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Data Management System for the Spruce Budworm Pheromone Trapping Network: User's Guide

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ABSTRACT

A data management system for spruce budworm pheromone trapping data has been developed to operate on a MS-DOS platform running Windows. The system produces contour maps of moth captures that can be used in a geographic information system (GIS). A graphic user interface (GUI), written in Visual Basic, actively links the system components. The GUI allows the user access to a database to enter and manipulate data. Point data are interpolated (and extrapolated) into complete spatial coverage using a geostatistical technique known as block kriging. The system uses a series of public domain FORTRAN software programs (GSLIB) for analysis and in-house developed C++ programs for formatting and parameter file creation. The steps are highly automated using defaults calculated from the data set and "rules of thumb". Idrisi, which is a fully functional and inexpensive raster-based GIS, is linked to the system. Maps can be exported to other GIS formats; however, to produce publication quality maps, the user can export maps from the GIS to CorelDRAW! from within the GUI.

RÉSUMÉ

On a développé un système de gestion des données sur la capture de la tordeuse des bourgeons de l'épinette au moyen de pièges à phéromones; ce système tourne sur une plate-forme MD-DOS sous Windows. Il produit des cartes d'isolignes des niveaux de capture des insectes, cartes qui peuvent être utilisées dans un système d'information géographique (SIG). Une interface utilisateur graphique, rédigée en Visual Basic, relie dynamiquement les composantes du système. Cette interface permet à l'utilisateur d'accéder à une base de données dans laquelle il peut entrer et manipuler des données. Par interpolation et extrapolation des données recueillies, on obtient une couverture spatiale complète par la technique géostatistique du krigeage de blocs. Le système utilise une série de programmes FORTRAN du domaine public (GSLIB) pour l'analyse, et des programmes C++ développés à l'interne pour le formatage et la création de fichiers de paramètres. Les étapes du processus sont fortement automatisées grâce aux valeurs par défaut calculées à partir de l'ensemble de données et à des "règles pratiques". Idrisi, un SIG à images tramées fonctionnel et peu coûteux, est relié au système. Les cartes peuvent être exportées dans d'autres formats de SIG; toutefois, pour produire des cartes avec une qualité publiable, l'utilisateur peut les exporter du SIG vers CorelDRAW depuis l'interface graphique.

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INTRODUCTION

The spruce budworm, *Choristoneura fumiferana* (Clements), is the most serious defoliator of spruce (*Picea* spp.) and balsam fir (*Abies balsamea* (L.) Mill.) trees in the boreal forest of North America. The species is transcontinental, occurring from Newfoundland to Alaska and down into the northeastern US.

Females of the spruce budworm produce a powerful sex pheromone. The identification of this pheromone (Sanders and Weatherston 1976) allowed the development of a monitoring program for spruce budworm using sex pheromone traps. During the CANUSA Spruce Budworms Project the program was accelerated and resulted in a coordinated monitoring program across eastern North America. The program has now been further expanded to include the Prairie provinces (Sanders 1992, Sanders and Lyons 1993).

The rationale for the monitoring program is described in detail by Sanders (1992). Briefly, sex pheromone traps are far more sensitive and efficient than conventional branch sampling techniques and can track changes taking place at extremely low budworm densities between outbreaks. When set to monitor the same locations annually, pheromone traps can be used as an early warning system, detecting increasing population densities several years before defoliation is evident. Moreover, by establishing the relationship between moth catch and larval density, catches can also be used to indicate when populations have reached threshold densities that can be assessed more definitively by conventional sampling techniques. Protocols for the deployment and handling of the traps were outlined by Allen et al. (1986) and subsequently updated by Sanders[1].

Spatial Analysis

Conventional sampling of spruce budworm determines the number of insects per branch or unit of foliage. Conventional sampling and pheromone trapping generate point data. That is, samples for an area are collected at a single point. The number of samples collected is limited by available resources — labor, materials, and logistical costs — so it is usually not possible to sample all areas of interest. If the resulting data are plotted on a map using different symbols for population level categories, the end result is often a mosaic of dots with little interpretable pattern. Using point data, it is difficult to estimate population levels in areas between the sample points.

Complete spatial coverage resulting from aerial surveys or satellite imagery showing insect caused depredations (e.g., defoliation or tree mortality) are some of the few exceptions of indices of population density that are not point data. Complete spatial coverage is required for most geographical information system (GIS) applications. Contour map data can be electronically digitized into polygons or rasters from survey maps for use in a GIS. Year-to-year changes can be determined using map algebra in the GIS. Unfortunately, by the time that defoliation is apparent from the air or space, the time and the options available for forest management response are greatly reduced. Other population thematic data cannot be used in GIS-based predictive models if the data are in point format. Therefore, there is a need to transform point data into complete spatial coverage in a meaningful way. One solution to the problem is provided through the use of geostatistical techniques (Liebhold et al. 1993). These

[1] Sanders, C.J. (in prep.) Pheromone traps for predicting spruce budworm outbreaks: A user's guide. Nat. Resour. Can., Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON.

numerical methods, as the name implies, have their origins in geological explorations. Geostatistics provides the mathematical tools required to interpolate between sample points. Significant advances have been made in adapting these methods to forest entomological problems (Gage 1990, Liebhold et al. 1993, Lyons and Sanders 1993).

This manual describes a series of software tools, incorporating geostatistical techniques, that have been developed to produce contour distribution maps of male moth captures of the spruce budworm in pheromone traps for GIS analysis. The geographic location of each trap grid is defined using UTM (Universal Transverse Mercator) coordinates (Snyder 1987). The world is divided into 60 UTM zones that run from pole to pole. Each zone encompasses 6 degrees of longitude. Contiguous trap coverage (excluding traps in Alberta and Saskatchewan) occurs from zone 15 in western Ontario to zone 22 in eastern Newfoundland. For the Pheromone Trapping Network, the location of the traps within a zone is defined by a two-digit easting and a three-digit northing. This defines the location of the traps to the nearest 10 km by 10 km grid. Ten consecutive years of data are being analyzed from about 700 trap locations within the distribution of spruce budworm in North America. Contour intervals represent "isomoths" or regions of equal moth numbers or categories. The long term goal is to use these software tools to analyze patterns of spruce budworm populations and to develop models using these techniques to predict budworm outbreaks. This system also serves as a model to demonstrate the utility of the techniques for other entomological point data. This manual assumes that you are familiar with the Microsoft Windows operating environment, and that you have already installed the programs using the instructions in Lyons and Sanders[2].

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[2] Lyons, D.B., Sanders, C.J. (in prep.) A data management and map interpolation system for spruce budworm pheromone traps. Nat. Resour. Can., Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON.

GRAPHIC USER INTERFACE


SBW
System

When the *SBW System* icon is activated from Windows, the following graphic user interface (GUI) window will open.

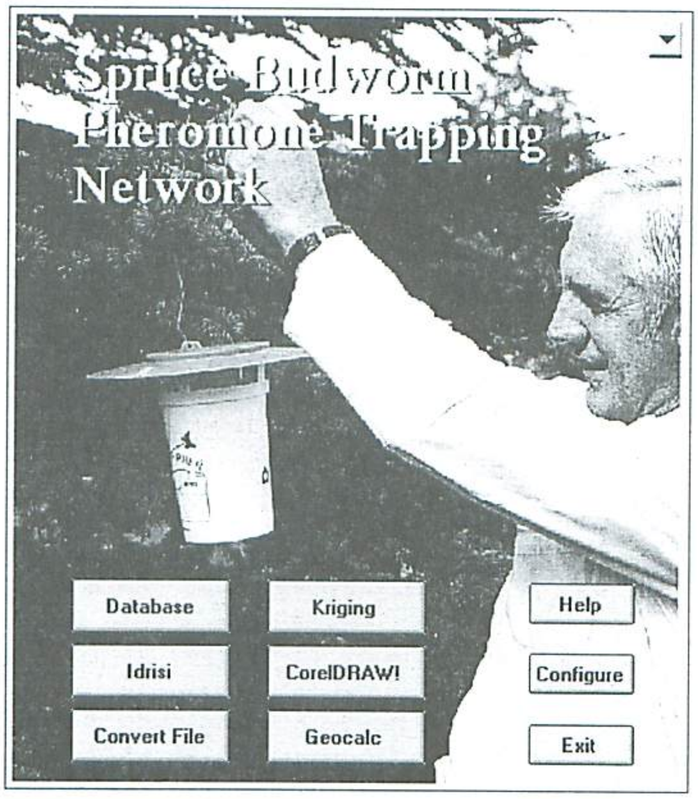


Figure 1. The graphic user interface (GUI) of the data management system for the spruce budworm pheromone trapping network.

The GUI is written in the Visual Basic Version 4.0 programming language. This window allows you to navigate through the system. There are six large buttons on the left side of the window, with the following functions:

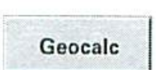
Opens the Trap Management Database for manipulation of the data.

Accesses the geostatistical module for conversion of point data into contour interval maps.

Accesses the geographical information system.

Launches the structured drawing program.

Launches a file conversion utility.



Runs the Geographic Calculator (Blue Marble Geographics, Gardiner, Maine), a map projection conversion program.

In addition, there are three smaller buttons on the right side of the window with the following functions:

Runs a Windows *Help* utility — essentially a hypertext version of this manual.

Allows you to custom configure the system for a specific computer.

Closes the program.

The modules and functions assigned to the GUI are shown in the following flowchart.

