



manual

THE AVE SYSTEMS OF
GEOGRAPHIC INFORMATION FOR
THE ASSISTANCE IN THE
EPIDEMIOLOGICAL SURVEILLANCE
OF THE AVIAN INFLUENZA,
BASED ON RISK



Cover photographs:

Left image: Paul Bingham, an outbreak of HPAI in British, Columbia in 2004

Centre: E. León, INTA, Argentina

Right image: Kung, N., Morris, R., Jackson, R., Stevenson, M., Shortridge, K., Peiris, M., 2006. Avian influenza virus transmission in the live poultry marketing system in Hong Kong. In, *Proceedings of the 14th Federation of Asian Veterinary Associations Congress and the Food Safety & Biosecurity, and Epidemiology & Animal Health Management Branches of the New Zealand Veterinary Association*, Auckland, New Zealand, pp. 193 - 195.

THE AVE SYSTEMS OF GEOGRAPHIC INFORMATION FOR THE ASSISTANCE IN THE EPIDEMIOLOGICAL SURVEILLANCE OF THE AVIAN INFLUENZA, BASED ON RISK

This manual has been drawn up within the framework of the Agreement between the Food and Agriculture Organization of the United Nations (FAO) and the National Institute of Agricultural Technology (INTA), in the course of 2007. The English editing was done by Ms. Wendy Maharey from Massey University, Institute of Veterinary, Animal and Biomedical Sciences, EpiCentre.
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E-ISBN 978-92-5-106318-7 (PDF)

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Foreword

The poultry sector in Latin America and the Caribbean (LAC) contributes considerably to food security, economic development and poverty reduction. Poultry meat and eggs are the most consumed products of animal origin in the region and the Americas hold first place in global poultry production. To maintain this successful activity it is necessary to preserve high animal health conditions.

At global level, since 2003 many severe outbreaks of Highly Pathogenic Avian Influenza (HPAI-H5N1) in poultry and wild birds have occurred. This viral disease is disseminated through migratory wild birds, poultry farms with deficient biosecurity measures, transport of poultry birds and avian products, live bird markets and legal and illegal wild bird trade.

The HPAI – H5N1 epizootic had its origin in Asia, and was disseminated progressively to the Middle East, Europe and Africa. To June 2008 the disease was reported in 62 countries, and till today the American Continent has not been affected. However it is exposed to be affected due to: the migratory routes, poultry products trade, movements of persons and other risk factors.

Due to the international alarm caused by the rapid global spread of this disease, in early 2006 several countries requested urgent technical assistance from FAO with the purpose of improving their animal health prevention systems. FAO responded with four sub – regional emergency projects covering thirty-three member countries of LAC. These projects trained the professional staff of the countries in HPAI-H5N1 diagnosis and epidemiological surveillance to improve its early detection and control, in the case of an eventual disease introduction.

One of the most important technical assistance activities during regional project implementation, was the development of the AVE System of Geographical Information for Highly Pathogenic Avian Influenza Epidemiological Surveillance Assistance (based on risk), prepared by FAO through a cooperation agreement with the Argentina's Institute for Agriculture and Livestock Technology (INTA for its acronym in Spanish) and the collaboration of the Epidemiological Center of Massey University in New Zealand. The AVE system considers eight risk factors in the introduction of the HPAI-H5N1 in to LAC countries (borders, airports, highways, rivers and bodies of waters, places where Migrant Waterfowl congregate, distribution of backyard-fowl, and commercial-fowl). Data of each one of these factors are placed in a map to evaluate the risk for possible disease introduction and to carry out an epidemiological surveillance based on risk, reducing the surveillance operations cost of the national veterinary services in the region.

This AVE System Manual will be useful for the national veterinary service staff to elaborate HPAI –H5N1 national risk maps or other avian diseases analysis, also as a support for private sector technical staff and the veterinary schools. In addition to the manual, FAO will develop a pedagogical tool, an e-learning course to produce risk maps using the AVE system.

FAO hopes that the AVE system and this manual will contribute to strengthen the epidemiological surveillance systems to prevent the introduction or early control of the HPAI-H5N1 in Latin American, to protect the poultry patrimony of the region and the health of its people. FAO thanks Doctors Emilio León, Mark A. Stevenson, Caryl Lockhart, Sergio J. Duffy and Ernesto Späth for their personal efforts to develop the AVE system and this Manual.

Moisés Vargas-Terán

Animal Health Officer

FAO/SLS

History

Since the year 2003 there have been several outbreaks of Avian Influenza (AI) in wild birds and domestic fowl. Cases have also been detected in human beings. Highly pathogenic avian influenza is caused by AI virus subtype H5N1. The etiologic agent is spread in several ways: migrating wild birds, fowl operations with deficient biosafety, movement of fowl and fowl products, live fowl markets and legal and illegal wild bird trade.

The initial outbreaks of the disease were in East and Southeast Asia (Cambodia, China, Indonesia, Japan, Korea, Laos, Malaysia, Thailand and Vietnam). However, since the beginning of 2004 HPAI due to H1N5 affected a greater number of wild and domestic birds and advanced northwest towards Hong Kong (January 2004) through Japan, Korea, China, Mongolia to Kazakhstan and Russia (August 2005). In October 2005 HPAI was diagnosed in countries in the Balkans, Romania and Turkey. In February 2006 the H1N5 virus extended to 13 new countries: Iraq, Nigeria, Azerbaijan, Bulgaria, Greece, Italy, Slovenia, Iran, Austria, Germany, Egypt, India, France and Nigeria.

The American continent has not yet been affected by the HPAI H5N1 virus, but the different migratory routes of migrant waterfowl (from Eastern Siberia to Alaska or from Island via Greenland to North Canada), trade in fowl products, movement of people and other risk factors mean that the American continent is exposed and introduction of this virus may take place at any moment.

Due to all the aforesaid the Food and Agriculture Organization of the United Nations (FAO) has developed four Regional Technical Cooperation Projects for assistance of emergencies for the early detection and prevention HPAI subtype H5N1 in Latin America and the Caribbean:

- TCP/RLA/3103 (Caribbean): Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominican Republic, Dominica, Granada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Santa Lucia, San Vicente and the Grenadines, Surinam, and Trinidad and Tobago.
- TCP/RLA/3104 (Central America): Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama.
- TCP/RLA/3105 (Andean Region): Colombia, Ecuador, Peru and Venezuela
- TCP/RLA/3106 (Southern Cone): Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay

The general aim of these projects was to reinforce the capacity of the beneficiary countries to generate and share information on HPAI, with the aim of strengthening the early warning and early action plans in the face of an introduction of HPAI, especially through migrant birds and trade in wild birds.

Within the framework of these 4 regional projects, FAO signed a letter of agreement with the National Institute of Agricultural Technology (INTA), through its Veterinary and Agronomic Sciences Research Centre (Centro de Investigación en Ciencias Veterinarias y Agronómicas, CICVyA), in Castelar, Argentina, with the aim of:

“Developing a model to identify potential high risk areas for the introduction and spread of HPAI H5N1 virus, by use of a geographic information system (SIG), so that it may serve as support to actions of epidemiological surveillance of HPAI in the 33 beneficiary countries.”

Activities took place from January to November 2007.

In this manual, the model developed is presented, the necessary parameters for it to function are described and some results are shown, obtained with data from Argentina.

PART 1

Geographic information systems

Definition

A geographic information system (GIS), as defined by University of Edinburgh's Dictionary of GIS terms, is:

A computer system for capturing, storing, checking, integrating, manipulating, analyzing and displaying data related to positions on the Earth's surface. Typically, a GIS is used for handling maps of one kind or another. These might be represented as several different layers where each layer holds data about a particular kind of feature (e.g. roads). Each feature is linked to a position on the graphical image of a map.

The primary value of a GIS is that it defines precisely the location of objects and provides users with the ability to visualize the spatial arrangement of those objects. Knowledge of location allows complex calculations to be performed (such as working out the shortest route and the shortest travel time between two locations). For epidemiologists, the ability to visualize spatial data is a powerful method for describing the patterns of disease, and is a useful technique for identifying factors that potentially influence patterns of disease.

The elements of geographic data

Geographic data are built up from single elements, or facts, about the real world. In its crudest form, an element of geographic data (termed a datum) links:

- Place
- Time
- A descriptive property about place and time

For example, the statement: 'The temperature at 12 noon on 10 June 2003 at latitude 45° and longitude 60° was 25° Celsius' ties place and time to the property (or attribute) of atmospheric temperature. In many cases geographical data are slow to change and for this reason time is often omitted from geographic descriptions. On the other hand, atmospheric temperature changes constantly, so time is an important component of this type of representation.

The range of attribute information in geography is vast. The various types of attribute information may be classified as follows:

- Nominal: attributes are nominal if they are given names or titles in order to distinguish one entity from another. Place names are a good example of nominal attributes
- Ordinal: attributes are ordinal if their values take on a natural order. For example, agricultural land may be classed in terms of soil quality with class 1 representing the best, class 2 second-best and so on
- Numeric: examples include temperature, height, and weight. Values vary on a discrete (for example, integer) or continuous scale

Just as attributes can be classed into different types, so too can spatial objects. The various types of spatial object include:

- A point: a spatial object that has neither length nor breadth and therefore has a dimension of zero; points may be used to indicate spatial occurrences or events; point pattern analysis is used to identify whether occurrences or events are interrelated
- A line: a spatial object that has length but no breadth, and hence a dimension of one; used to represent linear entities such as roads, pipelines and cables which are frequently assembled to form networks
- An area: a spatial object of two dimensions of length and breadth; may be used to represent natural objects such as countries, state boundaries or agricultural fields; areas may bound linear features and enclose points
- A surface or volume: a spatial object of length, breadth and depth; used to represent natural objects such as river basins, canyons, and mountains; surfaces are frequently derived by interpolating between lower dimension measurements such as point measurements of height
- Time: often considered to be the fourth dimension of spatial objects

Spatial resolution

The classification of geographic data into object types is dependent on scale. For example, at a low level of resolution a farm may be represented as a single point. At a higher level of resolution the same farm may be better represented as an area, where the exact farm boundaries are explicitly defined. At an even higher level of resolution the farm may be represented as a surface where, in addition to boundary information, details of height, aspect and slope are provided.

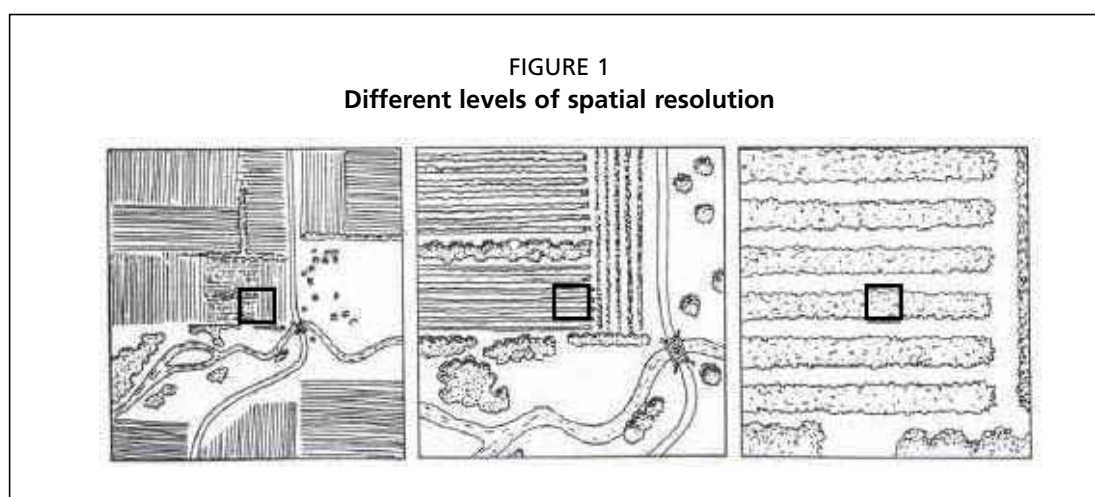
Figure 1 illustrates how, as spatial resolution increases, greater detail can be appreciated and the shape of spatial objects will change. Objects that appear as lines at low resolution (for example, in the left-hand and centre diagrams), are best represented by polygons when viewed at a high level of resolution (as in the right-hand diagram).

In principle, if we collected enough items of geographic information we would be able to build a complete representation of the world. In practice any representation that is made is partial in that it must limit the level of detail provided or ignore change that may occur through time. One common way of limiting detail is by ignoring information that applies to small areas, that is, to reduce the spatial resolution. A second way is to regard many attributes as remaining constant over large areas.

Spatial epidemiology involves viewing and querying spatial data and to do this efficiently a GIS is required. The activities that follow will introduce the software ArcView (from the Environmental Systems Research Institute, Redlands, CA, USA), one of the more commonly used GIS packages. Although the activities provided in these notes are described using ArcView, you will find that the principles remain the same for all GIS packages.

ARCVIEW EXERCISE 1

The data for this exercise can be found in the folder EJERCICIO 1 on the course CD-ROM. Copy the folder to the C:\ Directory on your computer.



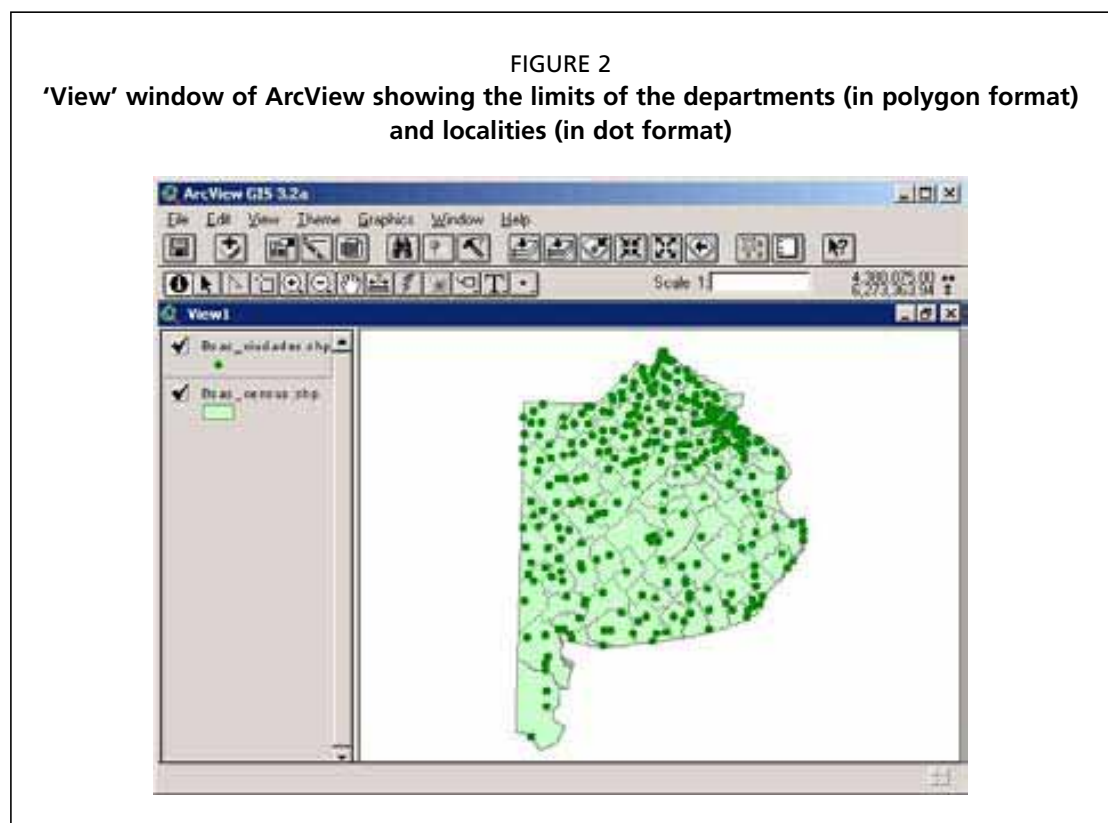
Start ArcView by double clicking the ArcView icon on the Windows desktop. The main ArcView window opens, which is called the ArcView Application window. You should enlarge it to full size for better viewing. Save the project to your working folder (FILE - SAVE PROJECT AS) giving it the name 'BUENOS_AIRES.'

