given rulebase can be displayed graphically by GIS functions. Typically, three color codes are used to represent stands that are highly desirable, desirable, or undesirable candidates for a particular prescription (see Figure 3). These functions, as well as the ability to view the logic behind a given rulebase decision, are all readily and easily available from the INFORMS-TX graphical interface.

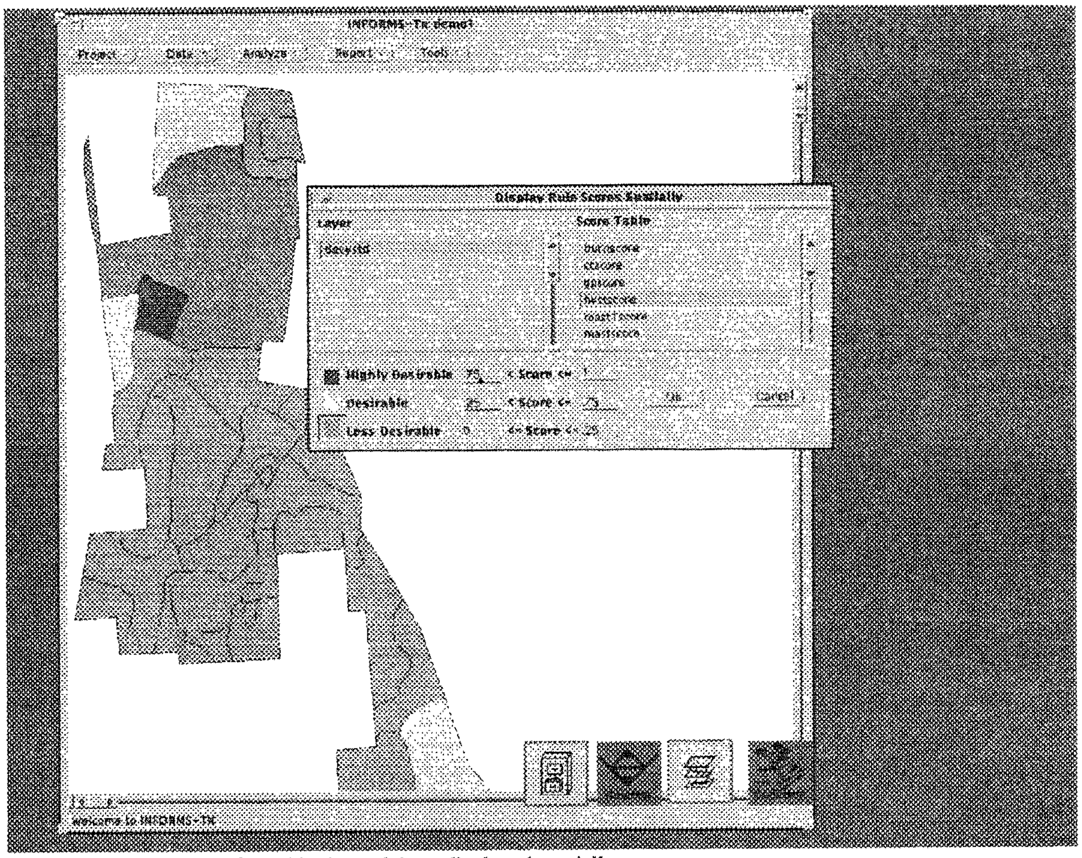

Fig. 3. The results of the thinning rulebase displayed spatially.

With the project area defined and the rulebase information generated, the manager then proceeds to build management alternatives for each of the stands in the study area. Rulebase scores generated in the previous step are used as an aid in preparing these alternatives. In building management alternatives for the study or project area, the manager will typically review rulebase scores, review the line of reasoning used to derive selected scores, and compare his/her alternatives against these scores for reasonableness. Using the mouse, the manager can "click" on any stand to view data and scores associated with that stand (see Figure 4). Sets of alternatives generated by the manager for managing the project area are easily stored for later use and evaluation.