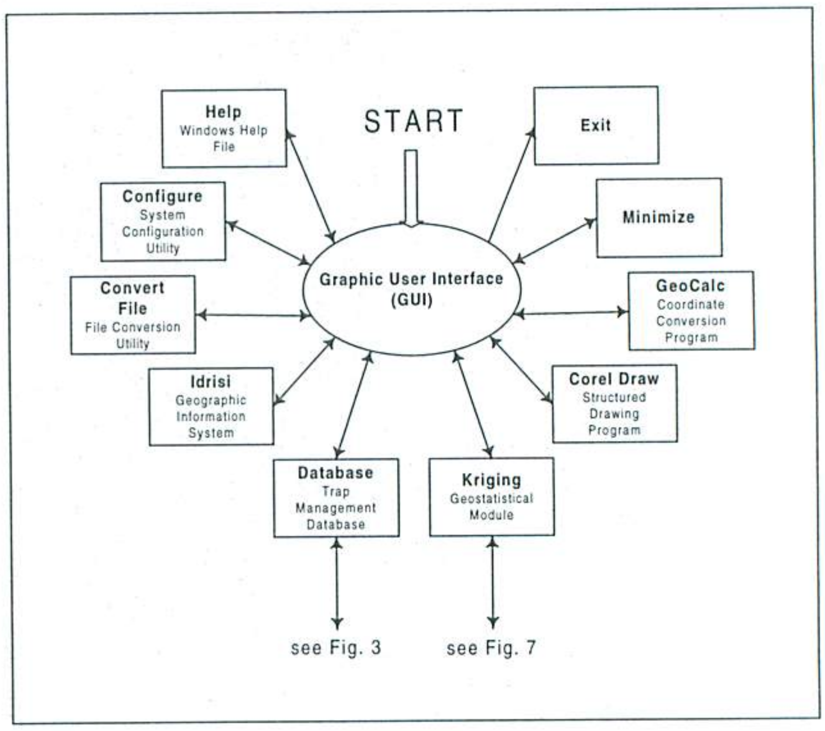


Figure 2. A flowchart showing the modules and functions that are accessed from the GUI.

A flowchart of the steps for editing and manipulating pheromone trap data in the Database module is shown in Figure 3.

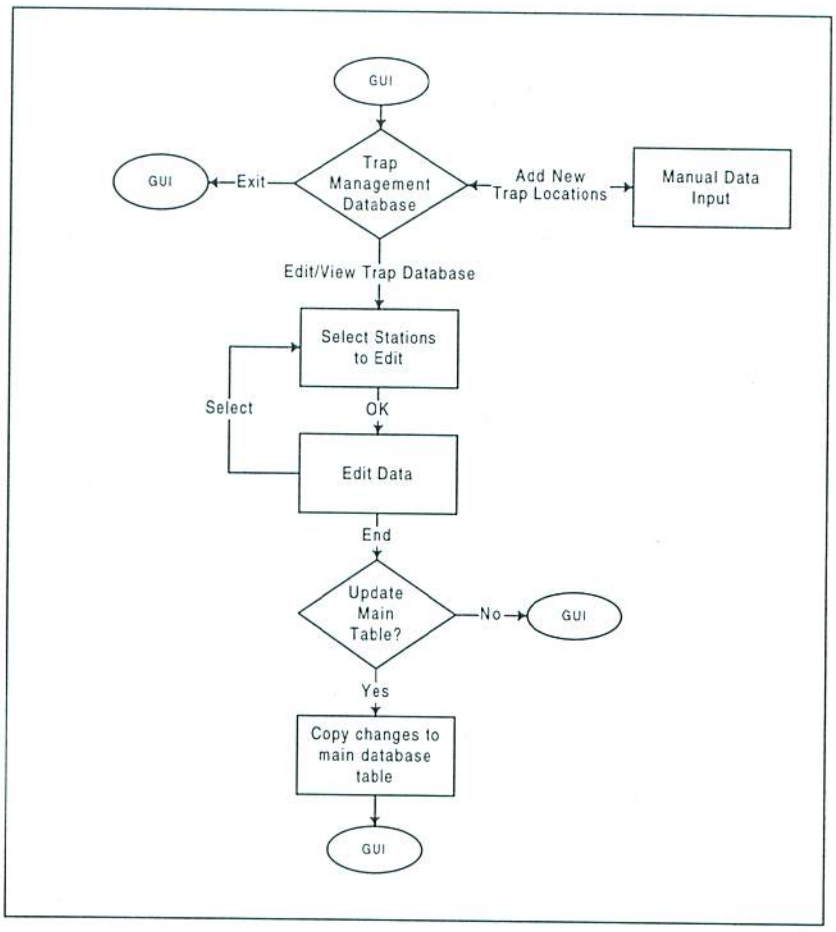


Figure 3. A flowchart detailing the steps for editing and manipulating data in the pheromone trap database.

Click the *Database* button on the GUI to open the Microsoft Access Version 2.0 database file. The following Trap Management Database window is displayed on the screen.

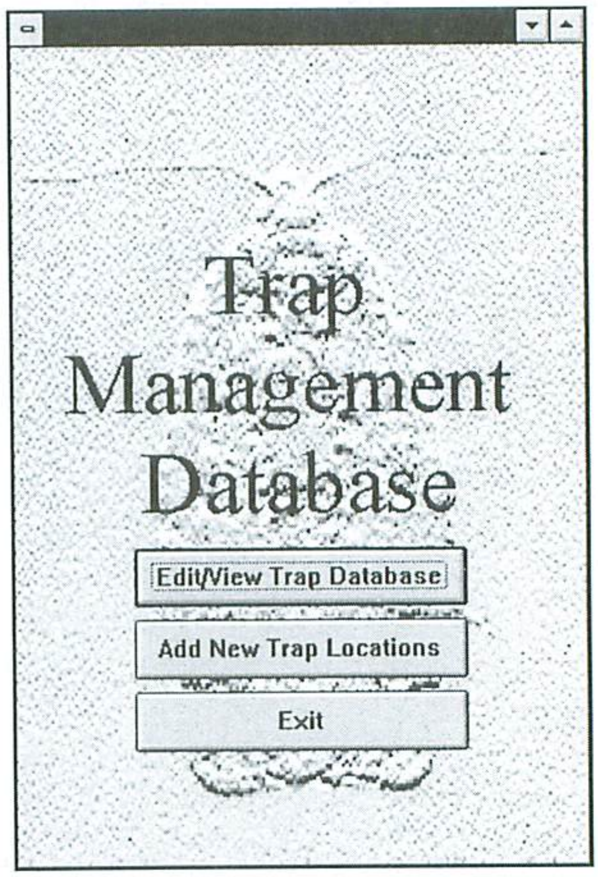
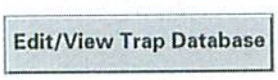


Figure 4. The Trap Management Database window in Microsoft Access.

This database file (e.g., SBW.MDB) contains all the data tables, screen forms and associated programs to edit and view the data. There are three options from this window:

Allows the user to enter new UTM locations.



Allows the user to work with existing data.

Closes the database and returns the user to the GUI.

Click the *Edit/View Trap Database* button. This will open the following *Select Stations to Edit* window.

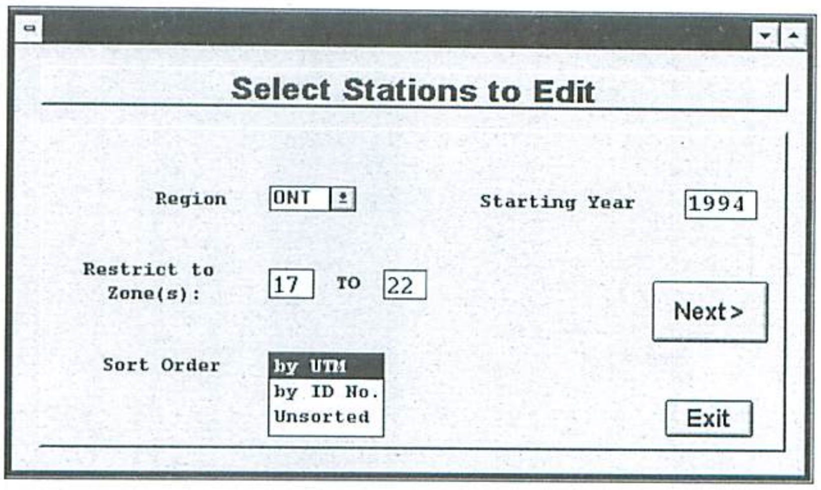


Figure 5. The data selection window for editing and viewing data in the Trap Management Database.

You are prompted to select a data set for editing or viewing from a predefined set of regions for a specific year. The six predefined regions, which can be selected from a pull-down list, are Ontario (ONT), Quebec (QUE), Maritime Provinces (MAR), Newfoundland (NFLD), Prairie Provinces (NOR) or United States (USA).

You are also asked to provide a *Starting Year*. Any year from 1984 to 2000 can be typed into the text window. If the *Starting Year* text box is left blank, 1984 is selected. (If you enter a year outside this range, you will get the error message *No data available for that year!*)

Next, you must select a *Sort Order*. The options are *by UTM* coordinate system (i.e., 2-digit zone, 3-digit easting, 4-digit northing, with no spaces), *by ID No.* or left *Unsorted*. Each sample location is assigned a unique *ID No.* in the database.

You can select one or more UTM zones for editing by typing a zone number (e.g. 16) in the text box labeled *Restrict to Zone(s)*. When a value is entered in this box, a second text box opens, preceded by the word *TO*, allowing a range of values to be entered (e.g., 16 to 18). For the pheromone trap data, zone numbers range from 11 in Alberta to 22 in Newfoundland.

Once the desired starting point for editing is defined, click the *Next* button. This closes the *Select Stations to Edit* window and opens a data editing and viewing window like the following.