Projects are used by ArcView to store details of the views, tables, charts and layouts which form part of an ArcView application. A project (*.APR) file also records the location of map ('shape') files and data files associated with the project. Be warned, if you move files that have previously been saved as part of an ArcView project the project file won't be able to load properly the next time you try to open it.

The ArcView interface consists of a collection of Views (maps), Tables (attribute data), Charts (graphs), Layouts (for printing) and Scripts (programme macros). Records (observations) in View, Tables and Charts are linked in the sense that selecting an item in one will select the same item in each of the other modes.

Create a view

Select the Views option in the ArcView Application window and click the New button. Select View, Add Theme (or click on the + button). Browse the file system in the Add Theme dialogue box to find the file BSAS_CENSUS.SHP file; double click on the name of the file or select it and click OK. Select the theme to make it active and use the mouse to place a tick in the check box adjacent to the name of the theme. The spatial features of the theme should appear. The outlines represent the department boundaries for Buenos Aires. Repeat this procedure for BSAS_CUIDADES.SHP (a shape file defining location of populated places throughout the province). You should obtain something similar to what is presented in Figure 2.



A View is a visual representation of spatial data and the attribute data associated with it. This is where the content and visual presentation of a map is defined. A View consists of layers of geographic information which in turn contain spatial features such as rivers or property boundaries. In ArcView these layers are collectively called Themes.

The View window consists of two sections. The section on the left is the Table of Contents for the View. It lists the themes which are part of the map display. The Table of Contents lists the themes and shows the symbols used to represent each theme. The check box next to each theme indicates if it is included in the map display.

Explore the effect of changing the order of the themes in the View window's Table of Contents. Themes on the top of the list are drawn on top of those below. You can change the order by dragging a particular theme up or down in the list using the mouse.

Zoom in on an area of interest by clicking on the Zoom In tool on the lower toolbar. You can zoom back to the full extent of the map by clicking on the option Full Extent under the View menu or by clicking on the Full Extent tool on the top toolbar.

Attributes of a feature in a theme

Make sure the View window is active. Maximize the View window and make the theme BSAS_CENSUS is active. It should appear highlighted (raised) in the Table of Contents section of the View window (click on the theme if it is not active).

On the lower toolbar, click on the Identify tool, move the pointer over an area unit (department) and click. The Identify Results box displays attribute information that is associated with the selected spatial feature. In this case you will see the contents of a series of fields linked to the selected spatial unit, one of them will be the name of the department (variable DEPARTAMTO). Other fields contain livestock statistics (numbers of livestock establishments, total numbers of cattle, sheep, pigs and goats in each department).

Repeat the above exercise for the BSAS_CIUDADES theme. Find the point which represents the town of Oriente. You may want to zoom in, in order to be able to better differentiate point locations. Remember that BSAS_CIUDADES has to be the active theme. When you are finished save your project file once again.

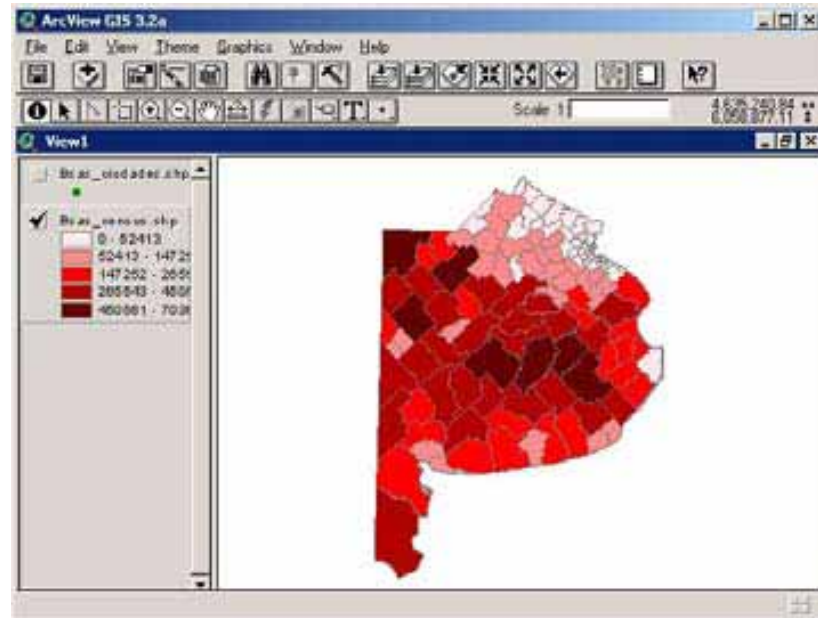
Attribute table

In the View window, make sure the BSAS_CENSUS theme is active (click on it). Select THEME - TABLE. The attribute table of the active theme BSAS_CENSUS appears as a new window with rows representing records (observations) and columns representing fields (variables). Check the table's properties by clicking on TABLE - PROPERTIES. A window with checked field names appears; uncheck some and see what happens after clicking the OK button.

Click on menu option Window and select BUENOS_AIRES.APR. You should now see the main Application window for the project. Minimize this window (don't close it). Select menu option Window again and click on Tile. You should now see the View window and the Attributes of BSAS_CENSUS window next to each other on the screen. Uncheck the theme BSAS_CIUDADES in the Table of Contents of the View window. Select observations in the attribute table. What happens in the map?

Close the window named Attributes of BSAS_CENSUS.

FIGURE 3
Choropleth map showing the total number of bovines by Department, in the Province of Buenos Aires



Draw a choropleth map

Make sure the View window is active and maximized and the box for the theme BSAS_CENSUS is checked (you see the map). You should uncheck the theme BSAS_CIUDADES.

Double click on the theme BSAS_CENSUS in the Table of Contents section; the Legend Editor opens. Under Legend Type, select Graduated Color, you will now also see the entry Classification Field. Select a Field (variable) from the Classification Field drop-down list (such as NBOVINOS, the total number of cattle in the department), click on the field name and an initial classification of the values in the field will be given.

Use the Classify button to change the classification. The default is Natural Breaks, but you could also try a quantile map or an equal interval map. Click the Apply button: a choropleth map will now be shown in the View window (see Figure 3).

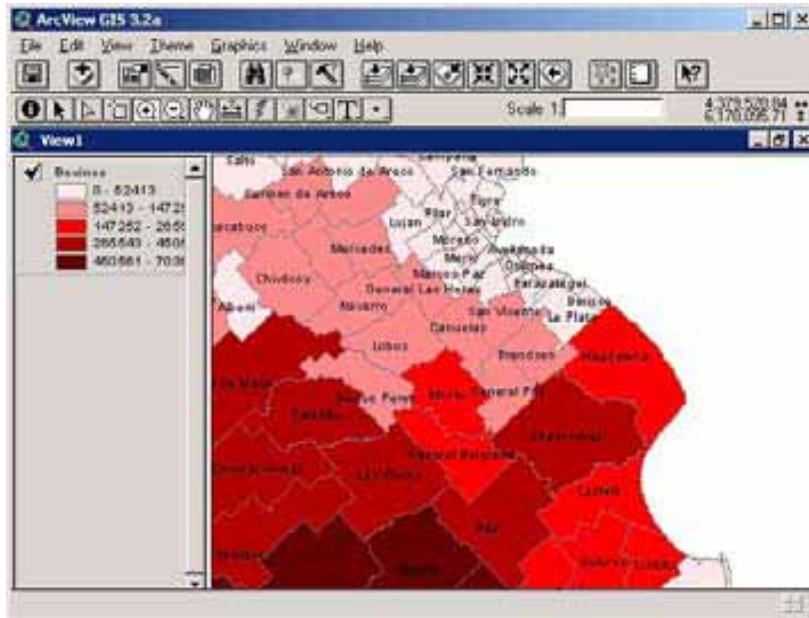
You may want to open the Legend Editor again and apply different color schemes by selecting different color ramps.

Create labels

Here we will label each of the departments on the map. First select an appropriate font size by opening the Show Symbol window under the menu option Window. Click on the fonts button and select a font size of 4. Close the Symbol window. Make sure the View window is active and maximized, and only the BSAS_CENSUS theme is checked and active. The BSAS_CIUDADES theme should be unchecked.

Click on the option Auto-label under the Theme menu. Select the label field DEPARTAMENTO, and then click the OK button. The map should now contain labels centered in each department. Zoom in to see the labels more clearly. The labels can be removed by selecting the option Remove labels under the Theme menu (Figure 4).

FIGURE 4
Detail of the map presented in Figure 3,
with the addition of the name of each Department



Generate a map layout

Menu option FILE - PRINT can be used for simple maps. For this exercise we will produce a more sophisticated layout.

Select menu option VIEW - LAYOUT, and then in the Template Manager form select Landscape as the template. ArcView will automatically generate a map display including title, legend and scale bar. You can edit the individual components in the map by selecting them. The title of each theme's legend can be edited in the View window via the Properties form (accessible through THEME - PROPERTIES) (see Figure 5).

More examples of maps

The attribute data in the above presented example was displayed as a choropleth map. ArcView can produce two other types of maps which are useful for presenting quantitative data: dot maps and chart maps.

Make sure the View window is active and maximized and the tick box for the choropleth theme BSAS_CENSUS is checked (you see the shaded map). You should uncheck BSAS_CIUDADES. Double click on the choropleth theme BSAS_CENSUS in the Table of Contents section to open the Legend Editor. Under Legend Type, select Dot. The objective is to represent different densities of a variable through different densities of randomly placed dots inside each area unit. In this case you could use the variable ESTABLECIM (the number of establishments in each department) as the density field. Click on the Calculate button. ArcView will automatically estimate the number of establishments to be represented by each dot. Before you close the Legend Editor select a pattern to distinguish missing (null) values, a cross-hatched pattern would be a suitable choice. Click on the Apply button and close the Legend editor. On the map there should now be different densities of dots

