VI.9 Geographic Information Systems (GIS) and Integrated Pest Management of Insects

W. P. Kemp, D. McNeal, and M. M. Cigliano

Space and Pests

An understanding of the geographic variability in distributions and densities of pests is required for any integrated pest management (IPM) program. Pest densities influence the intensity of sampling required to define the area infested and the timing and economics of various control options. However, until recently there has been a general lack of analytical and data management tools that pest managers and researchers could use in IPM planning and execution.

Among several new technologies evaluated and demonstrated by Grasshopper Integrated Pest Management (GHIPM) Project participants, the geographic information system (GIS) and Global Positioning System (GPS) technologies appear to be sufficiently well developed to be integrated into existing IPM programs for rangeland grasshoppers in the Western United States. Although the primary focus of this chapter is GIS, we have chosen to include additional information on GPS because of the obvious link between the two technologies.

First Consider GPS

GPS refers to an advanced navigational system that was developed primarily for military applications. GPS consists of a number of satellites orbiting the Earth. These satellites have the ability to communicate with any appropriately equipped plane, ship, vehicle, or individual and indicate the geographic position on the face of the Earth and the elevation of the receiver. Position accuracy within feet may be obtained with appropriate equipment.

Because of the obvious improvements in guiding or tracking for commercial uses, some portions of the GPS have been made available to the public. Hand-held GPS receivers (fig. VI.9–1) are finding wide usage throughout

Figure VI.9–1—One of the newest tools to aid pest managers is a hand-held Global Positioning System (GPS) instrument. GPS provides accurate latitude and longitude coordinates, aiding the process of mapping locations of grasshopper populations. (APHIS photo by Mike Sampson.)

the public and private sectors. For the purposes of IPM, the GPS offers several capabilities. The most highly developed aspect of GPS that has been exploited by the participants of the GHIPM Project is aircraft guidance (see II.22). We focus the following discussion of GPS application on field scouting and the obvious link to the GIS.

Those involved with pest management of rangeland grasshoppers have struggled with the problem of locating their position on a map. Agencies often use the U.S. Geological Survey 7.5 Minute Quadrangle Series Maps, frequently referred to as simply "topo maps" or "quad sheets," where 2 inches on the map represents 1 mile on the surface of the Earth. Using 2 inches = 1 mile map scale as an example, consider what a scouting activity frequently involves. Whether sampling for Mediterranean fruit fly in California or for grasshoppers in Montana, the problem is the same—how to mark a place on a map that represents the location of a sample site?

Over the years, most scouts develop experience, which helps them locate their position on a map quickly and accurately. Scouts usually become good "mappers." However, learning to read maps is an acquired skill, and new scouts cannot be expected to be able to locate their position at all times quickly and accurately (accuracy is possible, but most novices cannot work quickly). Furthermore, scouts vary in their ability to read maps. As with any human activity, some scouts are simply better mappers than others.

Currently, a number of GHIPM Project participants use hand-held GPS receivers (some of which are about the size of a large pocket calculator), which can provide positional accuracies of plus or minus 100 feet in normal operational mode or plus or minus a few feet when operating in an optional mode. The positional accuracy possible in point location and block location (for example, the location of an infestation of insect A) via GPS goes a long way toward reducing errors and helps minimize the differences between scouts in mapping activities. Furthermore, many of the currently available GPS receivers can be connected directly to microcomputers or field data recorders. These can manage data in standard GIS formats, so scouting information can be examined very rapidly and thoroughly.

On to GIS

A GIS is a set of computer programs that can store, use, and display information about places of interest. Examples of places of interest to a grasshopper pest manager might be a 20-acre field, a 20,000-acre watershed, or the 2 million square miles of rangeland in a particular State. Examples of information for any place of interest are soil types, rainfall and temperature patterns, land use, ownership patterns, roads, vegetation types, and topography (landform). A GIS stores two types of data that are found on a map, the geographic definitions of Earth's surface features (spatial reference) and the attributes or qualities that those features possess. It is generally agreed that a true GIS is capable of several characteristic activities: (1) the storage and retrieval of information with a spatial reference (point A is located in Section 20 of Township 5, Range 8 and has soil type B), as well as (2) the input, (3) analysis, and (4) reporting of spatially referenced information in digital form.