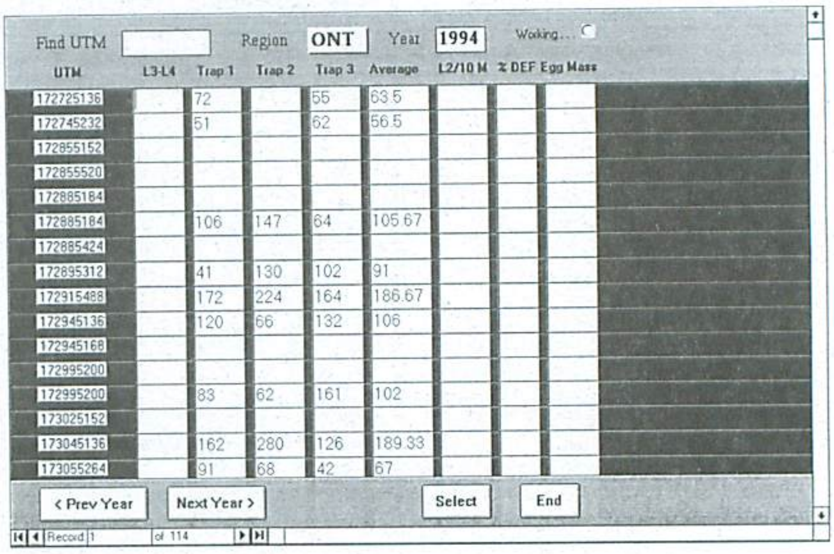


Figure 6. Data editing and viewing window in the Trap Management Database.

The editing and viewing window consists of three sections, a header, a footer, and a detail section.

The header displays the *Region* and *Year* selected and the titles for the data columns. The header's *Find UTM* text box allows you to locate a specific UTM coordinate. Type a UTM value, in the same format as described previously, into the text window and press the <Enter> key and the system will search the database for that coordinate and display it in the first line of the detail section. The circle labeled *Working...* will darken when information is being processed.

The detail section contains the selected data. Each row represents one pheromone trapping location. The first column displays the UTM coordinates of the sample location while columns 3 to 5 show the number of male moths captured in the three traps at that location. Column 6 displays the average for the three traps. This figure is automatically calculated as data is entered in the other three columns; however, if the cooperator providing the data only gives average values, these can be entered directly into the average column.

Additional columns in the detail section allow for input of auxiliary data. Columns 2, 7, 8, and 9 provide space for the number of 3rd and 4th instar larvae per branch (L3–L4), the number of 2nd instar larvae per 10 sq. m of foliage (L2/10M), the percent defoliation (% DEF), and the number of egg masses per branch (Egg Mass), respectively.

The footer section of the form contains four buttons. The *Prev Year* and *Next Year* buttons allow you to move backwards and forwards through the years of data. Pressing the *Select* button will return you to the data selection window. The *End* button exits the data editing and viewing window and returns you to the GUI. As you exit the database, a small window opens asking *Update Main Table?* Select *YES* or *NO* depending on whether or not the changes to the file are to be saved.

The following flowchart describes the functioning of the geostatistical module (Figure 7).

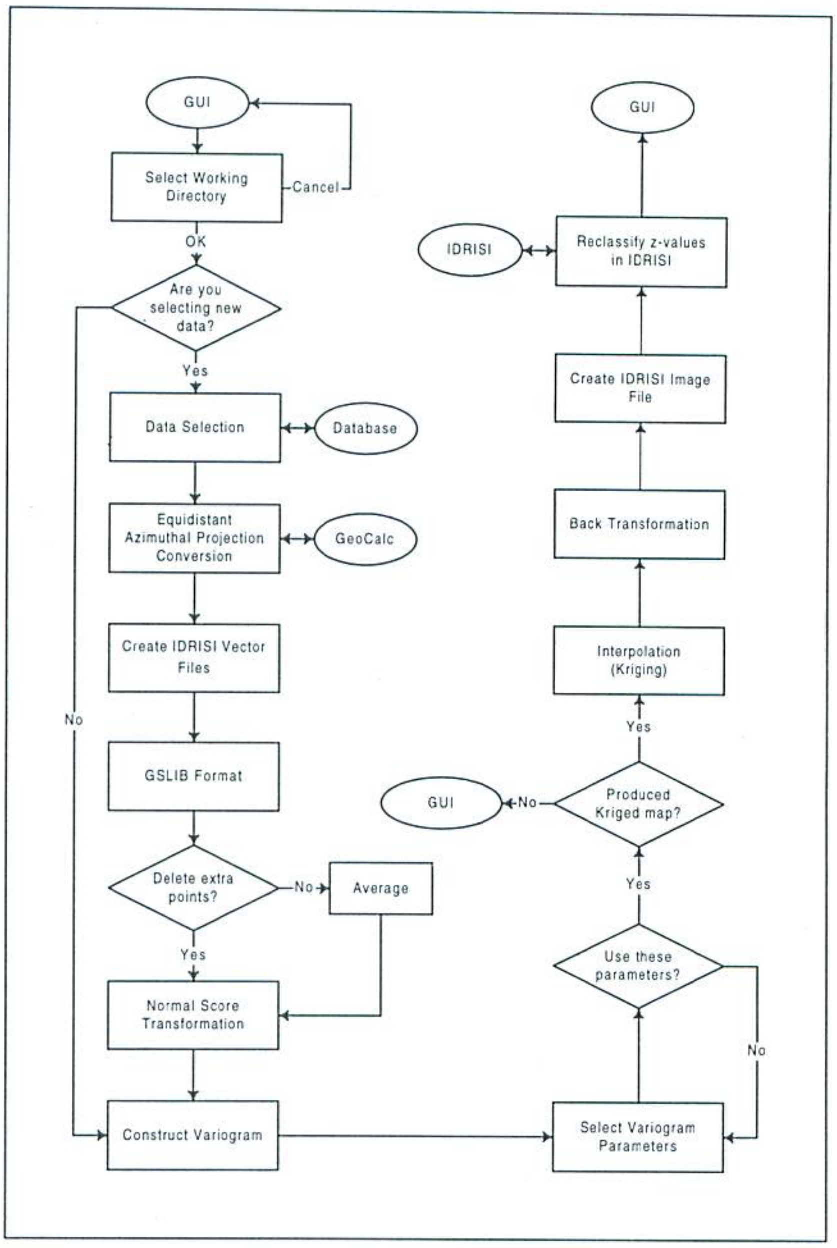


Figure 7. A flowchart showing the analysis steps in the kriging (geostatistical) module of the data management system for spruce budworm pheromone traps.

Like the GUI, this module is a shell program written in Visual Basic. Its purpose is to automate the interpolation of point data to raster map coverage in a meaningful way.

Launch the geostatistical module by selecting *Kriging* from the GUI.

Select Working Directory

When the geostatistical module is opened, the following window will prompt you to select a path to the working directory.

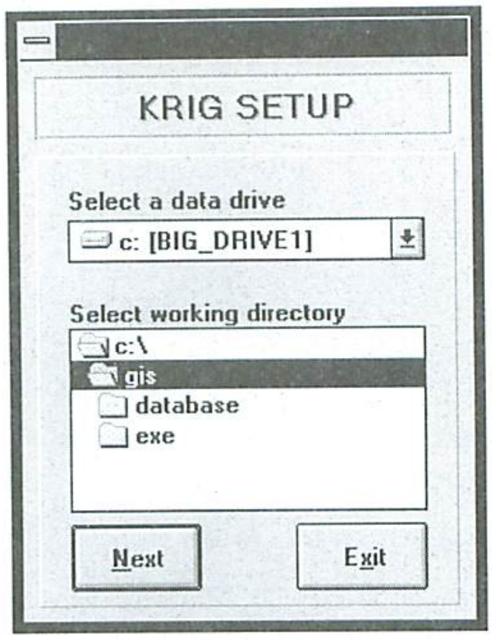


Figure 8. Data directory selection window in the kriging module.

The working directory is the drive and directory where all the output files from the various steps will be written. (An explanation of these output files is provided in Appendix 1.) Select the data drive and working directory, then click the *Next* button.

Select Data Set

Next, the *Action Request* window opens and asks the question *Are you selecting new data?*. A *No* response allows you to continue working with a previously selected data set.

Click on *Yes*, and the program opens the following two new windows.

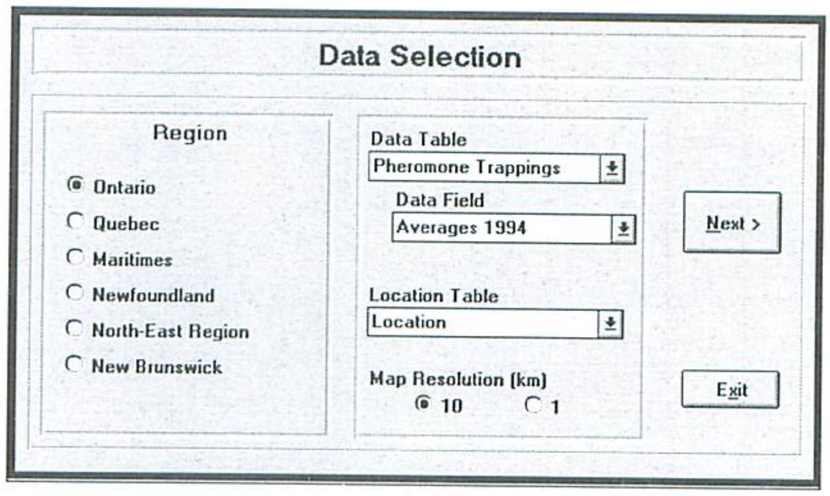


Figure 9. Data selection window in the kriging module.

The *Data Selection* window (Figure 9) allows you to select a region and year for processing.