FIGURE 5
Example of the layout window

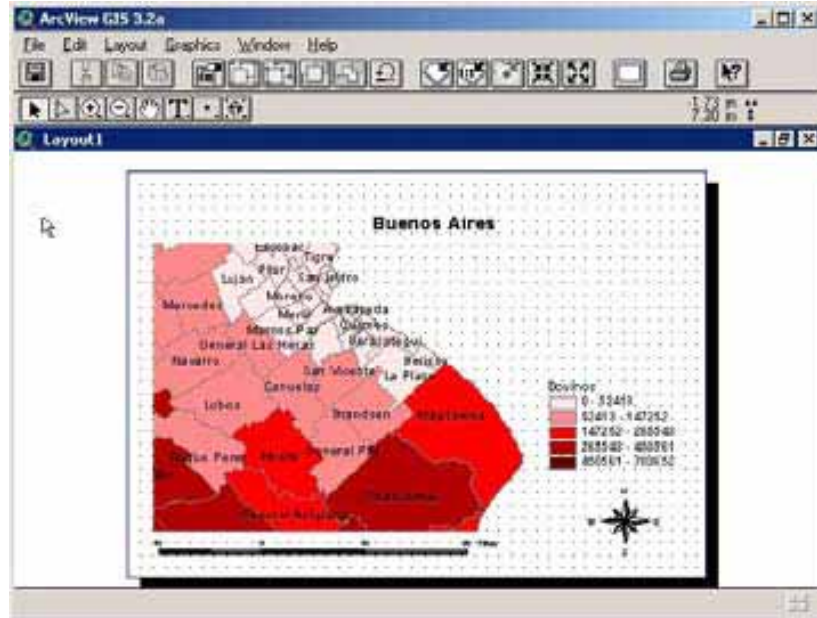


FIGURE 6
Dot map that represents the density of farms by Department

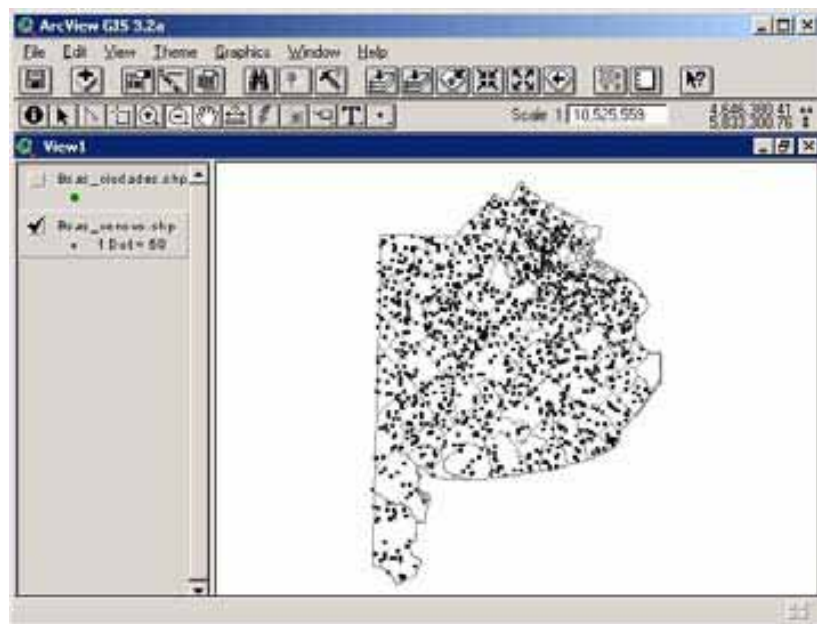


FIGURE 7

Graph map, showing the relative number of animals of each species by Department

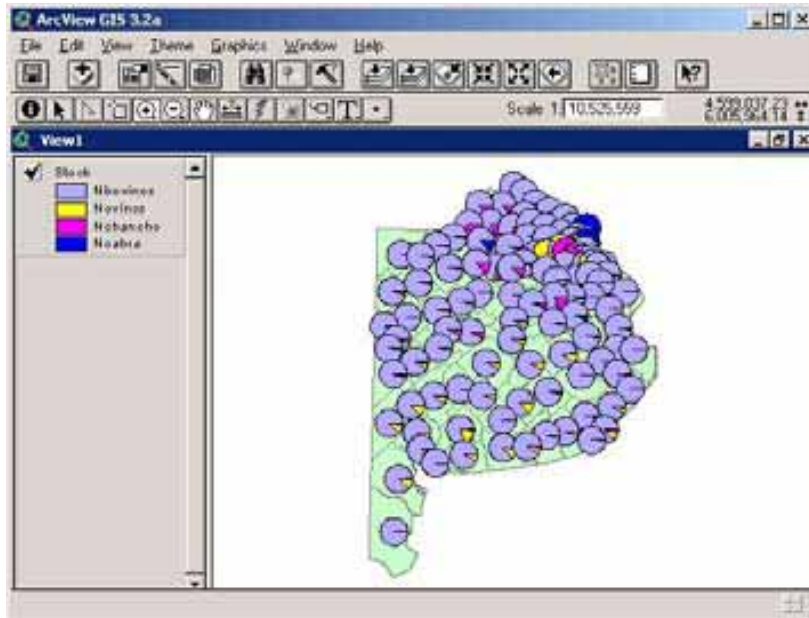
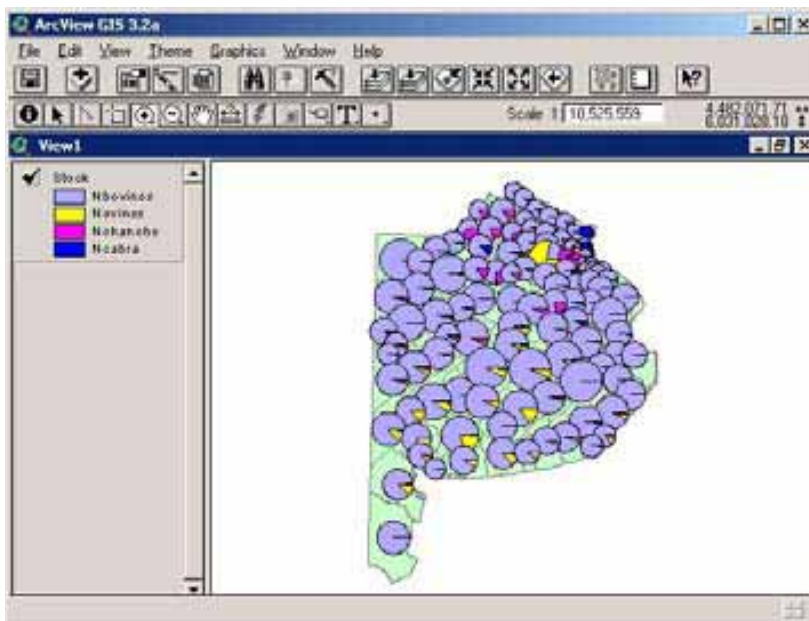


FIGURE 8

Similar to Figure 7, but in this case the size of each pie is proportional to the total number of animals by Department



for each department. Be aware that these dots do not represent actual locations, as the software placed them randomly into each area unit (Figure 6). How do you interpret the information displayed on the map?

Another way to visualize this data is to use a chart map. Open the Legend Editor again and under Legend Type select Chart. Select the fields NBOVINOS, NOVINOS, NCHANCHO, and NCABRA individually and click the Add button. Click on Properties button and set the minimum pie chart size to 4 and the maximum to 12. Click OK, then Apply and close the Legend Editor (Figure 7). Cattle represent the predominant species in each department. In the south of the province, sheep constitute a larger proportion of stock numbers. One or two departments have relatively high proportions of goats. Since this is inconsistent with the data set as whole, the data for these departments should be checked for errors.

It is also possible to scale the pie charts according to a third variable, which in this case could be the total number of stock in each department (NTOTAL). The variable has to be specified as the size field under Properties in the Legend editor (Figure 8).

Data formats

Spatial data may be stored in either raster or vector formats with a GIS. Vector data are composed of points, lines, and polygons. Raster data sets are composed of rectangular arrays of regularly spaced square grid cells. Each cell has a value, representing a property or attribute of interest. While any type of geographic data can be stored in raster format, raster data sets are especially suited to the representation of continuous, rather than discrete, data.

VECTOR DATA

Vector data are composed of points, lines, and polygons. This spatial data model is known as 'arc-node topology.' Arcs are composed of nodes and vertices. Arcs begin and end at nodes, and may have 0 or more vertices between nodes. The vertices define the shape of the arc along its length. Arcs which connect to each other will share a common node.

Points represent discrete locations within a study area. These are either true points, such as the highest point on a mountain, or virtual points, based on the scale of representation. For example, a city's location on a driving map is represented by a point even though in reality a city occupies a defined area. Lines represent linear features such as rivers and roads. Each line is composed of a number of different coordinates, which make up the shape of the line, as well as the tabular record for the line vector feature. Polygons form bounded areas. Polygons are formed by bounding arcs, which keep track of the location of each polygon (see Figure 9).

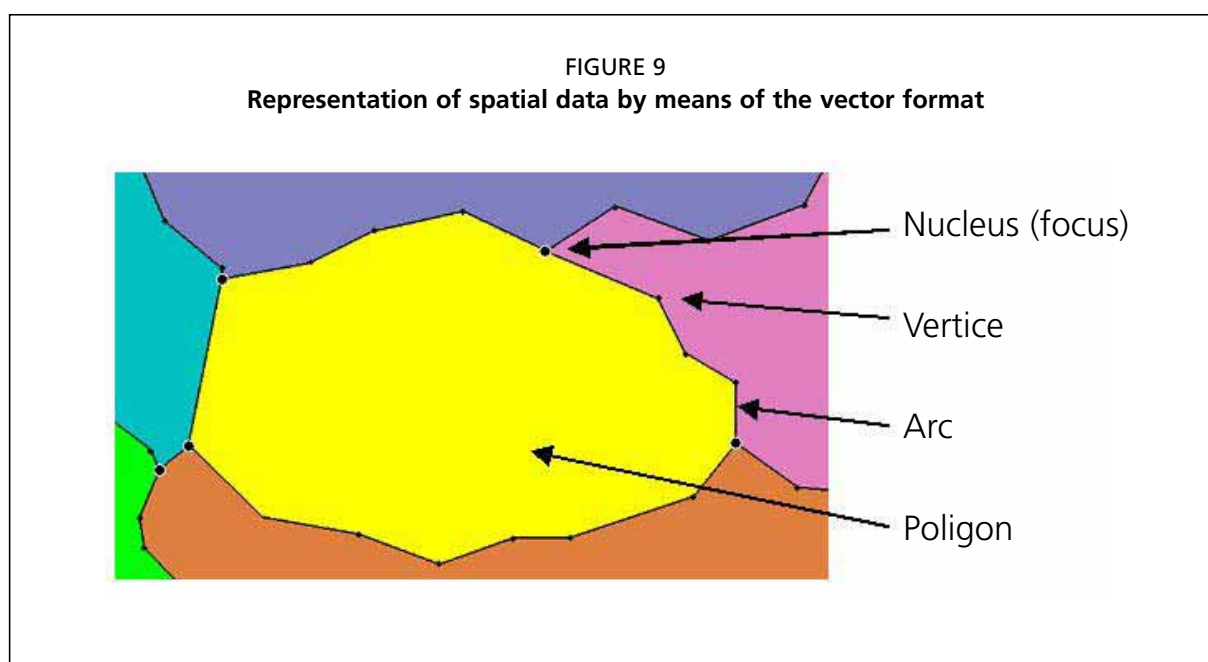


FIGURE 10
Representation of spatial data by means of raster format

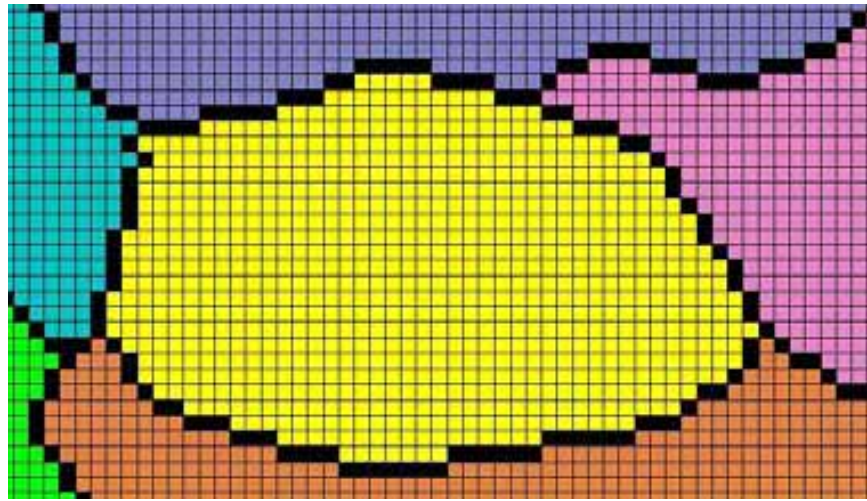
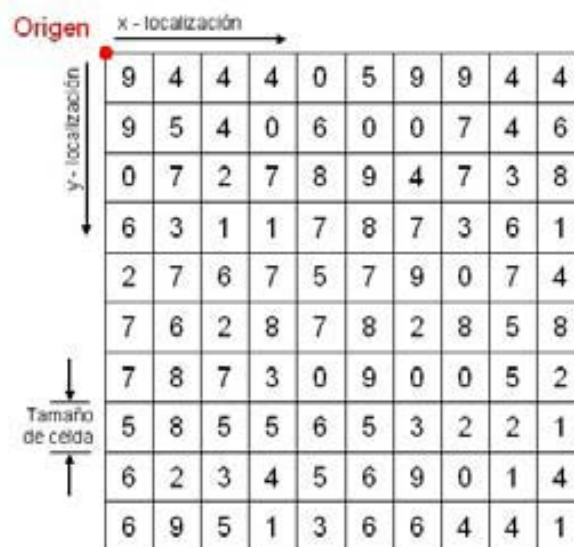


FIGURE 11
Spatial referencing of a raster area



RASTER DATA

In a raster representation, geographic space is divided into an array of cells (a matrix), as shown in Figure 10. These cells are sometimes called pixels.

Generally, cells are assigned a single numeric value, but with grid themes (a proprietary ArcInfo data format), cell values can also contain additional text and numeric attributes. All raster data sets are spatially referenced by a very simple method: only one corner of the raster theme is georeferenced (Figure 11). Because cell size is constant in both the horizontal and vertical directions, cell locations are referenced by row-column designations,

rather than with explicit coordinates for the location of each cell's centre. Different raster file formats may have an origin located at the lower left rather than at the upper left. Each cell or pixel contains a value representing some numerical phenomenon, or a code use for referencing to a non-numerical value.

With vector data, each point, node, and vertex has an explicit and absolute coordinate location. Raster cells, in contrast, are georeferenced relative to the theme's coordinate origin. This enhances processing time immensely in comparison to certain types of vector data processing. However, the file sizes of raster data sets can be very large in comparison to vector data sets representing the same phenomenon for the same spatial area. Also, there is a geometric relationship between raster resolution and file size. A raster data set with cells half as large (e.g. 10 m on a side instead of 20 m on a side) may take up 4 times as much storage space, because it takes four 10 m cells to fit in the space of a single 20 m cell.

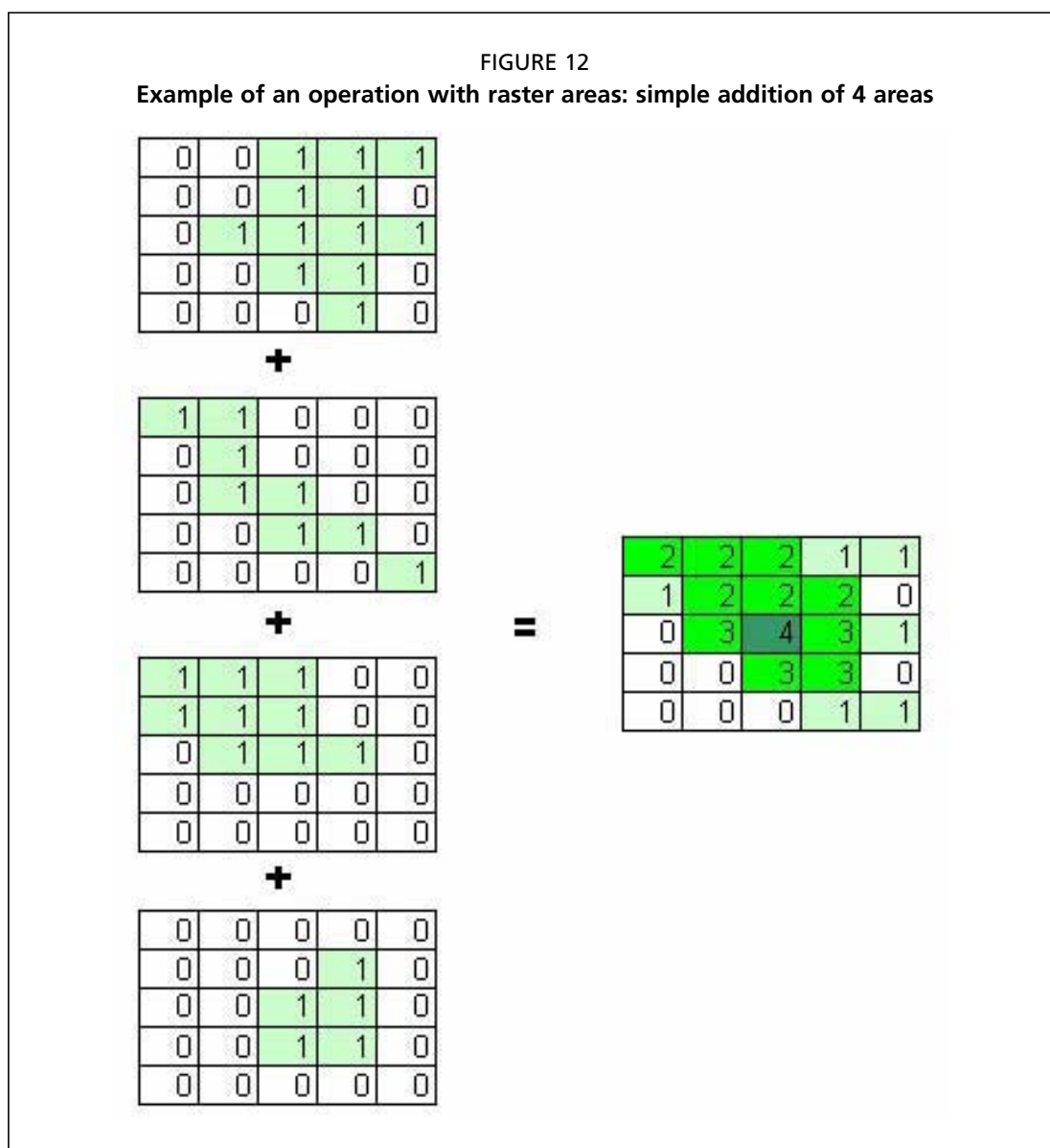
Cells may either have a value (0 - infinity) or no value (null, or no data). The difference between these is important. Null values mean that data either fall outside the study area boundary, or that data were either not collected or not available for those cells. In general, when null cells are used in analysis, the output value at the same cell location is also a null value. Grid data sets can store either integer or floating-point (decimal) data values, though some other data formats can only store integer values. Typical simple image data will have limits on the number of unique cell values (typically 0 - 255).