GIS Storage and Retrieval

A basic feature of any of the hundreds of GIS products available today is the ability to represent map information in a form that a computer can use. In the world of information management, people generally reserve the term "map" for paper, acetate, or Mylar™ maps, whereas the representation of the map in the GIS is called a "coverage" or "map layer." For the sake of simplicity, we will use "coverage" throughout for the GIS representation of a paper map. Of the approaches used by various GIS products, the two most often heard about are "raster" and "vector."

A GIS that uses a raster approach is similar to observing an attribute such as soil type through a grid or to the view that one has of the world through a screen door. With raster-based GIS products, a coverage of the frequency of grasshopper outbreaks in Montana consists of hundreds of tiny cells each with only one value for the number of years when outbreaks were observed (fig. VI.9–2). Raster-based GIS products keep track of the arrangement of each cell. Each cell and its unique outbreak frequency value have one and only one correct location on the coverage, so when pest managers want to view the grasshopper outbreak frequency coverage of Montana, the GIS always displays the same arrangement of the cells.

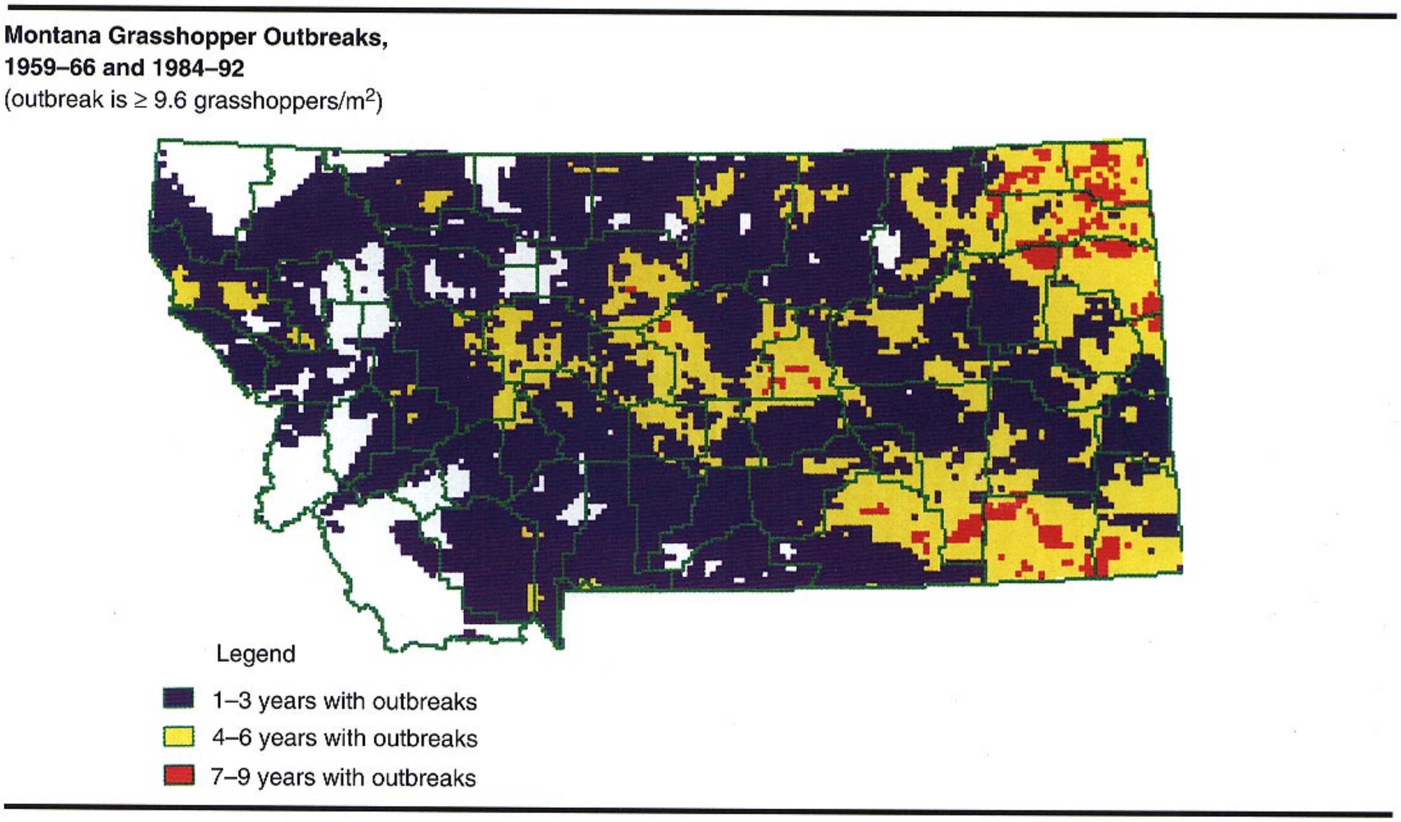


Figure VI.9–2—Rangeland grasshopper outbreak frequency in Montana, an example of a raster-based GIS product.

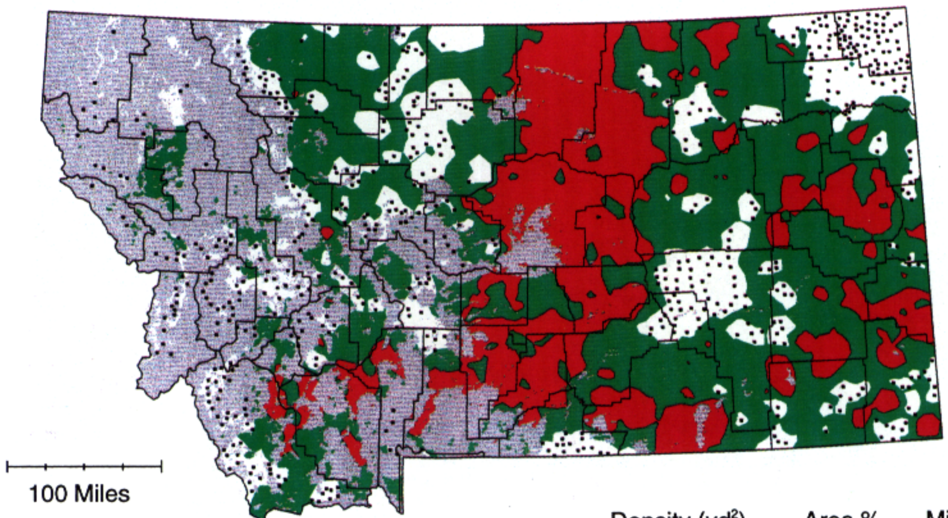
A GIS that uses a vector approach stores information in a somewhat different manner. For example, rather than viewing grasshopper densities as a collection of discrete cells that, when taken together, make up the entire image (the raster-based GIS approach), vector-based GIS