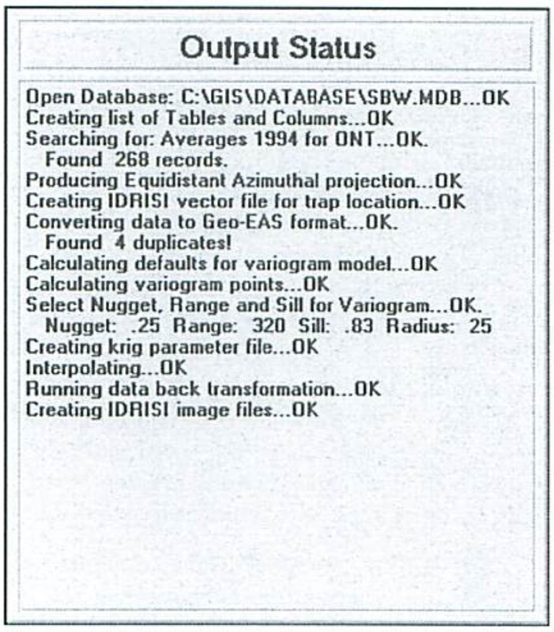


Figure 10. Output status window of the kriging module, after completion of analysis, showing output text.

The *Output Status* window (Figure 10) is strictly an output window and allows you to track the progress of the analysis.

In the *Data Selection* window, click on a region name or on the circular button beside a region name. Select the *Data Table, Data Field and Location Table* to be mapped, then click on the *Map Resolution (km)* for the resulting map.

When the selection is complete, click the *Next* button. The Data Selection window will close, and the text *Searching for:...* appears in the Output Status window, indicating that the appropriate dynaset is being selected from the Trap Management Database via a dynamic link from the Visual Basic program.

Next, a small window, like the following, lists the number of records found.

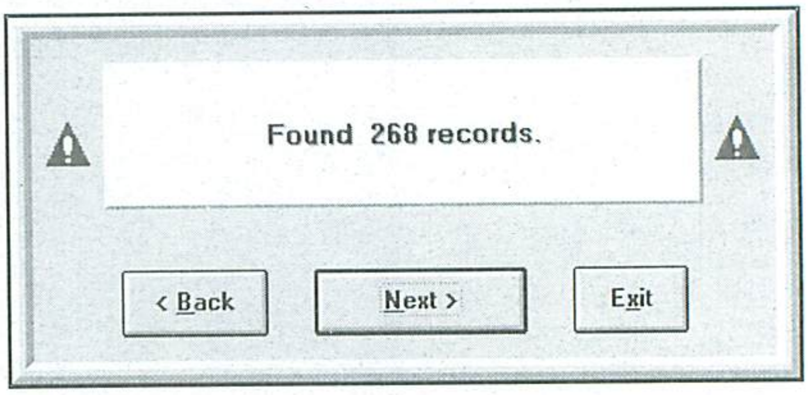


Figure 11. Information window stating the number of records selected from the database.

At this point, you can either select the *Back* button and go to the previous *Data Selection* window, *Exit* the program or click the *Next* button in this window to continue.

The output filename (Appendix 1, Example 18), although not displayed, is made up of the three letter region code, plus the last two digits of the year, followed by the extension ".PTS". Thus, the output filename for 1992 data from Quebec would be QUE92.PTS. The output file contains the sample point locations in latitude/longitude coordinates.

Equidistant Azimuthal Projection Conversion

Next, *Producing Equidistant Azimuthal Projection* is displayed in the output window to indicate that the selected data are about to be converted from the Geodetic (latitude/longitude) coordinate system to an equidistant azimuthal projection. An equidistant projection is used for the interpolation procedure, since it requires that we work in real world distances between points. At this point the geostatistical module opens The Geographical Calculator. The opening screen with the company logo is briefly displayed and then the conversion window is displayed. In the conversion window, the conversion systems (predefined for each region) are displayed. The coordinates within a region are specified in positive and negative distances (m), north or south (Y coordinate) and east or west (X coordinate) of a point in the centre of the region. You do not need to provide any input at this step.

Once the conversion is completed the program indicates the number of points processed from the input file to the output file. The output filename for the conversion consists of the input file, preceded by the letter E for equidistant (Appendix 1, Example 19). So, the input file QUE92.PTS would produce the output file EQUE92.PTS.

A second information window opens at this point and gives the same information about the number of points processed and the input and output filenames. Click *OK* to continue. Close The Geographic Calculator window by clicking the button on the upper left corner or opening *File* from the menu bar and selecting the menu item *Exit*.

Create Idrisi Vector Files

Creating IDRISI vector file for trap location (Appendix 1, Example 28) is displayed in the output window indicating that this file has been created. This file can be used, at a later step, to display the pheromone trap locations on the created contour map in the GIS.

GSLIB Format

The next message, *Converting data to Geo-EAS format*, indicates that the data has been converted to the input format (Appendix 1, Example 4) required by the GSLIB (Deutsch and Journel 1992) geostatistical programs. At this step a window, like the following, indicates the number of duplicate coordinates.

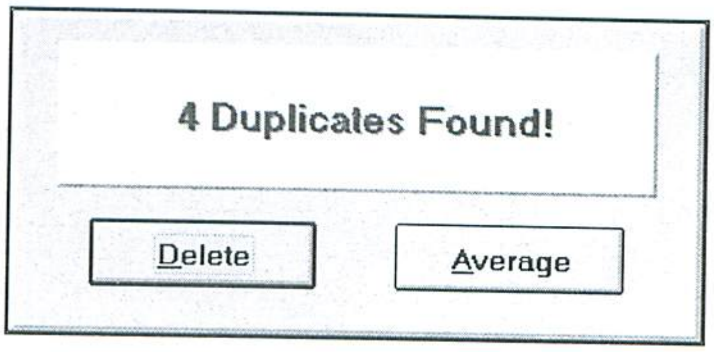


Figure 12. Information window stating the number of duplicate records with option buttons to select how to treat the duplicates.

The GSLIB routines cannot handle multiple records with the same coordinates. You are offered two options for dealing with the duplicates: you can either click the *Delete* button to delete the extra points, in which case the first records encountered will be used in the interpolation, or you can click the *Average* button, in which case the data for duplicate coordinates are averaged.

Construct Variogram Model

The message *Calculating defaults for variogram model...* indicates that the system is beginning to construct the variogram.

A variogram is a function that relates the autocorrelation between points as a function of distance between points. The calculation is based on the assumption that points closer together are more closely related.

The first step in the process is to transform the z-values to normal scores, thereby stabilizing the variance. The transformation is accomplished using the GSLIB utility NSCORE. All the GSLIB routines (Deutsch and Journel 1992) were obtained by the authors as FORTRAN source code and compiled for use as Windows programs on a PC platform.

Parameter files for all the GSLIB programs can be displayed in Windows Notepad prior to execution. If you are an experienced user, you can make changes to the parameters before executing the program. A sample parameter file for NSCORE is shown in Appendix 1, Example 16.

The transformation utility produces the normal scores data file NSCORE.DAT (Appendix 1, Example 2) and the transformation table NSCORE.TRN (Appendix 1, Example 20).

While the program is executed from the geostatistical module, the NSCORE output screen is displayed in a window. The characteristics of the selected data set are displayed in a window titled *Process Message*, which shows the number of data points, the extents of the x and y coordinates, the minimum and maximum z-values (i.e., the number of male moths), the suggested maximum separation, and parameters relating to lag classes for the variogram. The x and y extents are displayed in kilometres and the minimum dimension of the shell of points is indicated as being in the x or y direction. The system uses an isotropic variogram model and assumes that the autocorrelation is equal in all directions. The *Suggested Maximum Separation is* defined as half the width of the narrowest dimension of the shell of data points (Liebhold et al. 1993). The system attempts to use 20 lag intervals with at least 30 pairs of points in the first lag class. Less than 30 pairs of points reduces the reliability of variogram (Liebhold et al. 1993). If the minimum number of lag intervals is not achieved, the system reduces the number of lag intervals until 30 pairs is achieved. If 30 pairs of points is not possible, processing continues but a warning message is displayed in this window. Parameters nlag, xlag, and xltol, which are displayed in the window, are the number of lag intervals, unit separation distance, and lag tolerance, respectively.

Next, the system opens the Windows Notepad and displays the file GAMV2.PAR. This is the parameter file for the GSLIB routine GAMV2 (Deutsch and Journel 1992) that constructs the variogram. If you are an experienced user, you could change parameter values at this point; usually, however, this window is closed by clicking the button on the upper left corner or opening *File* from the menu bar and selecting the menu item *Exit*.

The user must now fit a variogram model to the variogram data. The message *Select Nugget and Range for Variogram Model* is displayed in the output window, and a *Variogram Plot* window like the following will open.

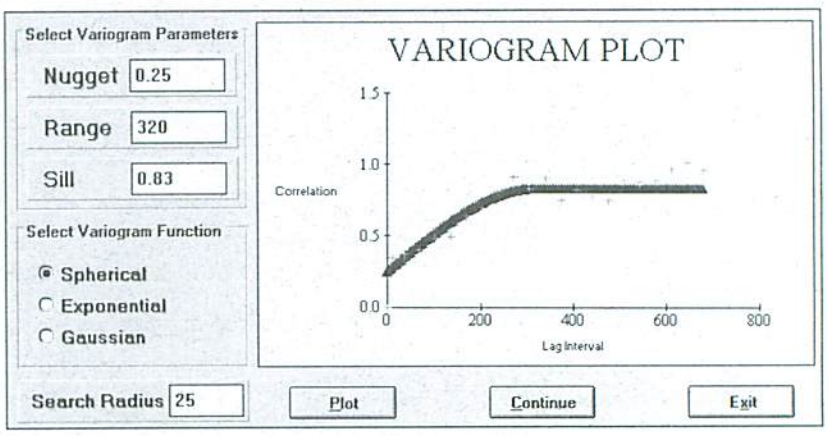


Figure 13. Variogram plot window in the kriging module.