When information is represented in raster format each component cell is assigned a single attribute value and all detail about variation within the component cell is lost. The size chosen for cells within a raster surface depend on the resolution of the data used to create the surface. The cell must be small enough to capture the detail required, but large enough so the data can be stored and analyzed efficiently. As the homogeneity of the data increases so too can the designated cell size.

When creating raster data several rules may be applied to specify how a cell will be coded: in most situations the attribute with the largest share of the cell's area gets the cell attribute value. In other circumstances the rule is based on the central point of the cell and the attribute values at the central point are assigned to the cell. Although the largest share rule is almost always preferred, the central point rule is commonly used because it is quick to calculate.

Raster calculations

There are three basic categories of functions for the creation of new raster surfaces: global, focal, and zonal. Global functions perform their algorithm on every cell in the data set (Figure 12). You can think of the global function calculation engine as starting at once cell location, performing a calculation once on the inputs at that location, and then moving on to the next cell location, and so on. Focal functions consider neighborhoods, so that the output cell is the result of a calculation performed on either a group of cells determined by a window of cells (known as a kernel or focus) around each cell of interest. For example, a smoothing (low-pass filter) algorithm will take the mean value of a 3×3 cell kernel, and place the output value in the location of the central cell. If the kernel contains locations that are outside of the grid, these locations are not used in the calculation. Zonal functions perform analyses on a group of cells with a common value (a zone) in one of the inputs.



For most raster functions, other than those which simply identify a selected group of cells, operations take the conceptual format of an algebraic expression. For this reason, the syntax of raster analytical operations is often referred to as “map algebra”.

$$\text{output} = \text{input_grid1} \text{ operator } \text{input_grid2} \dots$$

For example, to multiply two input rasters `slp_grid` and `dem` the following syntax would be used:

$$\text{slp_dem} = \text{slp_grid} \times \text{dem}$$

Usually the input and output data sets are raster surfaces, but they can also be vector data sets, such as polygonal zones or isoline themes. In ArcView 3.x map algebra statements and other analytical functions are created using the Map Calculator and Map Query

TABLE 1
Features of raster and vector representations in a GIS

Factor	Raster	Vector
Source	Remote sensing	Printed maps, digitised maps
Applications	Environmental applications	Social, economic, administrative
Resolution	Fixed	Variable
Volume of data	Depends on size of cells used	Depends on level of detail
Efficiency	Efficient	Relatively inefficient

tools. The Map Calculator contains controls for selecting layers (which can be thought of as values in the Map Algebra expression), numbers, and operators. There are different classes of operators (arithmetic, relational, Boolean, logarithmic, trigonometric, and powers) which can be used to develop map algebra expressions.

Table 1 summarizes the features of raster and vector representations in a GIS.

ARCVIEW EXERCISE 2

Grid themes are graphical representations of the ArcView implementation of the raster data model. Grid themes are stored with a numeric value for each cell. Cell values are either integer or floating-point. Integer grids have integer values for the cells, whereas floating-point grids have value attributes containing decimal places. Cell values are stored in summary tables known as Value Attribute Tables (VATs) within the info subfolder of the working folder. Because the possible number of unique values in floating-point grids is high, VATs are not built or available for floating-point grids. VATs for integer grids that have a range of values (maximum minus minimum) less than 100,000 and a number of unique values less than 500.

Although Map Queries can be performed on both integer and floating-point grids, normal feature or table queries are only possible on integer grids with VATs. This is because a normal feature query is dependent on the existence of a theme table. Grids without VATs have no theme tables, and are therefore unavailable for normal queries.

Grid theme properties can be viewed by selecting THEME - PROPERTIES from the View menu while a grid theme is active. The Theme Properties dialogue (Figure 13) shows the Theme Name as it appears in the Table of Contents, the Source file location, the Cell Size, the number of Rows and Columns, the lower-left and upper-right coordinates, the grid Type (Float or Integer), and the Status (Temporary or Permanent).

Grid themes are added to views in the same manner as feature or image themes, by using VIEW - ADD THEME. In the Data Source Types drop down list, select Grid Data Source. The list of themes will be updated to include only grid data themes. To load grid themes into a view within the project, the Spatial Analyst Extension must be loaded. If the Spatial Analyst Extension is not loaded, it is still possible to add grid data sources to a view, but only as simple images. Image themes cannot be queried or analyzed in any way. Image themes are not associated with any attribute values, other than a simple numeric value used for color mapping.

FIGURE 13
Properties of a grid

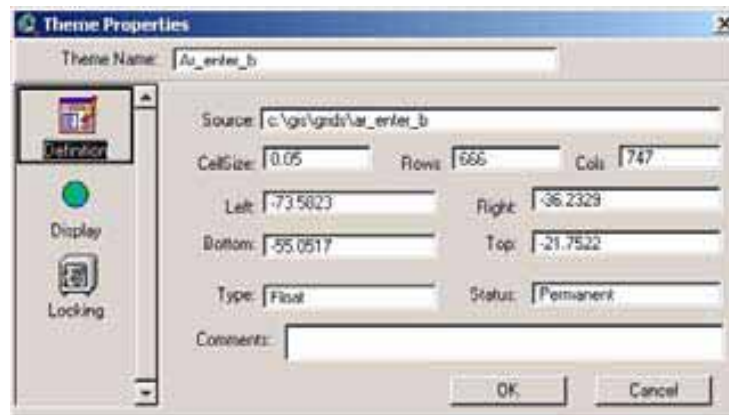
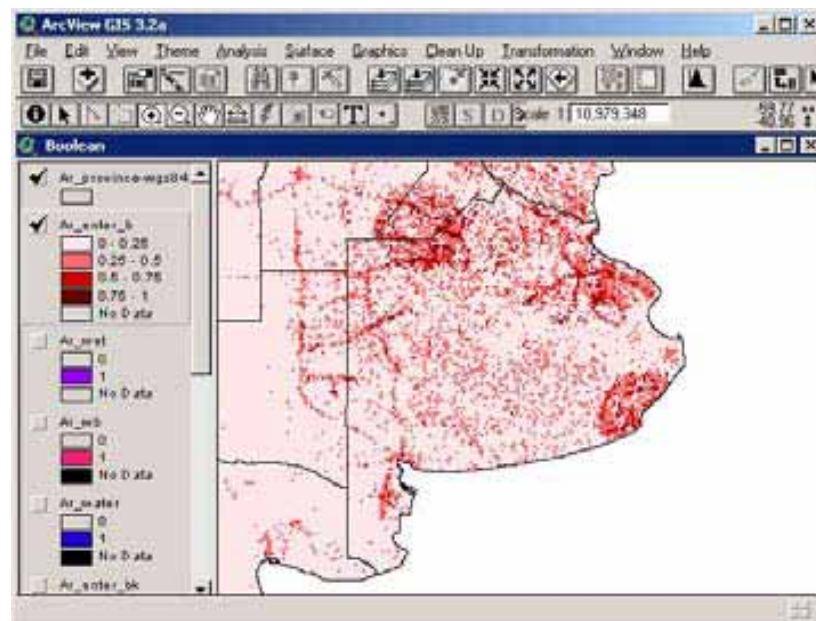


FIGURE 14
View of a raster format (or grid)

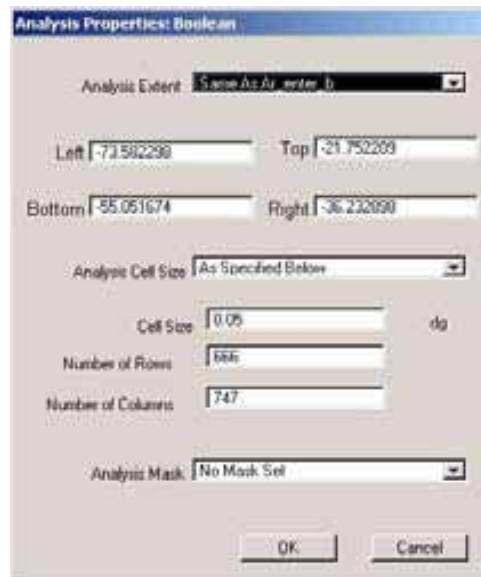


Grid theme displays are changed in exactly the same way as feature themes. Changes to the display of grid themes are done using the Legend Editor. Like polygon feature themes, shading of fills can be changed by altering the symbols of individual classes, by changing the color ramp, legend labels, and classification properties (Figure 14).

For all grid themes, individual cell values can be queried using the Identify tool. Clicking on a cell for the active grid theme will display the attribute values for the theme. The Identify Results dialog will display the name of the grid theme, the X and Y coordinates of the cell, and the cell's value.

When the Spatial Analyst performs operations that create new grids on the fly, these

FIGURE 15
Window to determine properties for analysis



new grids are stored in the working directory. If the theme is deleted from the view, the grid will be deleted from the disk. To make sure that newly created grids are saved, either save the project or select THEME - SAVE DATA SET from the menu. When you do save grid themes, you can choose the file system directory and the name of the theme, rather than accepting the default name and location of the data set assigned by ArcView.

If you need to manage grid data sets, you can use FILE - MANAGE DATA SOURCES in the View menu. This tool allows you to copy, rename, and delete grids in the same way you have used it to manage shape files. Grids can be copied or moved to different names, or to different places in the file system. In order to be able to copy, rename, or delete a theme, all references to the theme must be removed from the project.

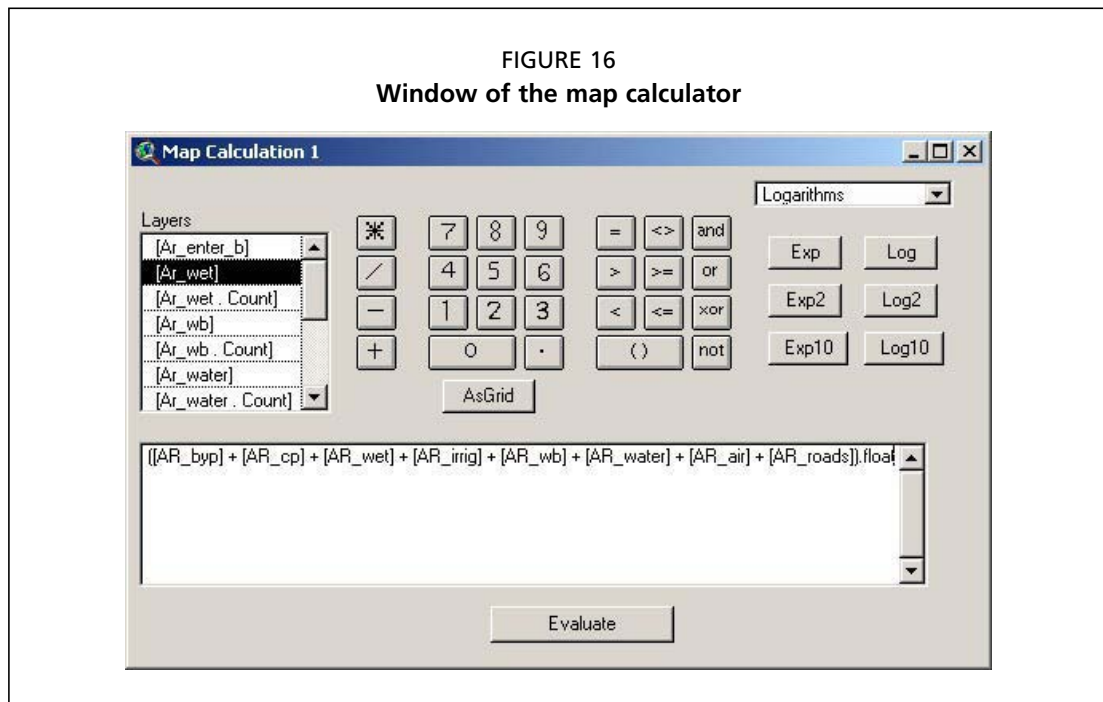
Setting grid theme and analysis properties

When new grids are created by spatial analysis operations, the user can select properties of the created grid. The properties are set by selecting ANALYSIS - PROPERTIES from the menu. After the analysis properties are set, and the project is saved, the same properties will be used for every analysis within the view whose Analysis Properties were set. The various Analysis Properties can be copied from existing themes, or entered manually (Figure 15).

The spatial extent of the analysis determines how large (spatially) the output grid will be. It is possible to set the analysis extent manually to any valid coordinates, to the view's or display's extent, or to the spatial extent of a theme within the view. Output data will be generated only for the cells within the Analysis Extent. This is frequently used when you are interested in analyzing a small area, rather than performing the operation over an entire study area. The Analysis Extent is a simple rectangle.

Be aware that altering the analysis extent will alter the registration of grids. If you create a new grid from an existing grid, but with a different analysis extent (even if the cell

FIGURE 16
Window of the map calculator



size is the same), the two grids will not overlay properly unless the analysis extent has an origin that is located at a cell corner for the original grid. This can have significant effects on further processing, calculations, and measurements.

Existing grids are stored with a certain known cell size. You can check the cell size of any grid theme by making the grid theme active and choosing THEME - PROPERTIES from the View menu. It is preferable when performing multi-grid analyses to choose an output cell size that is the same as the largest of the input cell sizes. It is always possible to decrease information content by resampling cells to a larger cell size, but it is impossible to increase information content by splitting cells. Because the individual cell is the smallest resolvable feature in a grid, it is not advised to subdivide the cell into different values. Cell size equals the length of the side of a single cell, not the area of a cell. Also remember that cell size is stored in the map units for the data set.

The number of rows and columns can be automatically determined by the combination of cell size and bounding coordinates. Or the number of rows and columns can be set manually, in which case the cell size will change to accommodate the new number of rows and columns.

Grid analyses

Raster analytical functions are performed by accessing functions contained within the ANALYSIS and SURFACE menus while the Spatial Analyst Extension is loaded. We will cover various types of raster analysis in the next section. Raster analyses that use multiple grids are possible because of the spatial referencing of grids to a common coordinate space.

For most grid functions, other than those which simply identify a selected group of cells, operations take the conceptual format of an algebraic expression. Map algebra statements and other analytical functions are created using special tools, such as the MAP CALCULATOR and MAP QUERY tools. The MAP CALCULATOR contains controls for selecting Layers

(which can be thought of as values in the Map Algebra expression), Numbers, and Operators. There are different classes of operators (Arithmetic, Relational, Boolean, Logarithmic, Trigonometric, Powers). The expression area is where you build the Map Algebra expression, either by clicking on parts of the graphic user interface, or by writing a valid Avenue-syntax expression. The output of the Map Calculation is a temporary grid whose name is shown on the title bar of the Map Calculator (Figure 16).