products keep track of borders. Vector-based GIS products then associate a particular density to each unique area or polygon area found on the coverage (fig. VI.9–3). With vector representation, the boundaries of the features are defined by a series of points that, when joined with straight lines, form the graphic representation of that feature. The attributes (information) of features are then stored within a standard data-base management software program. The vector-based method is similar to what pest managers do when they draw insect-infested areas on a map in pencil.

Although some applications are more logically approached with either a raster or vector GIS product, in reality it is possible to convert map coverages from raster to vector format and vice versa. If one has purchased a raster-based GIS, he or she is not limited from obtaining a coverage from a vector-based GIS. Whether the basic unit of a coverage is a raster or a polygon, it is not uncommon to have more than one attribute (for example, soil type, vegetation type, or elevation) associated with it. The way that this task is accomplished varies from one GIS product to another.

Data Input and Spatial Analyses

An obvious, yet underappreciated (see more on this below in GIS—The Growth Years), GIS activity is getting the information on the map that you have in front of you into the GIS. In reality, there are a variety of data types that GIS products (paper maps showing point samples or infested areas, digital line graphs, or remotely sensed data) can use. With, for example, a soil type map resting on your desk, you have two logical ways, either “digitizing” or “scanning,” of getting the information from that map into the GIS that resides on your desktop microcomputer or workstation.