This window contains a graph of observed variogram class values. You must now modify the parameters by trial and error until you have created a plot with a good fit. This model will then be used in the interpolation procedure. (Models must be fitted this way, rather than by a nonlinear regression technique, because of the disproportionate weighting of lag classes.)

In the upper left corner of the window is the section titled *Select Variogram Parameters*. Here you may enter parameter values for the model. Three parameters are required: *Nugget, Range,* and *Sill.*

The nugget is the Y value at which the proposed model intersects the Y axis. This represents the local discontinuity of the data and the reason the model does not pass through the origin. The sill is the Y value where the data reaches a plateau and the range is the lag interval where the Y values reach the plateau, that is the distance over which sample points are autocorrelated.

Below the parameter values, select *Variogram Function*. The three optional semivariogram models (Figure 14) used in the system are:

(1) a spherical model;

$$\gamma(h) = \begin{cases} c_0 + c\left[1.5\frac{h}{a} - 0.5\left(\frac{h}{a}\right)^3\right], & \text{if } h \le a \\ c_0 + c, & \text{if } h > a \end{cases}$$

(2) an exponential model; and,

$$\gamma(h) = c_0 + c\left[1 - \exp\left(-\frac{h}{a}\right)\right]$$

(3) a Gaussian model;

$$\gamma(h) = c_0 + c\left[1 - \exp\left(-\frac{h^2}{a^2}\right)\right]$$

where γ(h) is the semivariance, c_0 is the nugget variance, c is the structural variance, h is lag interval, and a is the range parameter (actual range for spherical model). The sum of c_0 and c is the sill. Selection of model type is determined subjectively, depending on which model adequately reflects the distribution of points.

When these values have been estimated, click the plot button and the chosen function, using selected parameter values, is fitted to the data points on the graph. Improve the fit of the model by selecting new parameter values until you find the fit that looks best.

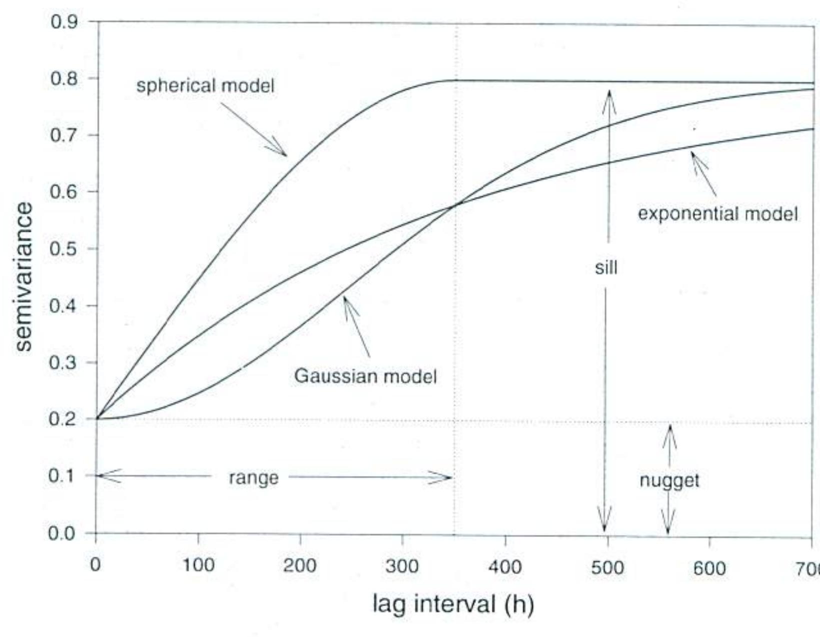


Figure 14. A hypothetical variogram showing the nugget, sill, and range. Three model types with the same parameter values are shown.

You may also select the search radius in the *Variogram Plot* window. This is the value the interpolation algorithm uses to determine the (linear) distance that it will search for points to use in its estimation. The default value in the pheromone trapping network is 150 km and can be changed by an experienced user by typing a new value into the text box. The 150 value has no biological basis but was selected based on ranges of observed data and is a value that produces a minimum of unestimated cells.

When you are satisfied with the values, click the *Continue* button.

Interpolation (Kriging)

An *Action Request* window reminds you of the selected values and asks *Use these parameters?*. If you were to click *No* at this point, you would be returned to the model development window.

Click on *Yes*. The output window will display the message *Creating krig parameter file*, and the Windows Notepad program will open, displaying the file OKB2D.PAR. This is the parameter file for the GSLIB routine (Deutsch and Journel 1992) OKB2D that carries out the two-dimensional ordinary kriging to interpolate between sample points. The experienced user can modify this file. When you have finished, or if you do not wish to modify the parameters, close Notepad by clicking the button on the upper left corner or selecting Exit from the File menu.

Next, an *Action Request* window asks *Produce Kriged Map?*. A *No* response at this point would stop processing and return you to the GUI. The files are kept and available when you reenter the system.

Click on *Yes* to run the OKB2D routine. The line *Interpolating...* appears in the output window and the screen goes blank. The OKB2D output window is displayed indicating kriging is in progress.

The routine uses the input file NSCORE.DAT (Appendix 1, Example 2) and produces the file OKB2D.OUT (Appendix 1, Example 9) that contains the kriged estimates. Another file, OKB2D.DBG, is also created and contains the debugging information. It is not used further.

Back Transformation

The next line to appear in the *Output Status* window is the line *Running data back transformation*. The output window from the GSLIB (Deutsch and Journel 1992) routine BACKTR appears on the screen. This routine performs a back transformation that converts the estimated z-values in normal scores back to number of male moths.

The input file is OKB2D.OUT and the output file is OKB2D.BTR (Appendix 1, Example 1). NSCORE.TRN is the transformation table (Appendix 1, Example 20).

Create Idrisi Image File

The message *Creating IDRISI image file* in the output window means that the output from the back transformation has been converted to an Idrisi image file format. The message *Creating IDRISI.DOC file* indicates that the companion document file is also being created. The Idrisi GIS system requires both types of file for displaying raster data.

The image file, with the extension .IMG, contains the kriged estimates for each raster in a single column. The .DOC file (Appendix 1, Examples 5 and 6) contains the spatial information to plot these rasters, including the number of columns and rows and the X and Y extents for the data.

Reclassify z-values in Idrisi

The line *Reclassifying z-values* in the output window means that the system is about to reclassify the z-values (i.e., estimated number of male moths) into discrete categories. This is because the interpolated values are continuous data and must be classified into categorical data for contour mapping. The classification system used by the pheromone trapping network is shown in Table 1.

Table 1. Reclassification values used in Idrisi to produce contour map of moth captures.

Reclassified value	Range of moth captures
1	1-10
2	11-30
3	31-100
4	101-300
5	301-1000
6	1001-3000
7	>3000

At this point, you should see the information window titled *Krig* containing the message *Kriging Completed.* This means the geostatistical module has completed processing. Click the *OK* button to return to the GUI.

Idrisi

To display the kriged output map, click the *Idrisi* button from the GUI to open the geographical information system. The Idrisi menu system will appear.

Use the arrow keys to select *Display* from this menu and press <Enter>. The Display submenu will open. Select *Color* by pressing the <Enter> key when this item is highlighted. You will be prompted to enter the name of the file you want to display. Enter the name of the reclassified image file, without the .IMG extension (which is assumed). So, for the file REMAR90.IMG, you would enter "REMAR90".

When you are prompted to enter the palette you desire, select *4* for *User-Defined palette.* At the prompt *Enter the name of the palette file (".pal" extension assumed),* enter *krig* to select the file KRIG.PAL (Appendix 1, Example 10). The program responds with *Do you wish a legend.* Select *1* for *Yes.*

Next the program asks the question *Do you wish to display factors by hand (default = "n").* Press the <Enter> key, for the default no option. The contour map will be displayed. To display a posting of sample points over the contour map, press *v* for vector. *Enter file name:* is displayed at the bottom right corner of the screen. Enter the name of the vector point file (Appendix 1, Example 28) created in the geostatistical module. Do not add the .VEC extension: it is assumed.

When Idrisi prompts you to *Enter color code*, provide a number between 0 and 15. It doesn't matter what number is provided, because Idrisi uses a default color. A vector map can also be overlaid on the contour map, if one is available, by using the *v* option. The coordinates of any point on the map and its z-value can be obtained by typing *c* or *x*, moving the cursor to the desired point, and pressing the right mouse button.

A kriged contour map of pheromone trap catches for Ontario in 1992 follows.

The contour map produced can now be manipulated using any of the Idrisi GIS functions. For more information about Idrisi consult the user's guide (Eastman 1992a), technical reference manual (Eastman 1992b), and update manual (Eastman 1993).

To convert a raster image file to a vector file to export the map for use in CorelDRAW!, select *Polyvec* from the *Spatial Data Management* submenu. The program prompts you to enter the name of the image to be processed and the vector file to be created.

To eliminate the background, type *Y* for yes when you are asked if there is a background polygon that should not be processed, and enter the number *0* when you are prompted to enter the identifier number of the background polygon. To bypass the next prompt (i.e., select the default *n*), press <Enter> when asked *Do you wish to process only the polygons listed in a values file (y/n).*

The next step in producing a vector output file is to select *Outpost* from the Import/Export submenu. This creates a vector file in a format suitable for importing into CorelDRAW!. Alternatively, an image file can be exported in raster format as a .TIF file and then displayed in CorelPHOTO-PAINT!, but the vector format provides more flexibility.

Exit the program and return to the GUI by selecting *Exit Menu System* from the Idrisi main menu or by pressing the escape key twice.