Georeferencing

Georeferencing refers to the process of assigning location information to geographic data. The primary requirements of a georeference is that it is unique so that there can be no confusion about the location that is referenced; and that its meaning is shared among all working with the information. In addition, a georeference must be persistent in time. In all cases georeferences are based on some type of coordinate system to define the location of points in two-dimensional or three-dimensional space.

René Decartes (1596 - 1650) introduced systems of coordinates based on orthogonal (right angle) axes. These two and three-dimensional systems used in analytic geometry are often referred to as Cartesian systems. Similar systems based on angles from baselines are often referred to as polar systems. Before discussing the various types of coordinate systems used in geography, some background information on ellipsoids and map projections is provided.

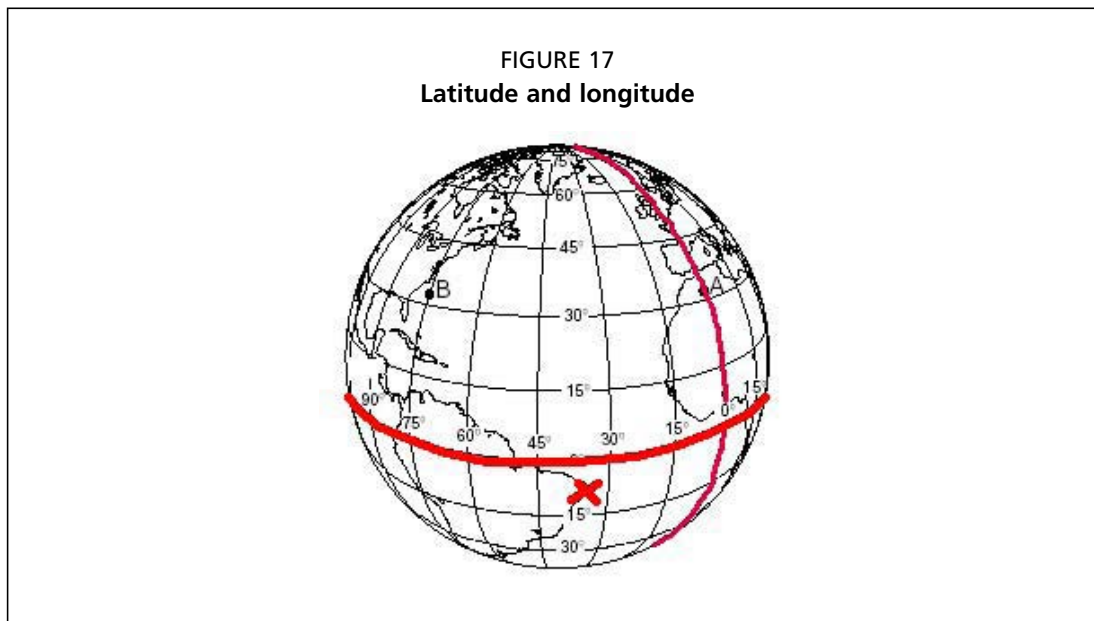
PROJECTIONS

The best model of the earth would be a 3-dimensional sphere in the same shape as the earth. Spherical globes are often used for this purpose. However, globes have several drawbacks: (1) globes are large and cumbersome, (2) they are generally of a scale unsuitable to the purposes for which most maps are used, and (3) we usually want to see more detail than is possible to be shown on a globe. In addition standard measurement equipment cannot be used to measure distance on a sphere, as these tools have been constructed for use on flat surfaces.

The latitude-longitude spherical coordinate system expresses positions on the earth's surface in terms of angles rather than easting and northing (Cartesian planar) coordinates. Using this system, 'horizontal' or east-west lines are lines of equal latitude or parallels. 'Vertical' or north-south lines are lines of equal longitude or meridians. These lines encompass the globe and form a gridded network called a graticule. The line of latitude midway between the poles is zero latitude and is called the Equator. The vertical axis, which defines the line of zero longitude, is called the Prime Meridian. For most geographic coordinate systems, the Prime Meridian is the longitude that passes through Greenwich in the United Kingdom. Other countries use as prime meridians longitudes that pass through Bern, Bogotá, and Paris.

The point where the Equator and the Prime Meridian intersect defines the Origin (0,0). The Earth's sphere is then divided into four geographical quadrants based on compass bearings from the origin. Above and below the Equator are north and south, and to the left and right of the Prime Meridian are west and east. Latitude and longitude are traditionally measured in decimal degrees or in degrees, minutes and seconds (DMS) (Figure 17).

Latitudes are measured relative to the Equator and range from -90° at the South Pole to $+90^\circ$ at the North Pole. Longitude is measured relative to the Prime Meridian (shown as



a red line running from north to south in Figure 17) positively, up to 180° , when traveling east and measured negatively, to -180° , traveling west. If the Prime Meridian is at Greenwich, then the most eastern point of South America (marked as a \times in Figure 17) has a latitude of approximately -7° (negative, because it is south of the Equator) and a longitude of approximately -37° (negative, because it is west of the Prime Meridian at Greenwich). The latitude and longitude of this point would be written S 7° W 37° .

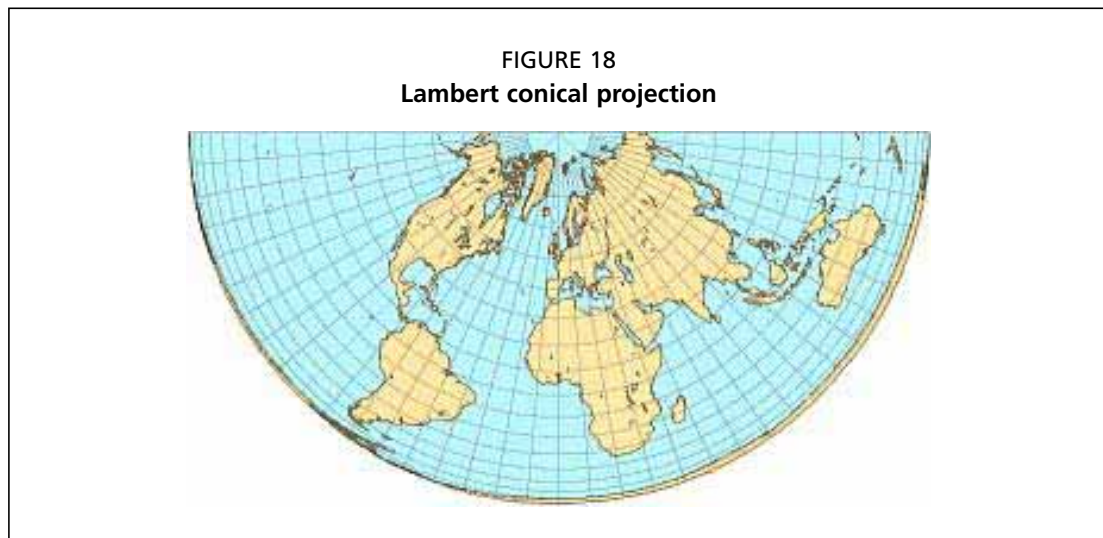
When the earth's shape is based on the WGS 84 Ellipsoid one degree of latitude at the Equator equals 110.57 kilometers. At the poles, one degree of latitude equals 111.69 kilometers. One degree of longitude at the Equator equals 111.05 kilometers. At 60° N one degree of longitude equals 55.52 kilometers. Note:

- Quote latitude values first, then longitude (you can remember this because 'latitude' comes before 'longitude' alphabetically).
- Use decimal degrees in preference to degrees, minutes and seconds.

Map projections are sets of mathematical models which transform spherical coordinates (such as latitude and longitude) to planar coordinates. Cartesian coordinate systems assign two coordinates to every point on a flat surface by measuring distances from an origin parallel to two axes drawn at right angles. These axes are often termed x and y , and the associated coordinates are termed x and y coordinates, respectively. Because it is common to align the y axis with the North in geographic applications, the coordinates of a projection on a flat sheet are often termed easting and northing. The basic types of projections are conic, cylindrical, and planar.

Conic projections

In the conical case the Earth is projected onto a tangent or secant cone which is then cut lengthwise and laid flat. The parallels (lines of latitude), are represented by concentric circular arcs, and the meridians (lines of longitude), by straight, equally spaced, radiating lines. This type of projection is used for mapping mid-latitude regions, such as Canada and



the United States. The result is less overall shape distortion of land and water areas. The Lambert Conformal Conic projection is a commonly used version of the conic type (Figure 18).

Cylindrical projections

In the cylindrical case, the Earth is projected on to a tangent or secant cylinder which is also cut lengthwise and laid flat. The result is an evenly spaced network of straight, horizontal parallels and straight, vertical meridians. A straight line between any two points on this projection follows a single direction or bearing, called a rhumb line. This feature makes the cylindrical projection useful in the construction of navigation charts. When the cylinder is used as a surface to project the entire world on to a single map, significant distortion occurs at the higher latitudes, where the parallels become further apart, and the poles cannot be shown. The Mercator projection is the best known example of this class and one of the earliest of all projections (circa 1569) (Figure 19).

Planar or azimuthal projections

With the planar projection, a portion of the Earth's surface is transformed from a perspective point to a flat surface. In the polar case, the parallels are represented by a system of concentric circles sharing a common point of origin from which radiate the meridians, spaced at true angles. This projection shows true direction only between the centre point and other locations on the map. Although these projections are most often used to map Polar Regions, they may be centered anywhere on the Earth's surface. The gnomonic is one type of planar projection on which any great circle appears as a straight line. A great circle is the circle created when a plane cuts the Earth through its centre. This term is most often used in the expression, 'great circle route', which is the shortest path between two points on the Earth (Figure 20).

It is appropriate to choose a projection based on which measurement properties are most important to your work. For example, if it is very important to obtain accurate area measurements (e.g. for determining the home range of an animal species), you would select an equal area projection.

FIGURE 19
Equidistant cylindrical projection

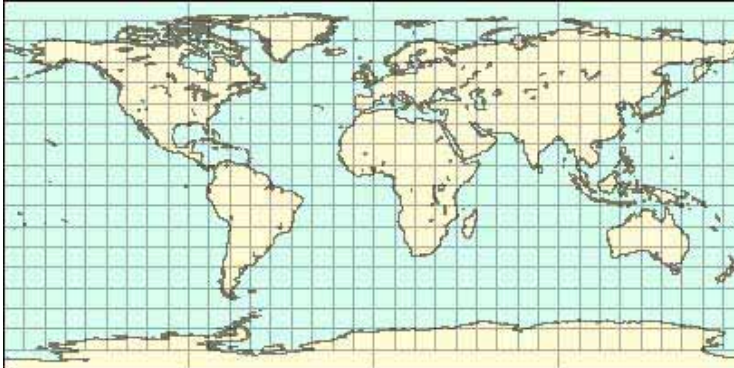


FIGURE 20
Azimuthal projection, Central Meridian 70°



Datums

The actual shape of the Earth is spheroid (a slightly 'flattened' sphere) rather than perfectly spherical. To account for this, large numbers of surveys have been conducted over the years, resulting in a large number of ellipsoid definitions (examples are given in Table 2). The generalized earth-centered coordinate system (WGS84) provides a good overall mean solution for all places on the earth. However, for specific local measurements, WGS84 cannot account for local variations. Instead, local datums have been developed. The local North American Datum of 1927 (NAD27) more closely fits the earth's surface in the upper-left quadrant of the earth's cross-section. NAD27 only fits this quadrant, so to use it in another part of the earth will result in serious measurement errors. For mapping North America, in order to obtain the most accurate locations and measurements, NAD27 or NAD83/91 are used.

Datum is a term you might also come across when dealing with map projections. A datum defines the position of the spheroid relative to the centre of the Earth. Local datums are often used to align a given spheroid to more closely to the Earth's surface in a particular area. A local datum is not suited for use outside the area for which it was designed.

TABLE 2
Common ellipsoid definitions used in geography

Title	Length of major axis (meters)	Flattening
Airy 1830	6377563	299.325
Australian National	6378160	298.250
Bessel 1841	6377483	299.153
Clarke 1866	6378206	294.979
Clarke 1880	6378249	293.465
Helmert 1906	6378200	298.300
GRS 80	6378137	298.257
South American 1969	6378160	298.250
WGS 72	6378135	298.260
WGS 84	6378137	298.257

Coordinate systems

Once geographic data are projected onto a planar surface, features must be referenced by a planar coordinate system. The geographic system (latitude-longitude), which is based on angles measured on a sphere, is not valid for measurements on a plane. Therefore, a Cartesian coordinate system is used, where the origin (0, 0) is toward the lower left of the planar section. The true origin point (0, 0) may or may not be in the proximity of the map data you are using. Coordinates are then measured from the origin point. However, false eastings and false northings are frequently used, which effectively offset the origin to a different place on the plane. This is done in order to minimize the possibility of using negative coordinate values (to make calculations of distance and area easier) and to lower the absolute value of the coordinates (to make the values easier to read, transcribe, and calculate). Systems for georeferencing can be divided into two groups:

- Global systems, which are used to define position at all locations across the Earth's surface.
- Regional systems, which are defined for specific areas, often covering countries, states, or provinces.

Whatever coordinate system is used, it must have the following features:

- It must be unique, so that there can be no confusion about the location that is referenced;
- Its meaning must be shared among all working with the information;
- It must be persistent in time.

Table 3 lists and describes some of the commonly used systems of georeferencing.

The Transverse Mercator projection

The simplest of all projections is the Transverse Mercator projection where longitude is plotted as x and latitude as y. The result is a heavily distorted image of the Earth, with the poles extending across the entire top and bottom edges of the map (Figure 21). The Transverse

TABLE 3
Commonly used systems of georeferencing

System	Domain	Resolution	Example
Place name	Will vary	Varies by feature type	Sydney, Canada Sydney, Australia
Postal address	Global	Size of location that has one postal address - typically a house or building, but may mean a large farm or station	105 Woodham Lane Addlestone, Surrey
Post code	Country	Area occupied by a defined number of mailboxes	The post code of Addlestone, Surrey, UK, is KT15 3NB
Telephone calling area	Country	Varies from country to country	If you are phoning a residence in New Zealand with a phone number that starts with 06, you know that the place you are calling is located somewhere in the south of the North Island.
Cadastral system	Local land authority	Area occupied by a single parcel of land	A map of land ownership maintained for the purpose of taxing land or creating a public record of land ownership.
Latitude and longitude	Global	Infinite	E113°59'53.0", N22°22'36.6"
State plane coordinates	Unique to country or state	Infinite	UK national grid

Mercator projection has straight meridians and parallels that intersect at right angles. Scale is true at the equator or at two standard parallels equidistant from the equator.