1994 Montana Rangeland Adult Grasshopper Survey



Data source:
USDA Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Billings, MT 59101

Prepared by:
USDA Agricultural Research Service
Rangeland Insect Laboratory
Bozman, MT 59717-0366

	Density (yd^2)	Area %	Million acres
Uninfested	<3	16.4	15.4
Threatened	3–8	35.8	33.7
Infested	>8	18.5	17.5
Forested		29.3	27.6
Sample locations in uninfested areas			

Figure VI.9–3—The 1994 annual adult grasshopper survey for Montana, an example of a vector-based GIS product used in integrated pest management.

A digitizer device connected directly to your GIS by a cable from your computer may be as small as the blotter on your desk or as big as a draftsman's table. The digitizer has a device, called a "puck," that looks like the mouse on your PC (personal computer), but has more buttons as well as a set of cross hairs to allow you to trace the outlines of soil types on your paper map. The tracing process and some additional steps taken with your GIS successfully convert the information from your paper map into an electronic version or coverage, as we explained above. This process should sound a lot like the vector-based GIS approach we discussed above.

A scanner, on the other hand, performs a task much like a facsimile machine in a home or office and may range in size from a small hand-held device to the large-format photocopy machines that you have seen in photocopy shops. A scanner simply performs a raster (grid) scan of the map that you insert and senses and records the light reflectance of each raster cell. This information is stored in a file format the GIS on your computer can read and convert into a desired coverage. As mentioned, although digitizing and scanning are two commonly used methods for getting map data into a GIS, digital line graphs (DLG), published electronically by government agencies such as the U.S. Geological Survey, provide information in GIS-ready formats. Formats include attributes like elevation, political boundaries, highways, soils, land use, and more.

As mentioned, when people discuss GIS applications or the potential of the technology, they frequently gloss over the "minor details" of getting data into a GIS and concentrate on what we call the spatial analysis capabilities of GIS. Perhaps the most important process common to all true GIS products is the "overlay." An overlay is simply a GIS procedure where two or more coverages (perhaps vegetation type, river courses, and primary highways) are combined and the result is a new coverage that represents a combination of the originally separate coverages. In another example, one coverage (environmentally sensitive areas, for example) may be used to mask out portions of a second coverage. Lastly, it is possible to compute the sum of specific attributes from a series of yearly coverages to compute, for example, the number of years each county in Utah has seen problem populations of rangeland grasshoppers or Mormon crickets.

In addition to the overlay, most GIS products offer a variety of spatial measurement techniques or area analyses. Examples include calculating the area of rangeland in a particular county with more than 20 grasshoppers/yd^2, estimating the area of a lake, or computing the proportion of a chemical control block devoted to buffer zones. All true GIS products also offer solutions to people interested in overlaying coverages of different scales (and projections—although we have chosen for the sake of simplicity to discuss only different scales). Consider, for example, a situation where you want to identify those vegetation types in a particular county where grasshopper densities exceeded 20 grasshoppers/yd^2. If scouts collected density data on maps with a scale of 2 inches = 1 mile (a 7.5-minute quad) and vegetation data was mapped at a scale of 1 inch = 1 mile (a 15-minute quad), you can use the capabilities of a GIS to rescale one map or the other. You could produce a correct overlay to depict only those vegetation types with more than 20 grasshoppers/yd^2.

Maps, Graphs, and Tables

GIS products offer a bewildering array of report types. Reports can consist of paper maps, tables, charts, graphs, or computer images. Selecting which report type is the most useful will depend on your particular application (see Cigliano et al. 1995). For viewing an overlay consisting of vegetation type, land use, rivers, and roads, you would likely choose a simple paper map presentation. If you wanted to forecast grasshopper densities throughout a State for next year, you could select options that would produce a contour map (for example, fig. VI.9–3). In short, GIS offers pest managers a great deal of flexibility in the presentation of information.

GIS Applications and IPM of Insects

Liebhold et al. (1993) described GIS's as "enabling technology." As previously stated, a GIS provides pest managers with the capabilities to store, retrieve, process, and display spatially referenced data. It seems only logical that GIS technology will be rapidly embraced because so many questions from insect ecology to pest management have a spatial component. Whether studying the patch dynamics of host and herbivore or predicting multi-State pest hazards, GIS technology provides today's researchers and pest managers with the ability to answer questions that frustrated their predecessors.