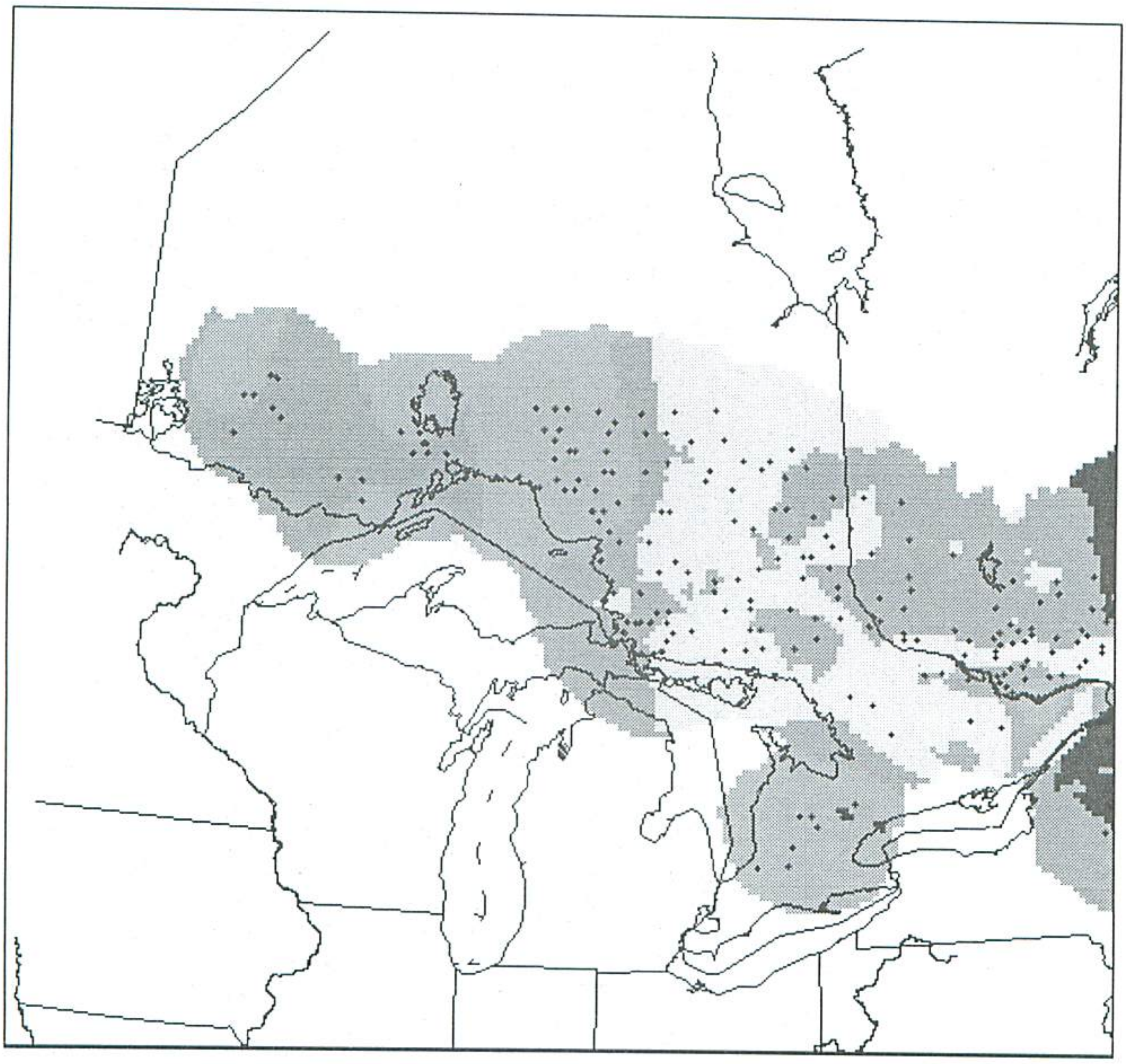


Figure 15. A kriged contour map of pheromone trap catches for Ontario in 1993 displayed in Idrisi with geographic areas overlaid as vectors. The symbols are a vector overlay of sample points.

We have chosen CorelDRAW! version 4.0 as our structured drawing program, although other products would be adequate. It can be used to produce publication-quality maps like the one below, which is a contoured map of budworm male moth numbers for northeastern North America in 1994.

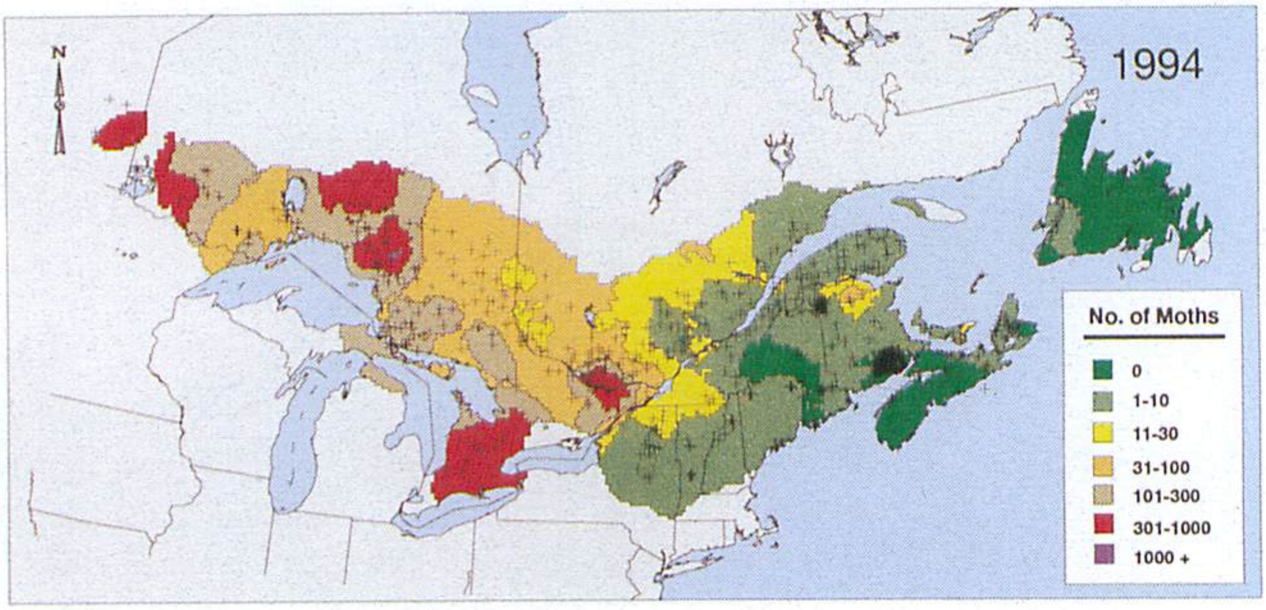


Figure 16. A kriged output map of pheromone trap catch for northeastern North America in 1994 displayed and annotated in CorelDRAW!.

CorelDRAW! is a vector-based drawing program. Vector files exported from Idrisi using outpost are in Adobe Illustrator format with the file extension .AI.

CorelDRAW!

Select *CorelDRAW!* from the GUI. CorelDRAW! will open, with a blank workspace. From within CorelDRAW!, go to the *File* menu and select *Import*. At the file directory window, select *Adobe Illustrator* as the file type, then select the directory and filename. The vector image retains the look of a raster file, which serves to illustrate the resolution at which it was created. The imported image can be layered over or under other geographic themes (e.g., landmasses, bodies of water or political boundaries).

For more information about CorelDRAW! consult the user's manual (Corel Corporation 1993).

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APPENDIX 1. OUTPUT FILES FROM THE PHEROMONE TRAPPING NETWORK

The following files (excluding KRIG.PAL) are created by one complete execution of the data management system for the spruce budworm pheromone trapping network. Ideally, all output files should be directed to a unique data directory to ensure ease of backup or deletion. The file KRIG.PAL (see below) is an Idrisi palette file and must be kept in the data directory. The files are listed below in alphabetical order by file type extension. Within the file type description the files are listed alphabetically. In some cases only a sample of the text in the file is presented to illustrate the format. In the examples containing only samples of the file contents, three periods (i.e., ...) represent a continuation of the data.

Back Transformation File

The file OKB2D.BTR (Example 1) is the output file of kriged estimates after back transformation from normal scores to number of male moths. The first line in the file is the title, while the next four lines are the number of variables and their names. The data starts on the 6th line of the file. The columns are kriged estimate, estimate of variance, and back transformed value. A value of -9 represent no estimate.

```
OKB2D ESTIMATES WITH: Normal Score Trans
 3
Estimate
Estimation Variance
Back Transform
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
...
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
    -9.000000    -9.000000    1.000000
  6.050000E-01  8.680000E-01   100.000000
  6.070000E-01  8.590000E-01   100.000000
  8.460000E-01  9.050000E-01   163.287900
  8.720000E-01  8.860000E-01   175.281500
  9.090000E-01  8.730000E-01   190.264300
  9.320000E-01  8.650000E-01   192.788700
  9.890000E-01  8.640000E-01   201.340000
     1.055000  8.690000E-01  214.098100
...
```

Example 1. File OKB2D.BTR.

The file GEOEAS.DAT (Example 2) is the data exported from the database converted to GEOEAS format suitable for input into the GSLIB routine NSCORE. The first line is the title and the next four lines define the variables and their position in the file (i.e., 3 variables, X, Y, Z). Beginning on line five, the three fields are x coordinate (km), y coordinate (km), and the average number of male moths at that point.

```
Krig Source Points
3
X
Y
Z
-540.097        68.592      87.0
-514.432       116.192    1008.0
-526.021       -74.400     100.0
-514.718        25.272     318.0
-517.129       -85.471      57.0
-512.703       -45.665      65.0
-500.471       -26.787     224.0
-479.509      -109.945      78.0
-475.037       -70.042      15.0
-455.758        99.300     213.0
...
```

Example 2. File GEOEAS.DAT.