The Universal Transverse Mercator system

The Universal Transverse Mercator (UTM) system is based on the Transverse Mercator projection and is often used in military applications and in datasets with global or national coverage. Under the UTM system the Earth is divided from east to west into 60 zones (called UTM zone numbers where numbers range from 1 to 60), with each zone corresponding to a width of 6° (Figure 22). Each zone is mapped by the Transverse Mercator projection with a central meridian in the centre of the zone. UTM zone number 1 applies to longitudes from W 180° to W 174° (a line drawn between the Soviet Union and Alaska, straight through the Pacific Ocean).

Each UTM zone is divided from north to south into designators. There are 20 latitudinal zones spanning the latitudes 80°S to 84°N and denoted by the letters C to X, omitting the letter O. Each of these is 8 degrees south-north, apart from zone X which is 12 degrees south-north. Areas are referenced by quoting the longitudinal zone number, followed by the latitudinal zone letter. For example, the southern end of South America is 19F. Locations within a UTM zone are measured in metres eastward from the central meridian and north-

FIGURE 21
Mercator transverse projection

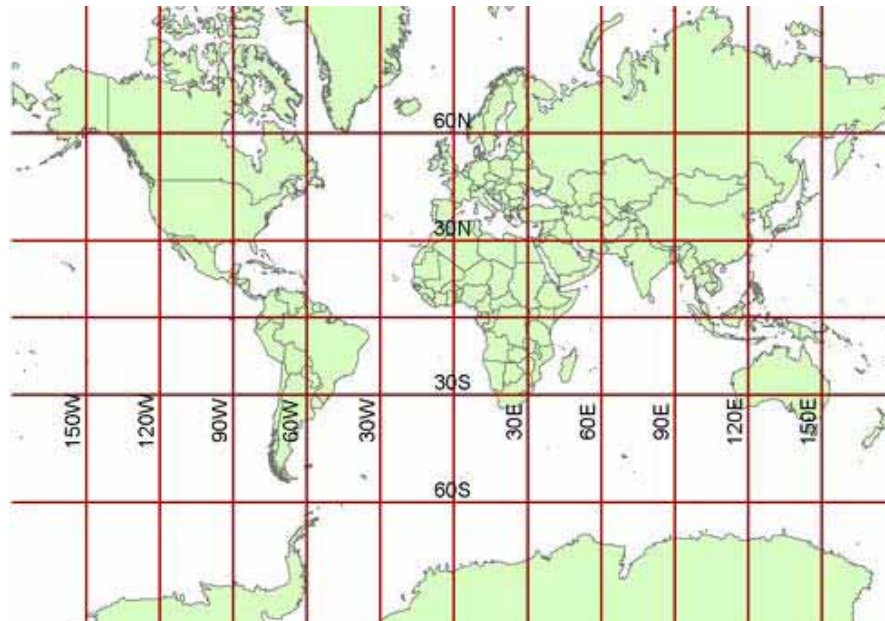
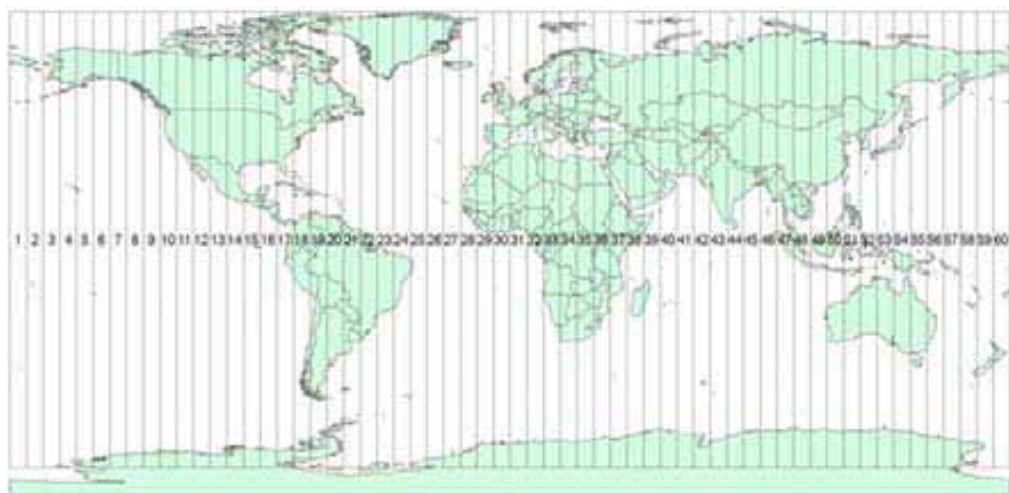


FIGURE 22
Universal transverse Mercator projection (UTM)



ward from the Equator. However, eastings increase eastward from the central meridian which is given a false easting of 500 km so that only positive eastings are measured anywhere in the zone. Northings increase northward from the equator with the equator's value differing in each hemisphere. In the Northern Hemisphere the Equator has a northing of 0. For Southern Hemisphere locations the Equator is given a false northing of 10,000 km.

Because there are effectively 60 different projections in the UTM system, maps will not

fit together across a zone boundary. Zones become such a problem at high latitudes that the UTM system is normally replaced with azimuthal projections centered on each pole above 80° latitude (these are known as UPS or Universal Polar Stereographic systems).

UTM coordinates are easily recognized because they commonly consist of a six-digit integer and letter (563257E, 4467843N for example). They are useful for spatial analyses conducted over large areas because distances can be calculated for points within the same zone with little error (typically no more than 0.04%). UTM grids are marked on many topographic maps and many countries project their topographic maps using UTM, so it is easy to obtain UTM coordinates from maps for input into digital datasets.

Transverse Mercator Grid Systems

Many countries have defined grid systems based on Transverse Mercator coordinates that cover their territory. The British National Grid (Figure 23) is an example of a national grid system based on the Transverse Mercator projection.

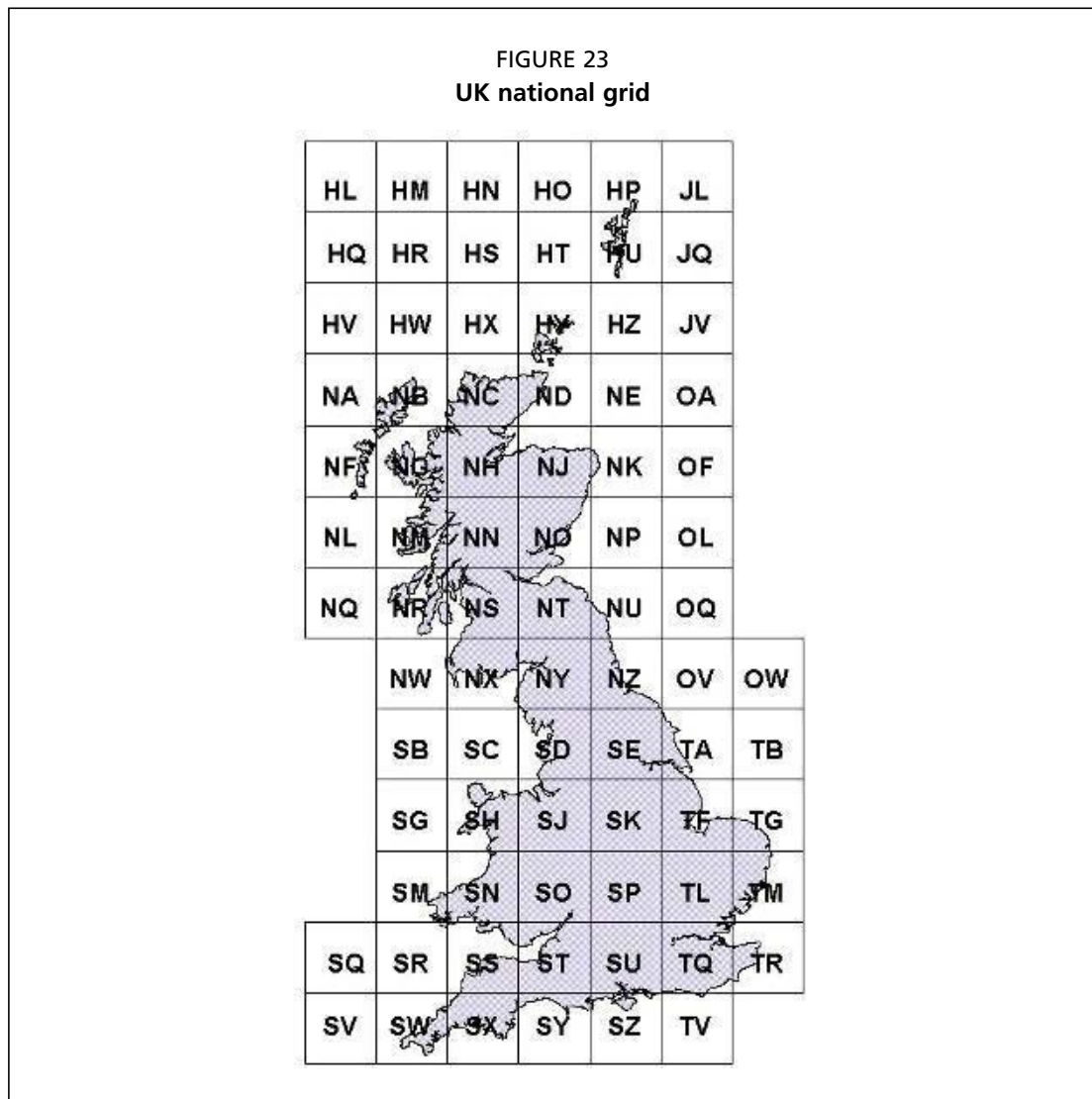
The British National Grid is administered by the Ordnance Survey of Great Britain and provides a unique georeference for every location in England, Scotland and Wales. The true origin of the system is at N 49° and W 2°. Grids are 100 kilometers from east to west and 100 kilometers from north to south. The first two letters of a National Grid reference define in which of the grids the location is situated (Figure 23). The next three digits represent multiples of 100 meters and define the easting coordinate (relative to the origin of the respective grid). The last three digits (again, in multiples of 100 meters) define the northing coordinate relative to the origin of the respective grid.

Take for example the British National Grid georeference SP254186. The origin of the SP grid (that is, its south-western corner) is 400 kilometers east and 200 kilometers north of the map origin (N 49° and W 2°, the most south-west corner of the grid labeled SV in Figure 23). The location is $(254 \times 100) / 1000 = 25.4$ kilometers east and $(186 \times 100) / 1000 = 18.6$ kilometers north of the origin of the SP grid. The grid coordinates for this location would be 4254000, 218600.

State plane coordinates

In the United States each state has its own State plane coordinate system. State plane systems were developed in order to provide local reference systems that were tied to a national datum. In the United States, the State Plane System 1927 was developed in the 1930s and was based on the North American Datum 1927 (NAD-27). NAD-27 coordinates are in English units (feet).

A cadaster is defined as the map of land ownership in an area, maintained for the purposes of taxing land or for creating a public record of land ownership. The process of subdivision creates new parcels of land by dividing existing parcels. Parcels of land in a cadaster are often uniquely identified by number or by code and they are also reasonably persistent through time, thus satisfying the requirements of a georeferencing system. However, identification codes tend not to be widely known outside of the jurisdictions in which they are used or follow a generally interpretable sequence. As a consequence they are rarely used except for administrative purposes.



ARCVIEW EXERCISE 3

If the spatial data in your view is in decimal degrees you may want to consider reprojecting your data. You don't have to reproject your data but be aware that ArcView will draw the view by treating the latitude and longitude coordinates as planar x and y coordinates. If your project doesn't require a high level of locational accuracy and if you won't be performing queries based on location and distance, reprojecting your map won't be necessary. For all other applications reprojection is recommended.

In epidemiology it is usual to use the UTM projection because distances between points can be accurately computed. Reprojecting data from decimal degrees to UTM is therefore a common task. These notes provide step-by-step instructions for reprojecting data in decimal degree format to UTM. For the purpose of this exercise we work with a map Uruguay in decimal degree format. The aim of the exercise is to reproject this data into UTM format (zone 48N).

With the project window active, load the projection utility wizard using FILE - EXTENSIONS. Activate a view and select the ArcView Projection Utility from the FILE menu. Select

FIGURE 24
First step for the definition of the desired projection:
indicate the file format which is to be re-projected

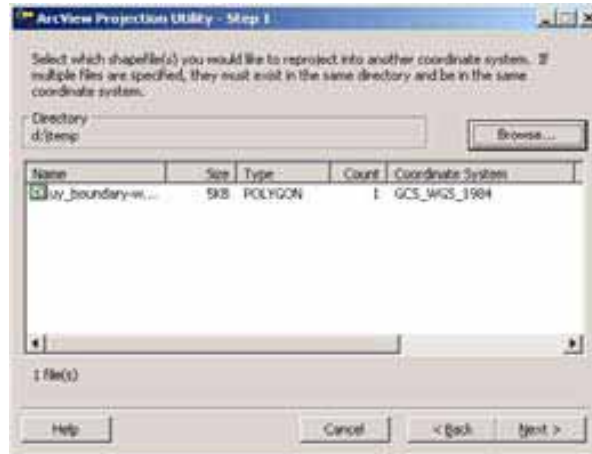
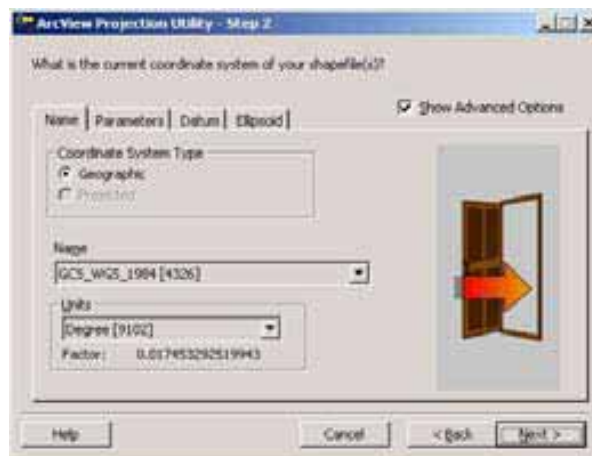


FIGURE 25
Second step for the definition of the desired projection: definition of the system of coordinates to be applied to the shape file indicated in the first step



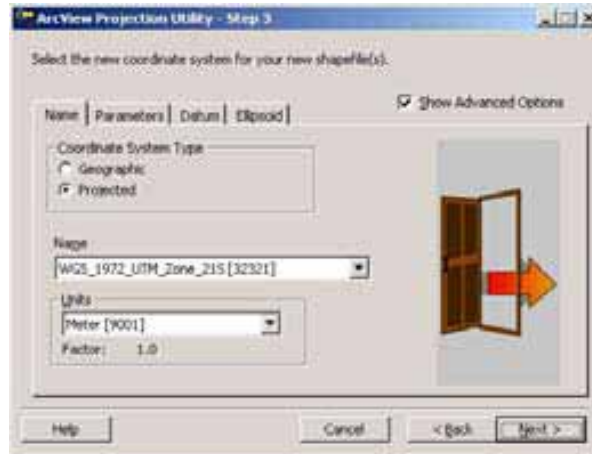
the shape file to be reprojected: 'UY_boundary-WGS84.shp' (Figure 24) and click the Next button.