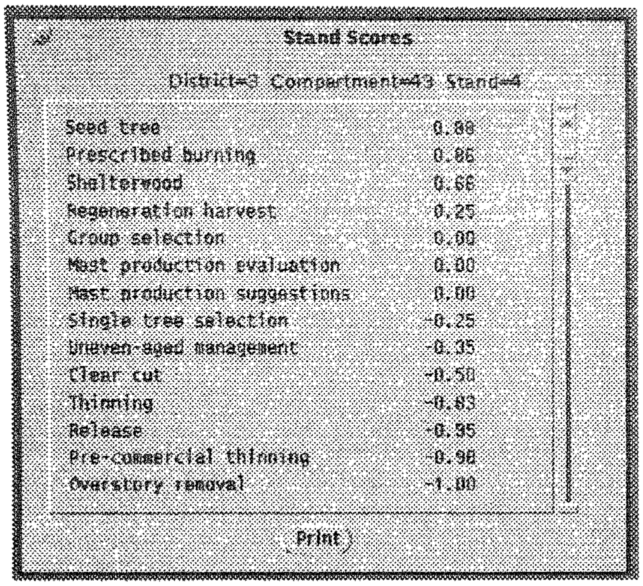

Fig. 4. The rulebase scores for a chosen stand.

Most USFS ranger districts will utilize various natural resource models to evaluate the possible effects of their management decisions. INFORMS-TX can incorporate these models into the other tools mentioned (see Figure 5). Typical models include timber growth, wildlife habitat, and pest models, among others. After developing various alternatives for managing stands within a project area, the manager using INFORMS-TX can evaluate these alternatives by running these alternatives through the selected models. Models give an indication of the long-term effects on various issues, such as pest activity, as a result of a management action.

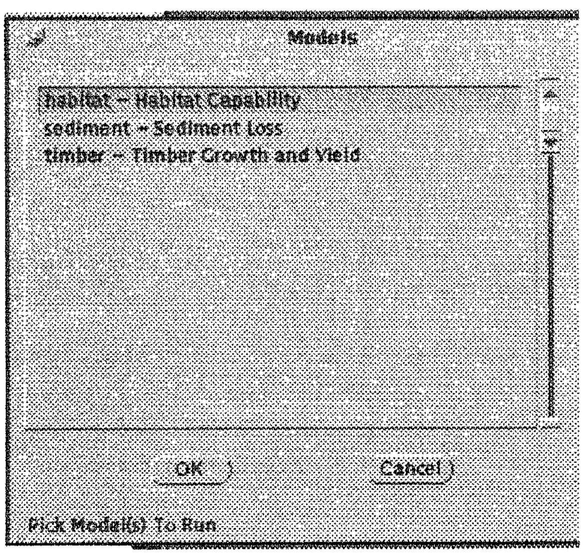

Fig. 5. The Models dialog box.

All of the above steps represent important processes involved with determining appropriate management actions for a forest area. The INFORMS-TX tool facilitates these processes. The forest manager can at any time move back and forth between these steps to adjust various factors related to the project, and maintain a more organized and documented approach to planning.

INFORMS: SUMMARY AND FUTURE

INFORMS-TX captures only the GIS, DBMS, and other software functions necessary to support project-level planning. The intent is not to recreate a full featured GIS or DBMS, but to provide the user, through an easy-to-use interface, with the functions necessary to get the job done. The tool is meant to be simple yet useful.

At this juncture in time, INFORMS-TX has been built around the data and operations of the Neches Ranger District in Texas. To fine tune INFORMS-TX as it exists now, Region 8 Management Systems has committed to implement INFORMS-TX into as many as four other ranger districts within Region 8. Also, MAG expects to implement INFORMS-TX in a ranger district in Oregon in Region 6. These experiences are meant to test the flexibility of the system and to determine how easily models and GIS data can be integrated into INFORMS-TX. Ongoing with these activities is the effort to create thorough and professional user guides and installation manuals to facilitate the use of INFORMS-TX or a similar product.

INFORMS-TX is actually part of a larger concept called INFORMS, which will hopefully combine the best ideas and techniques from both INFORMS-TX, INFORMS-DG, and other similar decision-support systems. Several issues are yet to be resolved for INFORMS-TX and INFORMS in general. One issue involves the desire to tap more of the potential of a GIS as related to models. As now designed, models embedded within INFORMS-TX rely only on individual stand data to generate results. The effects of activities and conditions on adjacent or nearby stands on the stand in question are not evaluated by the models. There are potentially large benefits for management in capturing more of the spatial interactions at play in stand management. The sediment model used in INFORMS-DG does to some extent utilize a more complete set of spatial information. INFORMS-DG also includes a data visualization capability that relies on spatial data and the digital elevation model (DEM) to simulate a three-dimensional view of the forest. Future research efforts on INFORMS may well focus on expanding the power of models as related to spatial data and expanding the role of data visualization in project planning, while at the same time minimizing the amount of custom code by building a shell such as INFORMS-TX to utilize existing commercial software products.

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