Data Files

The file NSCORE.DAT (Example 3) is the data in the same format as GEOEAS.DAT, with the addition of a fourth field, the z-value converted to normal score values.

```
Normal Score Transform:Krig Source Points
4
X
Y
Z
Normal Score value
-540.0970     68.5920     87.0000    .4907
-514.4320    116.1920   1008.0000   1.9777
-526.0210    -74.4000    100.0000    .5980
-514.7180     25.2720    318.0000   1.2943
-517.1290    -85.4710     57.0000    .2333
-512.7030    -45.6650     65.0000    .2908
-500.4710    -26.7870    224.0000   1.0877
-479.5090   -109.9450     78.0000    .4494
-475.0370    -70.0420     15.0000   -.6774
-455.7580     99.3000    213.0000   1.0388
...
```

Example 3. File NSCORE.DAT.

Debugging File

The file OKB2D.DBG (Example 4) is the output file for debugging produced by the GSLIB routine OKB2D.

```
    -9.000000      -9.000000
    -9.000000      -9.000000
    -9.000000      -9.000000
    -9.000000      -9.000000
    -9.000000      -9.000000
...
  6.052146E-01   8.677540E-01
  6.072496E-01   8.590689E-01
  8.463833E-01   9.045353E-01
  8.722976E-01   8.857850E-01
  9.086769E-01   8.725592E-01
...
```

Example 4. File OKB2D.DBG.

IDRISI Image Document Files

Files with the extension .DOC are Idrisi image document files. Two document files are produced, corresponding to the two image files (.IMG) created. The document file for kriged output image has the name convention E+*region*+*year*.DOC (Example 5).

```
file title      : Raw Krig output image
data type       : real
file type       : binary
columns         : 179
rows            : 129
ref.system      : plane
ref.units       : m
unit dist.      : 1.0000000
min. X          : -699160.
max. X          : 1090388.
min. Y          : -346186.
max. Y          : 947259.
pos'n error     : unknown
resolution      : 10000
min. value      : -1.0
max. value      : 5606.
value units     : moth catches
value Error     : unknown
flag value      : none
flag def'n      : none
legend cats     : 0
```

Example 5. File EQUE92.DOC.

The document file for the reclassified image has the name convention RE+*region*+*year*.DOC (Example 6).

```
file title      : Reclassification of rawkrig
data type       : integer
file type       : binary
columns         : 179
rows            : 129
ref. system     : plane
ref. units      : m
unit dist.      : 1.0000000
min. X          : -699160.0000000
max. X          : 1090388.0000000
min. Y          : -346186.0000000
max. Y          : 947259.0000000
pos'n error     : unknown
resolution      : 10000.0000000
min. value      : 0
max. value      : 6
value units     : moth catches
value error     : unknown
flag value      : none
flag def'n      : none
legend cats     : 0
```

Example 6. File REQUE92.DOC.

Idrisi image files consist of a single column of numbers, each number representing the value of an individual raster. Image files do not contain any positional or georeferencing information. Providing this coordinate information is the function of the image document files. The document files contain file attribute names in the first column and their associated values preceded by a colon in the second column.

Idrisi Vector Document File

The file with the name E+*region*+*year*.DVC (Example 7) is an Idrisi vector document file and is the companion file to the .VEC file with the same name. The DVC file contains attributes of the vector file such as the title, file type information, reference system information, and data extents in x and y directions.

file title	: Krig Source Points
id type	: integer
file type	: ascii
object type	: point
ref.system	: plane
ref.units	: m
unit dist.	: 1.0000000
min. X	: -699159.61
max. X	: 1090387.75
min. Y	: -346185.89
max. Y	: 947258.79
pos'n error	: unknown
resolution	: unknown

Example 7. File EQUE92.DVC.

Idrisi Environment File

The file IDRISI.ENV (Example 8) is an Idrisi environment file that defines where the program finds files, what file conventions are being used (e.g., file extensions), and the reference units being used. The file also provides Idrisi with information on color schemes for the screens and the ports for communicating with devices. In the example, the default drive and path to the data files is c:\krigtest\.

IDRISI Operating Environment	:	
default data drive	:	c:
default data path	:	\krigtest\
image file extension	:	.img
image documentation file ext.	:	.doc
vector file extension	:	.vec
vector documentation file ext.	:	.dvc
attribute values file extension	:	.val
attribute values doc. file ext.	:	.dvl
default reference units	:	m
banner color	:	9
dialog color	:	10
message color	:	12
digitizing tablet port	:	com1
plotter port:		com2
printer port:		lpt1

Example 8. File IDRISI.ENV.

IDRISI Image Files

Files with the extension .IMG are image files for producing raster maps in the Idrisi geographical information system. As indicated in their associated .DOC files, both image files are binary and unprintable. They can be converted to ASCII text files, in Idrisi, if necessary. The first file, with the name convention E+*region*+*year*.IMG (e.g., EQUE92.IMG), is the raw kriged values after back transformation. The second image file, with the filename convention RE+*region*+*year*.IMG (e.g., REQUE92.IMG), is the reclassified rasters (i.e., the final product).

Output File

OKB2D.OUT (Example 9) is the output file from the GSLIB routine OKB2D. The first two lines are the title and the next three lines define the columns. The two columns are the estimated kriged value for each raster and its associated estimation variance.

```
OKB2D ESTIMATES WITH: Normal Score
Transform:Krig Source Points
2
Estimate
Estimation Variance
 -9.000  -9.000
 -9.000  -9.000
 -9.000  -9.000
 -9.000  -9.000
 -9.000  -9.000
...
   .605    .868
   .607    .859
   .846    .905
   .872    .886
   .909    .873
...
```

Example 9. File OKB2D.OUT.

IDRISI Palette File

KRIG.PAL (Example 10) is an Idrisi custom palette file used by COLOR to produce the selected colors for the contour interval map of male moth density classes. Only the first 8 values (i.e., 0-7) are used, and they represent the seven categories of moth captures plus a null color. Each line in the file represents a color. The first column is the color's number while the numbers in the next three columns represent the strengths (values range from 0-63) of the three additive primary colors used to compose the color. The three columns are red, green, and blue.

0	46	46	46
1	0	44	4
2	11	63	0
3	62	63	0
4	63	46	0
5	50	0	13
6	63	0	2
7	44	0	51
8	63	63	63
9	46	46	46
10	0	61	63
11	63	63	63
12	63	63	63
13	63	63	63
14	63	63	63
15	63	63	63

Example 10. File KRIG.PAL.

Parameter Files

Files with the extension .PAR are parameter files. There are two types of parameter files used in the system. The first type (Examples 12, 14, 15) are parameter files used for processing internal data.

The second type (Examples 11, 13, 16, 17) are parameter files required as input by the GSLIB FORTRAN routines with the same names.

```
                         Parameters for BACKTR
                         *********************

START OF PARAMETERS:
okb2d.out                      \data file
1                              \Gaussian variable
-1.0e+21  1.0e+21              \trimming limits
okb2d.btr                      \output file for data
nscore.trn                     \input transformation table
1  5608                        \minimum and maximum data value
1  0.0                         \lower tail option/parameter
1  0.0                         \upper tail option/parameter
```

Example 11. File BACKTR.PAR.

```
1 1 1
okb2d.btr rawkrig.img
179 129
```

Example 12. File BTRTOIDR.PAR.

```
                    Parameters for GAMV2
                    ********************

START OF PARAMETERS:
nscore.dat                      \Data File in GEOEAS format
1 2                             \columns for x and y coordinates
1 4                             \nvar; column numbers . . .
-1.0e+21 1.0e+21                \tmin, tmax (trimming limits)
gamv2.var                       \Output file for variogram
20                              \nlag - the number of lags
20.41                           \xlag - unit separation distance
10.20                           \xltol- lag tolerance
1                               \ndir - number of directions
90.000 90.0 10000.00            \azm(i),atol(i),bandw(i)i=1,ndir
1                               \number of variograms
1 1 1                           \tail, head, variogram type
```

Example 13. File GAMV2.PAR.

```
2 2 1
EQUE92.pts EQUE92.vec
```

Example 14. File GEOTOIDR.PAR.

```
2 1 3
EQUE92.vec geoeas.dat
```

Example 15. File IDRTOGSL.PAR.

```
                    Parameters for NSCORE
                    ********************

START OF PARAMETERS:
geoeas.dat                          \data file
3 0                                 \variable, weight
0.0e+00 1.0e+21                     \trimming limits
nscore.dat                          \output file for data
nscore.trn                          \output transformation table
```

Example 16. File NSCORE.PAR.

```
                    Parameters for OKB2D
                    ********************

START OF PARAMETERS:
nscore.dat                          \data file
1 2 4                               \columns for x,y, and variable
-1.0e+21 1.0e+21                    \data trimming limits
okb2d.out                           \output File of Kriged Results
1                                   \debugging level: 0,1,2,3
okb2d.dbg                           \output file for debugging
179 -699.0 10.0                     \nx,xmn,xsiz
129 -346.0 10.0                     \ny,ymn,ysiz
1 1                                 \x and y block discretization
5 8                                 \min and max data for kriging
150.0                               \maximum search radius
1 0.25                              \nst, nugget effect
1 300.0 0.90 0.00 1.00              \it,aa,cc,ang1,anis: structure 1
```

Example 17. File OKB2D.PAR.