Fill out the Input for the shape file to be reprojected: coordinate system, datum, and units. If a projection file (*.PRJ) for the input shape file is present the reprojection utility will read the details from the projection file, providing appropriate values for the Name form (Figure 25). Click the Next button.

For projection step 3, fill out the output Name and Parameters tabs, as shown in Figure 26. Here we are re-projecting our map of Uruguay into UTM format. Select 'Projected' as the Coordinate System Type and 'WGS_1972_UTM_Zone21S[32321]' as the name of the projection.

FIGURE 26

Third step for the definition of the desired projection: define the name of the system of coordinates of the converted shape file



The final step is to specify the name of the converted shape file. Browse to select a suitable location, specify the name of the converted file (e.g. Uruguay_boundary-UTM21S.shp) then click Next and Finish to complete the job. A window will then be displayed showing you the progress of the conversion process (this can take some time if your map files are large and your computer is slow).

Create a new view and click -VIEW - ADD THEME to add the Uruguay_boundary-UTM21S map to the view. Compare the UTM projected map of Uruguay with the map of Uruguay projected in decimal degrees.

PART 2

The proposed system

Introduction

Commercial poultry production in Latin America and the Caribbean is constantly growing. This is important from several aspects, such as the growth of economic development, the supply of labor, and the fundamental role of supplying meat and eggs to the population. It is therefore of fundamental importance to preserve optimal avian sanitary conditions both nationally and regionally.

Currently the American continent is free of HPAI due to type A, subtype H5N1 virus. This disease has been spreading rapidly worldwide since 2003, it has proved to be one of the most important trans-border diseases in animals. It is currently an international health emergency in extensive regions of Asia, the Middle East, Africa and Europe. It causes losses in poultry production, reduces international trade in poultry and poultry products, with consequent unemployment, and affects food safety in the affected countries.

Up to September 2007 the death of 200 people has been confirmed in 11 of the 12 countries where infection was detected in humans. However, sustained transmission of the virus between humans has not yet taken place; it is therefore essential to combat the disease in domestic fowl to reduce the amount of circulating virus, decreasing the risk of contagion to humans and the threat of a possible human influenza pandemic.

Although HPAI subtype H5N1 is not present in the American Continent, other highly pathogenic subtypes of this virus have been seen: in Mexico in 1994 (H5N2), Chile in 2002 (H7N3), Canada (H7N3) and the USA (H5N2), as evidence of the possibility of this virus infecting fowl in the region, but also showing the capacity of countries of the American Continent to detect, control and eradicate the disease.

Epidemiological surveillance

In Annex 3.8.1 of OIE Terrestrial Animal Health Code epidemiological surveillance is defined as obtaining, verifying and analyzing data in a systematic and continuous fashion and the rapid transmission of information to those who need it to take the necessary measures (OIE, 2007).

In general terms the aims are.

- a. To demonstrate the absence of disease or infection
- b. To detect the presence of disease or infection (early detection of exotic and emerging diseases)
- c. To determine the temporal and/or spatial distribution of a disease or infection

Surveillance may be classified according to different criteria, including the following:

According to the means of collecting data: passive or active surveillance. In the case of passive surveillance, the main user of the information, usually official veterinary services, do not initiate data collection. The data are provided by different co-sources such as farmers, private veterinarians, slaughterhouses, and others. Data are usually collected by means of notification or disease declaration systems. In the case of active surveillance, on the other hand, the user of the information takes action that will initiate data collection. This can be by means of structured random or non-random studies.

According to its focus, surveillance may be specific or general. In the first case action is oriented towards the study of a special disease or agent, while in the second case all agents or diseases are detected.

According to the manner in which the units in a surveillance study are selected these studies may be structured random or non-random studies.

Non-random structured studies may be of different types, and it is advisable to use several at a time. They may be oriented to demonstrating the absence of disease, early detection, estimation of prevalence and incidence, etc. Amongst these are disease notification systems, control programs, specific analysis or studies, ante and post mortem inspection, register of laboratory results, and others. Random structured results include census and probabilistic sampling.

Epidemiological surveillance for avian influenza

The OIE defines Avian Influenza of obligatory report as an infection of domestic fowl by any influenza type A virus belonging to subtypes H5 or H7 or any avian influenza virus with an intravenous pathogenicity index greater than 1.2 (or that causes a mortality of at least 75% of cases), in Chapter 2.7.12 of the Health Code for Terrestrial Animals (OIE, 2007).

Furthermore, in Annex 3.8.9 of the same code there are different directives for surveillance for this disease. The OIE suggests that Official Veterinary Services should have a surveillance system for HPAI, with established procedures to: a - detect compatible clinical cases; b – take samples and send them quickly to a laboratory capable of diagnosing the disease; c – manage a diagnostic and surveillance data register, management and analysis system. The HPIA surveillance system must include an immediate alert that encompasses the entire production chain. On the other hand, serological and virological tests must be regularly carried out in high risk groups of animals, such as those in border areas or in areas where there is contact with wild waterfowl.

Surveillance based on risk assessment

Traditional epidemiological surveillance is implemented in all the susceptible population of a certain territory. On the other hand, epidemiological surveillance based on assessment of exposure risk focuses on the layer of the population that presents the greatest probability of presenting an event.

This is a relatively recent concept that was originally developed by bovine spongiform encephalitis surveillance programs (BSE) (Doherr *et al.*, 2001; Doherr and Audigé, 2001; Doherr *et al.*, 2002; Moriginat *et al.*, 2002).

It has recently been defined by Stärk *et al.* (2006) as a surveillance program in whose design the risk of exposure and presentation of an event has been assessed together with traditional approaches so as to achieve an effective collection of data with greater efficiency (lower cost/benefit ratio).

The OIE in Annex 3.8.9. of the Health Code for Terrestrial Animals recommends HPIA epidemiological surveillance based on risk assessment (OIE, 2007).

Geographic information system for the identification of areas at risk for the introduction and spread of HPAI virus

AIM

To improve the effectivity of HPAI surveillance systems, so as to favor early detection if the virus should enter the country and improve efficiency in terms of cost/benefit ratio.

OBJECTIVE

To identify the major risk areas for the entry and spread of HPAI virus.

METHODS

A geographic information system was developed to generate maps to identify high risk areas for HPAI.

The maps are the result of the integration of several themes or layers. Each theme is based on the geographic distribution of a single risk factor.

To draw up the maps and carry out spatial studies the ArcView 3.2 (ESRI) program was used. The data was administered by means of MS Access.

The data had different sources, which will be described below. Maps and data from Argentina were used to provide examples of the development and results of the model. Others who wish to use the model must have the required data, it is not necessary to have all the layers, less can be used, and it is also possible to add additional layers.

Risk Factors

To determine the risk factors and include them in the model the following was taken into account:

- a. The area of interest is free of the disease
- b. The virus may enter due to migratory wild birds
- c. The virus may enter through legal trade in live birds or products
- d. The virus may enter by illegal trade in live birds or products
- e. The virus may enter by legal trade in wild birds
- f. The virus may enter by illegal trade in wild birds
- g. The virus may enter due to movement of people
- h. Domestic yard-fowl are a potential source of multiplication and diffusion of the virus

- i. Domestic commercial fowl are a potential source of massive diffusion of the disease
- j. The areas where migratory wild birds, domestic yard-fowl and domestic commercial fowl co-exist are the areas of major risk of appearance of the disease

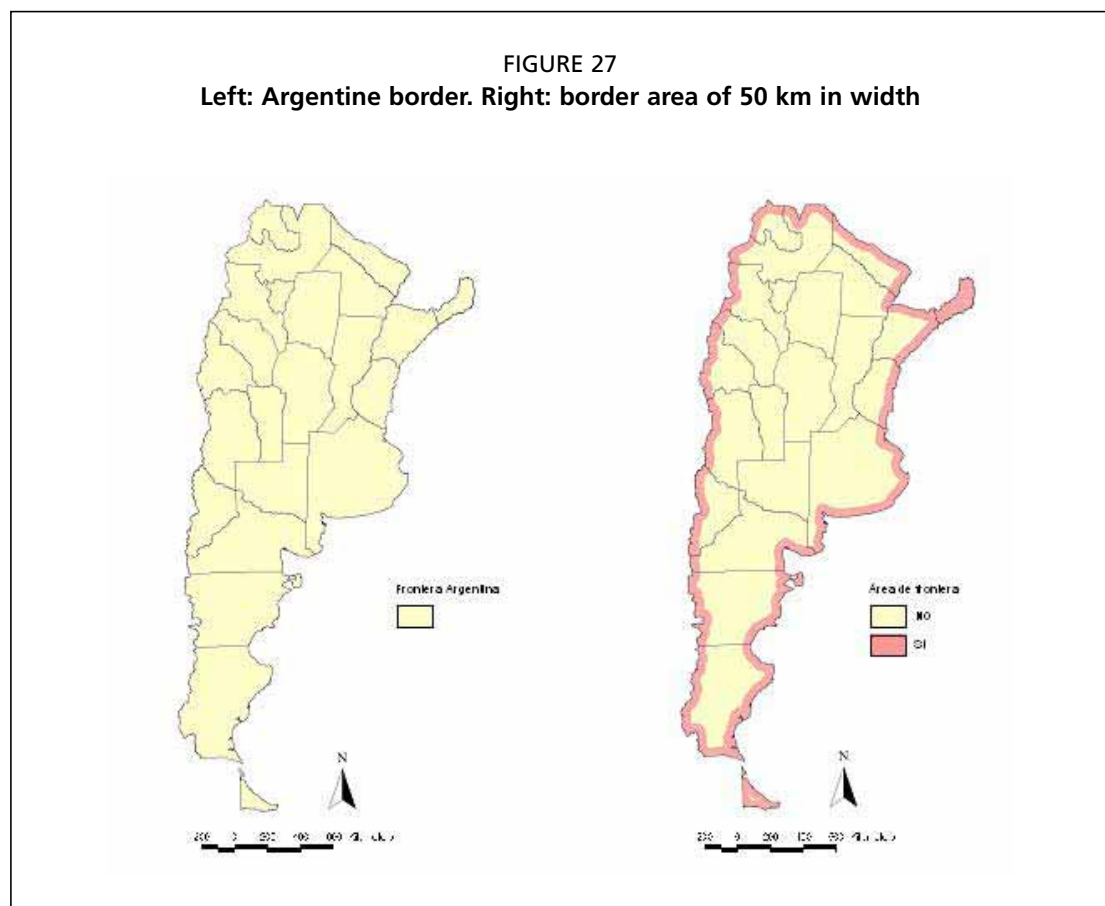
Many of these facts, as many of the risk factors described below, have been described by, amongst others, FAO (2004), Morris and Jackson (2005), FAO (2006) and Kilpatrick *et al.* (2006).

Borders

If the virus does not exist in the study area, it must cross the borders to enter it. This may be achieved by migratory wild birds, legal or illegal trade in animals or products or the movement of people. In the case that border areas, for example, neighboring countries have the same sanitary status of free of the disease, the border areas will be relatively low risk areas. If a neighboring country imports products from infected areas, then the risk in the border areas will increase. If the virus is present in a neighboring country, the risk in the border areas will, of course, be much greater.

Whatever the situation as described previously, there will be a map that will present the study area divided into two parts: a – absence of risk factors; b - presence of risk factors. The relative importance of the risk factors will be adjusted in a way indicated below.

In Figure 27 it is possible to see a map of Argentina showing the borders, and another



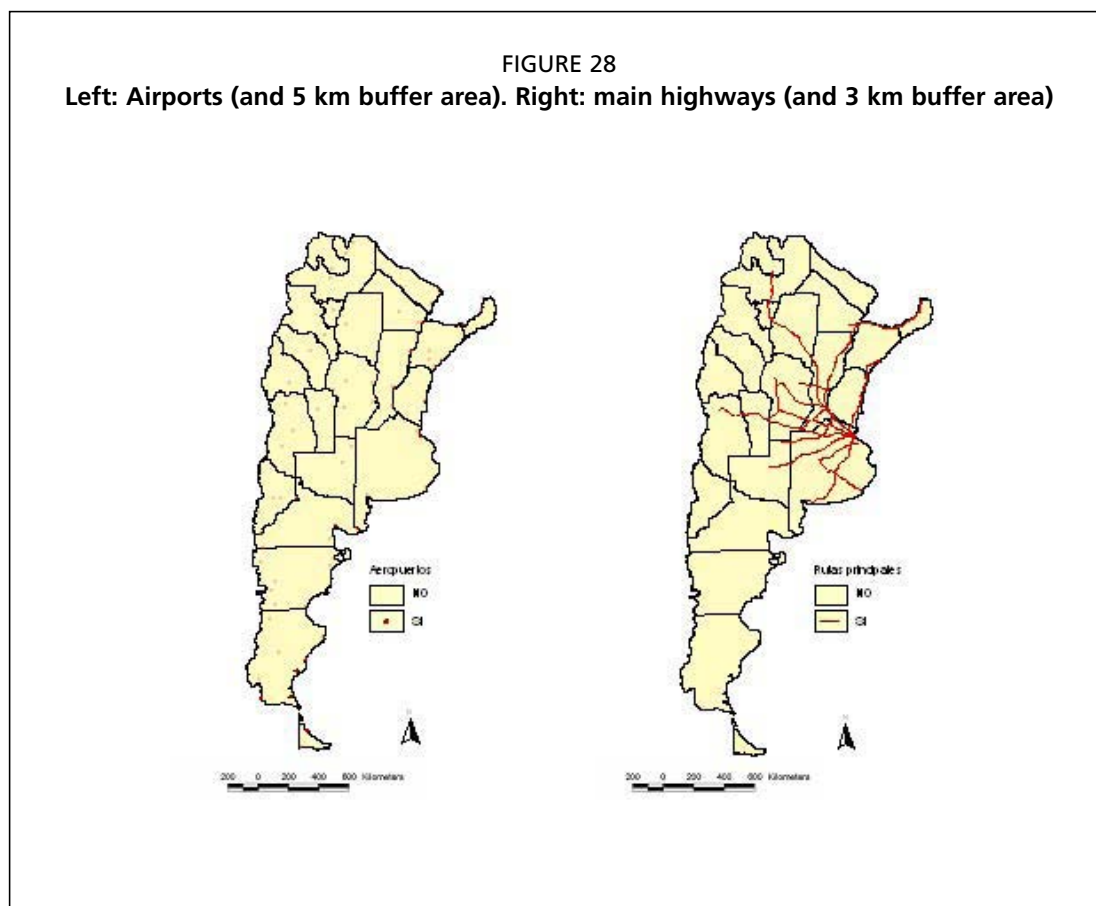
with a 50 km wide strip towards the interior along the borders, defining areas thought to be a risk for a HPAI into the country. The logic here is that if HPAI is to enter Argentina by land then the first point of release of the virus will be close to the national borders. The map of Argentina forms part of the files provided by ESRI together with the ArcView package. The border areas were determined using ArcView, using the function "Create buffer" of the "Theme" menu, defining a distance of 50 km from the border towards the interior of the theme.