Now it is possible to identify two general areas where GIS technology has been used in entomology—applied insect ecology research and insect pest management. Within the general area of applied insect ecology, perhaps the major use of GIS is in the relation of insect outbreaks to environmental features of the landscape. Using grasshoppers as an example, investigators in Canada used GIS products to examine the relationship between historical grasshopper outbreaks and soil characteristics (Johnson 1989a) and between weather and survey counts (Johnson and Worobec 1988). From these geographically referenced data, Johnson (1989a) found that grasshopper abundance in Alberta was related to soil type but not to soil texture. Furthermore, a significant association was found between rainfall levels and grasshopper densities. Populations tended to decline in areas receiving above average rainfall (Johnson and Worobec 1988).

Future efforts to characterize habitat susceptibility probably will use remotely sensed data extensively because of its high spatial resolution and its availability in virtually every portion of the globe (for a complete review of remote sensing in entomology, see Riley 1989). For example, Bryceson (1989) used Landsat satellite data to determine areas in New South Wales, Australia, that were likely to have egg beds of the Australian plague locust. Through the use of an index that indicated the general greenness levels of local vegetation, Bryceson was able to identify resulting nymphal bands geographically through changes in the greenness index that resulted from rains during March (nymphal bands tend to be associated with "green" areas that result from rain).

Similar "greenness mapping" exercises have been conducted in Africa for grasshoppers and locusts (Tappan et al. 1991). In addition to illustrating the apparent ecological association between nymphal bands of grasshoppers or locusts in Australia and Sahelian Africa and changes in greenness indices, studies of Bryceson (1989) and Tappan et al. (1991) have immense practical utility because they produce rapid estimates of the location and extent of potential pest problems. Through such methods, it has been possible to improve sampling efficiency vastly for detection of problems as well as to reduce the guesswork involved with planning and execution of pest management programs.

The second major area where GIS products have been used is for compilation and analysis of insect census data that are collected regularly by U.S. Department of Agriculture, Animal Plant Health Inspection Service (USDA, APHIS). One example of this application for rangeland insects in the United States is the use of a GIS for developing a distribution atlas for grasshoppers and Mormon cricket in Wyoming (Lockwood et al. 1993). Additionally, Kemp et al. (1989) and Kemp (1992 unpubl.) provide methods for the development of rangeland grasshopper GIS coverages and hazard forecasts, using annual survey data collected on adult grasshoppers in Montana. (See Johnson [1989b] for similar studies for grasshoppers in Canada.)

The compilation and interpretation of spatially referenced insect and habitat data is a complex process, if for no other reason than the sheer volume of information. Although GIS software is designed to handle this complexity successfully, these systems often are not easy to use. In order to make a GIS more accessible to applied problems, GIS is increasingly being linked as a part of a larger decision support system (DSS). These systems typically use a GIS to manage habitat, geophysical, political, and census data. The DSS uses these data, along with other data, as input to mathematical models and other modeling methods to produce useful abstractions or recommendations (Power 1988). These outputs might be maps of high damage hazard or even maps of proposed control areas. Hopper, the DSS for rangeland grasshoppers being developed by the GHIPM Project (Berry et al. 1991; see chapter VI.2), currently has the ability to display density coverages. Future plans include a closer link to GIS procedures. Coulson et al. (1991) use the term “intelligent geographical information system” (IGIS) to describe systems that use a GIS and rule-based models to combine landscape data and knowledge from a diversity of scientific disciplines.

GIS—The Growth Years

GIS brings a great deal of analytical horsepower to the complex tasks associated with managing America’s natural resource base. However, expectations frequently associated with bringing GIS activities into the IPM realm frequently result in frustration for both pest managers and GIS professionals. Two major reasons why frustrations develop already have been mentioned: (1) People generally underestimate the resources required to get information into a GIS, and (2) GIS products are, at present, frequently complex enough to require specialized training. Another confounding problem that we should add is communication. Pest managers frequently lack indepth familiarity with computer systems and at times may distrust all the apparent complexity involved with GIS activities. GIS technicians, on the other hand, frequently lack the biological expertise necessary to assist the pest managers with creative solutions to a particular problem. These communication problems can be frustrating to those on both sides of the table and may result in little advancement toward the solution to the current pest management problem.