Point Files

Files containing point data are given the extension .PTS. The file extracted from Microsoft Access database has the name *region+year*.PTS (Example 18). The file contains the columns: station identification number, latitude, longitude, and z value.

```
1/1 48.068 -79.456 86.
7/1 48.514 -79.172 1007.
8/1 48.514 -79.172 437.
9/1 46.803 -79.1 99.
10/1 46.803 -79.1 48.
15/1 47.702 -79.067 317.
16/1 47.702 -79.067 121.
17/1 46.711 -78.972 56.
18/1 46.711 -78.972 37.
19/1 46.711 -78.972 33.
...
```

Example 18. File QUE92.PTS.

The data file after conversion to an Equidistant Azimuthal Projection has the name convention E+*region+year*.PTS (Example 19). The file contains the columns: station identification number, x coordinate, and y coordinate (i.e., equidistant azimuthal coordinates in metres).

```
1/1 68592.2184 -540096.5384
7/1 116191.8250 -514432.1393
8/1 116191.8250 -514432.1393
9/1 -74399.5966 -526021.0239
10/1 -74399.5966 -526021.0239
15/1 25271.9169 -514718.1884
16/1 25271.9169 -514718.1884
17/1 -85471.2279 -517129.3873
18/1 -85471.2279 -517129.3873
19/1 -85471.2279 -517129.3873
...
```

Example 19. File EQUE92.PTS.

Transformation File

The file NSCORE.TRN (Example 20) is the transformation look up table created as output by the GSLIB routine NSCORE and used in the back transformation by the GSLIB routine BACKTR. The columns in the file are original data values and normal scores values.

```
   1.0000  -2.9035
   2.0000  -2.5405
   2.0000  -2.3565
   2.0000  -2.2288
   2.0000  -2.1295
...
 138.0000    .7613
 139.0000    .7737
 141.0000    .7862
 146.0000    .7989
 146.0000    .8117
...
```

Example 20. File NSCORE.TRN.

Text Files

Files with the extension .TXT are text files that are used to transfer data between modules in the system. Text files are the simplest method of passing data, especially between the Visual Basic modules and the C++ .DLL's.

There are five text files created during execution of the system. BTPARM.TXT (Example 21) contains the minimum and maximum z values required for the back transformation.

```
1. 5607.
```

Example 21. File BTPARM.TXT.

EXTENT.TXT (Example 22) contains the minimum and maximum values of x and y in kilometres (i.e., the coordinate extents for the shell of sample points) as well as the minimum and maximum z values.

```
-699.16 1090.388
-346.186 947.259
1.0 5607.0
```

Example 22. File EXTENT.TXT.

OKPARM.TXT (Example 23) contains the data required in the construction of the GSLIB parameter file for the kriging routine OKB2D. The first two rows of the file contains the number of rasters (e.g., 179 by 129), lower limit (minimum x = -699 km, minimum y = -346) and increment (10 km) for the kriged output for the x and y directions. The third row is the search radius value and the last row is the nugget, range, sill, and model type.

```
179 -699 10
129 -346 10
150.
0.25 300. 0.9 1
```

Example 23. File OKPARM.TXT.

The code for the region being analyzed and the data year are written to the text file REGION.TXT (Example 24).

```
QUE
 1992
```

Example 24. File REGION.TXT.

XVPARM.TXT (Example 25) contains variogram model parameters. The first row is the search radius, while the second row contains the nugget, range, sill, and model type values.

```
150.
0.25 300. 0.9 1
```

Example 25. File XVPARM.TXT.

Value File

E+*region*+*year*.VAL (Example 26) is a value file containing the station number and z value (i.e., the number of male moths).

```
1 86.
2 1007.
3 437.
4 99.
5 48.
6 317.
7 121.
8 56.
9 37.
10 33.
...
```

Example 26. File EQUE92.VAL.

Variogram File

GAMV2.VAR (Example 27) is the output file from the GSLIB variogram routine GAMV2 for irregularly spaced two-dimensional data. Data from this file are used to make the variogram graph. The first line in the file is the title followed by the variogram values. The columns are lag number, lag separation distance, semivariance value, number of pairs in the lag interval, the mean of the data contributing to the head, and the mean of the data contributing to the tail. The latter two values are the same since the same variable is used for the head and tail.

```
Semivariogram          tail:Normal  Score    head:Normal Score  direction
1
  1      .000     .00000     542      .00001     .00001
  2    10.030     .35723      70      .25338     .25338
  3    22.026     .31290     502      .09939     .09939
  4    42.011     .40610    1008      .07285     .07285
  5    61.858     .48892    1246      .11605     .11605
  6    81.657     .53251    1448      .08335     .08335
  7   102.014     .56095    1672      .01033     .01033
  8   122.835     .56720    1624     -.02597    -.02597
  9   143.085     .59239    1830      .01019     .01019
 10   163.856     .65867    1742     -.01053    -.01053
 11   183.659     .75355    1800     -.07746    -.07746
 12   204.309     .73936    1788     -.02652    -.02652
 13   224.790     .74221    1644     -.01251    -.01251
 14   244.847     .80386    1704      .03577     .03577
 15   265.108     .72165    1654      .07306     .07306
 16   285.589     .88109    1666      .12783     .12783
 17   305.993     .88002    1566      .11417     .11417
 18   326.612     .85828    1542      .13615     .13615
 19   346.666     .94474    1470      .14010     .14010
 20   367.298    1.02809    1460      .11962     .11962
 21   387.626     .99114    1292      .13877     .13877
 22   408.185    1.08973    1410      .06388     .06388
```

Example 27. File GAMV2.VAR.

Idrisi Vector File

The file with the naming convention E+*region*+*year*.VEC (Example 28) is an Idrisi point vector file. Each sample point (i.e., pheromone trap location) is defined by two rows of data. The first row contains the vector number and the number of nodes in the vector (for point data, all values for number of nodes are 1). The second row for each vector is the x and y coordinates in metres for each node. This file can be used to display the sample points as an overlay on the contour map using the vector overlay command in Idrisi. Each vector file must have an associated document file with the extension .DVC (see above) to be used in Idrisi.

```
1 1
-540096.538400 68592.218400
7 1
-514432.139300 116191.825000
8 1
-514432.139300 116191.825000
9 1
-526021.023900 -74399.596600
10 1
-526021.023900 -74399.596600
15 1
-514718.188400 25271.916900
16 1
-514718.188400 25271.916900
17 1
-517129.387300 -85471.227900
18 1
-517129.387300 -85471.227900
19 1
-517129.387300 -85471.227900
...
```

Example 28. File EQUE92.VEC.

back transformation–A transformation used to convert normal score values back to z-values (i.e., number of moths).

contour interval–In a contour map, these divide attribute classes into areas of equal value.

contour map–A map in which lines are used to enclose areas of equal value or attribute.

dynaset–A subset of data stored in a database that was extracted using a query.

equidistant azimuthal projection–A map projection that conserves linear distances in a portion of the world projected onto a flat surface.

geodetic coordinate system–A map coordinate system that uses latitude and longitude values to position locations in two-dimensional space.

geographic information system (GIS)–A set of computer programs that stores, manipulates, displays, and analyses spatial data.

geostatistics–A set of statistical techniques originating in the geological discipline that utilize adaptations of regression techniques to analyze natural phenomena that have spatial continuity.

graphic user interface (GUI)–A graphical method of interacting with a computer wherein the user uses a pointing device (e.g., mouse) to select options from menu icons or lists.

hypertext–A system of writing and displaying text that allows parts of the document to be linked to other text. Clicking the mouse button while hypertext is selected by the cursor causes the cursor to move to new place in the file or to open a new file.

isotropic variogram model–This is a type of variogram that depicts spatial autocorrelation in all directions as opposed to individual directions.

kriging–A method in geostatistics for interpolating between data points that is based on the assumption that relationships are spatially consistent.

lag class–The distance grouping of pairs of points in a variogram. All points within a range of distances are in the same lag class.

lag interval–The distance over which autocorrelation is modeled in a variogram.

map algebra–This is a mathematical system wherein maps can be used as variables in arithmetic and Boolean equations.

normal scores–This is a type of transformation that is used to normalize a highly skewed frequency distribution of z-values.

nugget–One of the parameters used to define a variogram. This is the value of the variogram model when the lag distance is 0.

palette file–This is a file used by Idrisi to define the colors that will be displayed in a map.

point data–A point occupies a location or coordinate in two- or three-dimensional space but has no area. Point data defines an attribute value at that point in space.

polygon–In a vector-based GIS system, areas of equal value are enclosed within lines or vectors. Polygons are made up of vectors that have their starting point and ending point at the same location in space.

range–One of the parameter values used to define the variogram model. This is the lag distance over which pairs of points are autocorrelated and have not reached the plateau or sill.

raster–In a raster-based GIS system, images are composed of matrices of equal-sized cells, each having an attribute value. Groups of rasters with the same attribute value represent features.

search radius–In the interpolation process (i.e., kriging), the search radius defines the maximum distance that points can be separated to be included as pairs.

shell of points–The area defined by the distribution of coordinate points in space.

sill–One of the parameters used to define the variogram model. The sill is the sum of the structural and nugget variance. This is where the variogram reaches a plateau.

structural variance–The structural variance is the difference between the nugget and sill variances.

thematic data–Map data that relates to an individual subject or theme (e.g., moth captures, forest cover type).

unit separation–This is the distance between lag classes in a scatter plot of semivariance values.

Universal Transverse Mercator (UTM) coordinates–Coordinates that define spatial locations in a UTM map projection.

variogram–A variogram is a plot of the variance of pairs of points in space as a function of distance between pairs of points.

vector data–Data represented by lines that connect points or nodes in space.

z-value–In two dimensional space, coordinate points are defined by their x and y coordinates. The z-values are the values of the attribute (e.g., number of moths) at that point in space.