At this time, to expect pest management professionals, for example APHIS, Plant Protection and Quarantine (PPQ) plant health directors, to be trained as GIS technicians is no more realistic than expecting them to be able service their personal computers. Rather, it indeed is logical to provide plant health directors or similar professionals with general training that highlights GIS capabilities, so they can in turn direct the activities of GIS technicians or cooperators. At present, the revamped APHIS, PPQ Cooperative Agriculture Pest Survey (CAPS) is being used by a number of plant health directors from individual States to contract small GIS projects, frequently involving rangeland grasshoppers. This is a way of exploring the uses of GIS products with minimal investment and an attempt to become more knowledgeable about potential GIS applications in other pest management problems.

In general, GIS–pest management activities coordinated through the CAPS program have received good reviews from the participants largely because of the ability of plant health directors from individual States to specify the types of GIS products best suited to their particular needs. For the future of GIS and rangeland grasshopper IPM, today's interactions among plant health directors, GIS technicians, and researchers will be the basis for tomorrow's creative solutions.

References Cited

Berry, J. S.; Kemp, W. P.; Onsager, J. A. 1991. Integration of simulation models and an expert system for management of rangeland grasshoppers. AI Applied Natural Resource Management 5: 1–14.

Bryceson, K. P. 1989. Use of Landsat MSS data to determine the distribution of locust egg beds in the Riverina region of New South Wales, Australia. International Journal of Remote Sensing 10: 1749–1762.

Cigliano, M. M.; Kemp, W. P.; Kalaris, T. M. 1995. Spatiotemporal characteristics of rangeland grasshopper (Orthoptera: Acrididae) regional outbreaks in Montana. Journal of Orthoptera Research 4: 111–126.

Coulson, R. N.; Lovelady, C. N.; Flamm, R. O.; Spradling, S. L.; Saunders, M. C. 1991. Intelligent geographic information systems for natural resource management. In: Turner, M. G.; Gardner, R. H., eds. Quantitive methods in landscape ecology. New York: Springer Verlag: 153–172.

Johnson, D. L. 1989a. Spatial analysis of the relationship of grasshopper outbreaks to soil type. In: McDonald, L. L., et al., eds. Estimation and analysis of insect populations: proceedings of a conference; 25–29 January 1988, Laramie, WY. New York: Springer Verlag: 347–359.

Johnson, D. L. 1989b. Spatial autocorrelation, spatial modeling, and improvements in grasshopper survey methodology. Canadian Entomologist 121: 579–588.

Johnson, D. L.; Worobec, A. 1988. Spatial and temporal computer analysis of insects and weather: grasshoppers and rainfall in Alberta. Memoirs of the Entomological Society of Canada 146: 33–48.

Kemp, W. P.; Kalaris, T. M.; Quimby, W. F. 1989. Rangeland grasshopper (Orthoptera: Acrididae) spatial variability: macroscale population assessment. Journal of Economic Entomology 82: 1270–1276.

Liebhold, A. M.; Rossi, R. E.; Kemp, W. P. 1993. Geostatistics and geographic information systems in applied insect ecology. Annual Review of Entomology 38: 303–327.

Lockwood, J. A.; McNary, T. J.; Larsen, J. C.; Cole, J. 1993. Distribution atlas for grasshoppers and the Mormon cricket in Wyoming 1988–92. Misc. Rep. B-976. Laramie, WY: University of Wyoming and Wyoming Agricultural Experiment Station. 117 p.

Power, J. M. 1988. Decision support systems for the forest insect and disease survey and for pest management. Forestry Chronicle 64: 132–135.

Riley, J. R. 1989. Remote sensing in entomology. Annual Review of Entomology 34: 247–271.

Tappan, G. G.; Moore, D. G.; Knausenberger, W. I. 1991. Monitoring grasshopper and locust habitats in Sahelian Africa using GIS and remote sensing technology. International Journal of Geographical Information Systems 5: 123–135.

Reference Cited—Unpublished

Kemp, W. P. 1992. Annual report for grasshopper population dynamics. In: Cooperative Grasshopper Integrated Pest Management Project, 1992 annual report. Boise, ID: U.S. Department of Agriculture, Animal and Plant Health Inspection Service: 39–44.