Airports

Other potential points of virus entry are airports, through which not only people move, but also products that may be carriers of the causal agent.

To draw a map of the airports, it is necessary to have the geographic coordinates of each airport in the study area. These can be obtained using a GPS or through searches on the Internet. A data base must be drawn up with the identification of the airports and the coordinates of each one. These data will be added to the model using the function "Add Event Theme" of the "View" menu. In this way the airports will be a new theme (layer) in the view. Subsequently an area around each airport must be created, using the function "Create buffer", on the airport theme.

Example: Figure 28 it is possible to observe the airports of Argentina, surrounded by a 5 km diameter area.



Highways

Highways can be an important route for HPAI virus spread, since cargo is moved over them, both live birds and products. They have therefore been included in the model.

Digital maps represent highways as linear segments. Currently they are relatively easy to get, since both official and private organizations provide digital maps of many countries. Frequently they are available on Internet.

Of the total number of highways and roads that exist in the study area, the model should only include those considered of importance in the theme, that is, those used for transport of a considerable amount of bird products. Once the theme with the most important highways is available, as in former cases, a surrounding area of the appropriate width must be marked. The appropriate width depends on several factors, such as quantity and frequency of the loads transported, types of trucks (open or closed), etc.

It is possible to see in Figure 28 the map of the main roads of Argentina. A 3 km wide area has been created surrounding each highway.

Rivers and Bodies of Water

Rivers, ponds, lakes, natural and artificial bodies of water, such as rice-fields, are sites chosen by migratory waterfowl to settle during their migration. Furthermore, these sites may be chosen by other wild birds, which are year round residents or local migratory birds. When ecological conditions or the season of the year is appropriate, it is usual to observe in these sites large congregations of birds, which could greatly increase the spread of HPIA.

The maps of bodies of water (ponds and lakes) and rivers must be requested from the official institutions who work with Cartography.

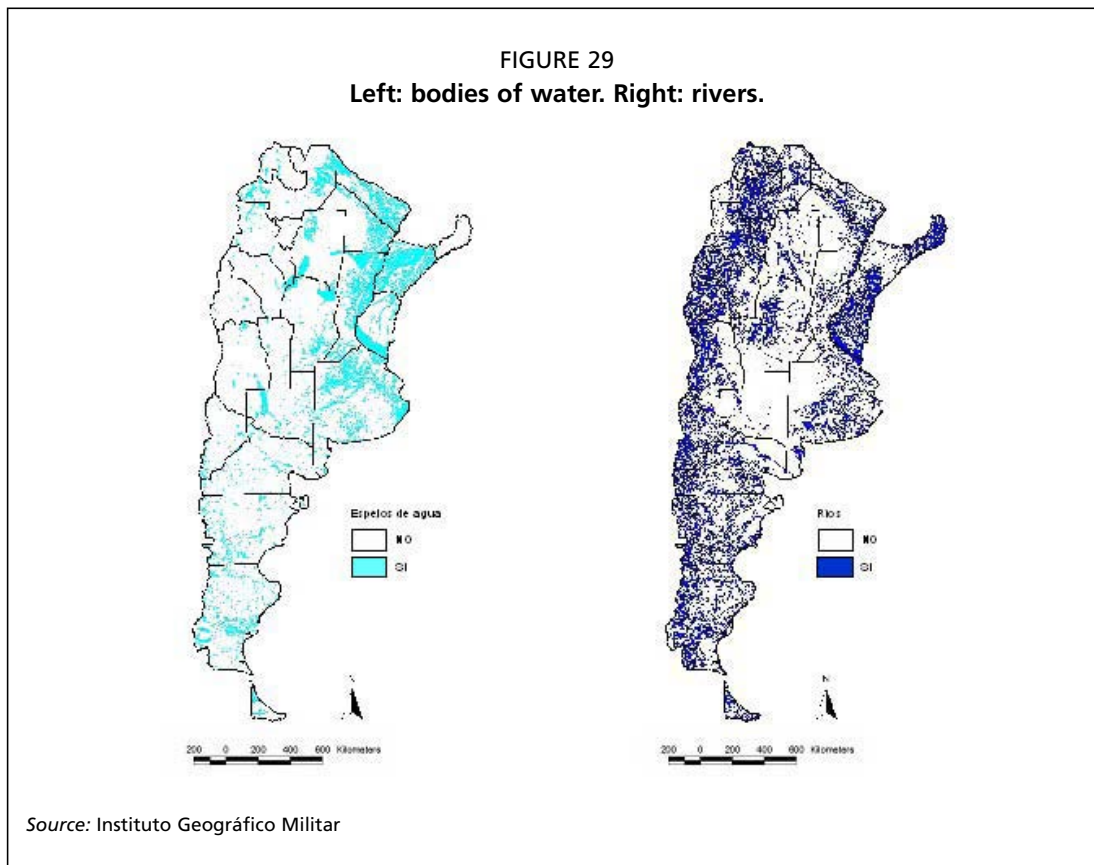
In Figure 29 it is possible to see maps of the distribution of bodies of water and rivers in Argentina, generated by the Instituto Geográfico Militar, which is the official institution of reference on Cartography in the country.

Places where Migrant Waterfowl Congregate

It is of crucial importance that in each country meetings should take place amongst the veterinarians of the official services and the main groups of biologists, ornithologists, and other professional experts on the subject, with the aim of defining: a – the main species of interest; b - migratory routes; c – the places where these species settle; d – the seasons during which these species are present in the country. In this sense the work carried out by a- British Trust for Ornithology, b- Wildfowl & Wetlands Trust and c- Veterinary Laboratories Agency for Department for Environment, Food and Rural Affairs (DEFRA), UK, constitutes a remarkable example (Crick *et al.*, 2006).

The recommendation of carrying out this sort of work jointly has recently been ratified by Wetlands International and The European Union for Bird Ringing in a report carried out by the European Commission (Atkinson *et al.*, 2006).

The wild birds of greatest interest are migrant waterfowl from the Northern Hemisphere (nearctic), represented in the Southern Cone of Latin America by species of the orders Anseriformes and Caradriformes. To define the species of greatest interest in the epidemiology of HPAI the following characteristics are taken into account: a – habitat: the virus survives better in fresh water than in salt water, therefore the species of birds that settle in fresh

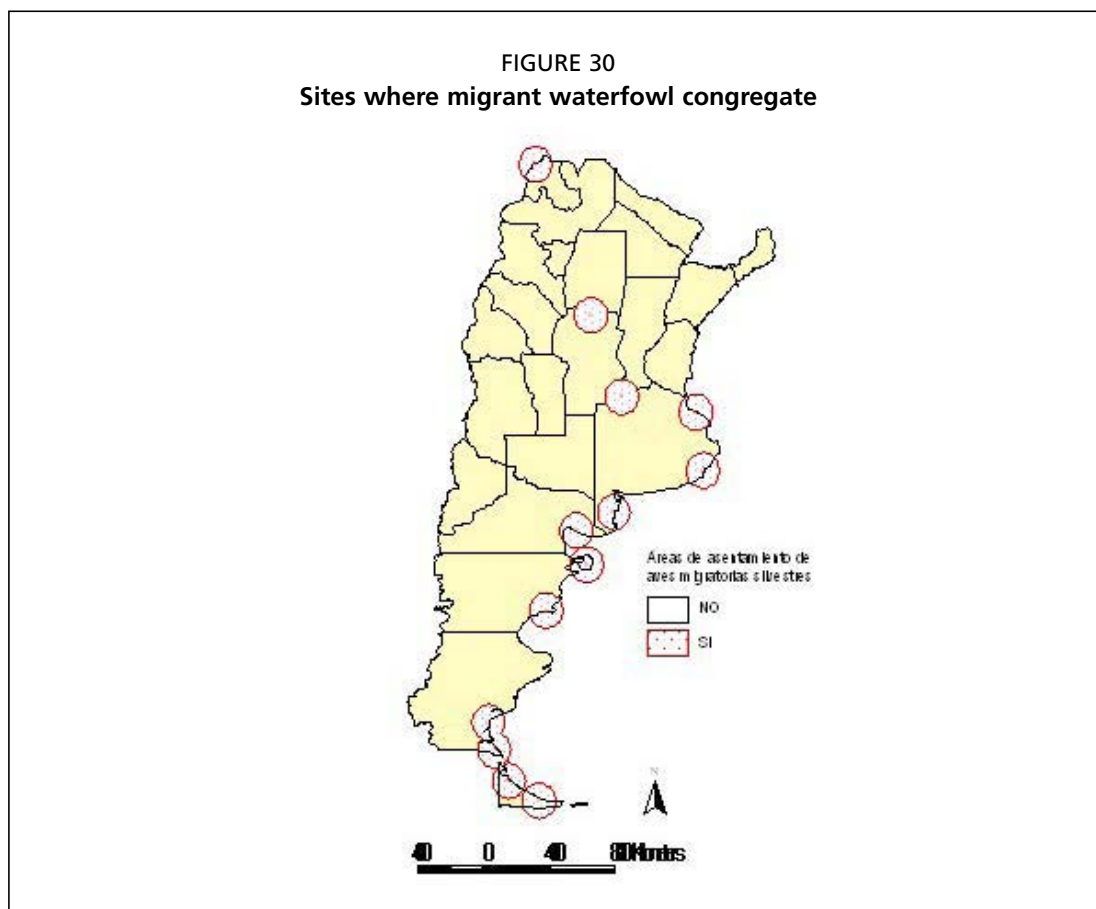


water are of greater interest; b – gregarious characteristics: the species that live in large density groups have a greater probability of transmitting the virus between individuals; c – conformation of mixed groups: species that live in close contact with individuals of other species have a greater probability of transmitting the virus.

Natural damp areas are the sites preferred by these birds. There they come into contact with species who are annual residents or local migrants, which move locally and occasionally may come into contact with domestic fowl kept in conditions without minimum biosafety safeguards, such as is normally the case with yard-fowl.

In Figure 30 it is possible to see the location of the main sites where nearctic migrant birds settle in Argentina, represented by dots, around which a surrounding area of 100 km diameter has been defined. These areas were defined during a workshop in Buenos Aires in 2007, at which expert ornithologists from several countries in the region were present, as well as experts from Wetlands International. The location of these sites is provisional and requires adjustments, which will be carried out as studies currently being carried out advance.

Migrant birds from the Northern Hemisphere are not present all year round, they are only found at a precise and defined time of year. In the case of Argentina, they start to arrive at the beginning of October and remain in the country for a period not greater than 6 months. At the end of March they have already completed their migration and between April and September they are absent from Argentina.



Distribution of Backyard-fowl

Undoubtedly domestic backyard-fowl play a potentially important role in the epidemiology of avian influenza, therefore their number and distribution must be taken into account when carrying out any risk assessment.

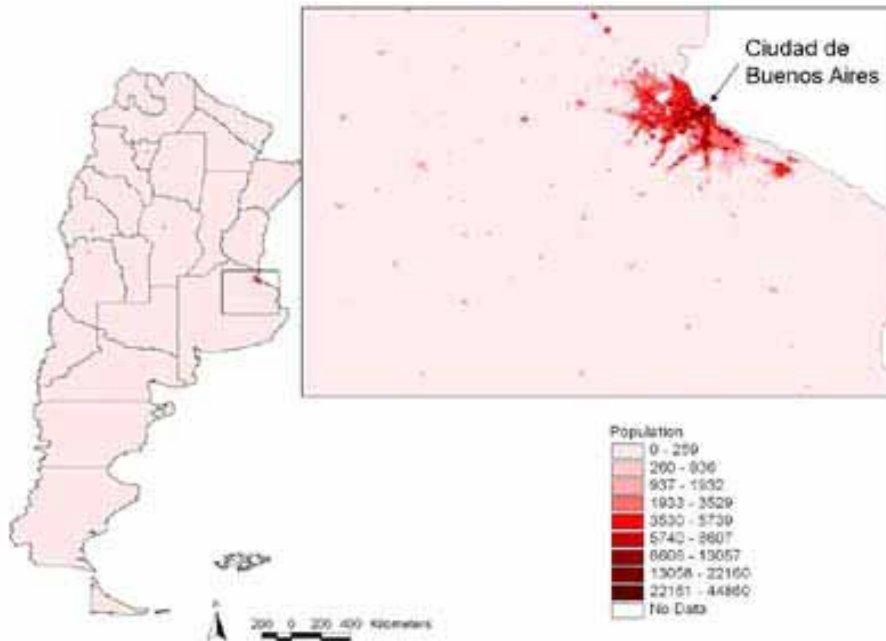
Under ideal conditions (and theoretical ones) a census should be carried out to determine the number and distribution of the human population of a country or region who own of this sort of bird. Under real conditions this is not possible.

For this model an estimation of backyard-fowl is used based on the distribution of human population. For this the following premises are considered valid: a) backyard-fowl exist only where there are people, if there are no humans there are no backyard-fowl; b) the probability of a family having yard-fowl is inversely related to the density of the population, there is a greater probability in rural areas than in high-density-population areas, such as urban areas.

The estimation of the distribution of backyard-fowl began with human population distribution data obtained from "LandScan" (www.ornl.gov/sci/landscan). This is a large database of human world population, compiled on a grid with 30" latitude by 30" longitude. In Figure 31 it is possible to see the distribution of the Argentine population and in the magnified part the city of Buenos Aires and other smaller urban centers.

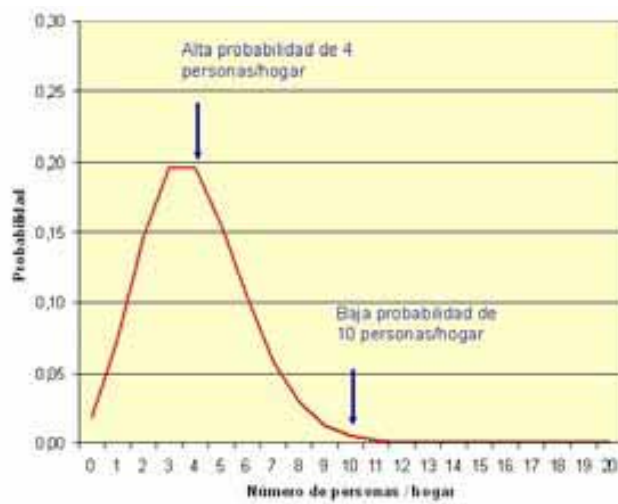
Based on the number of people per cell the number of homes per cell was estimated, based on the assumption that the number of people per home follows a Poisson distribution, which for Argentina is similar to that presented in Figure 32. Using an iteration func-

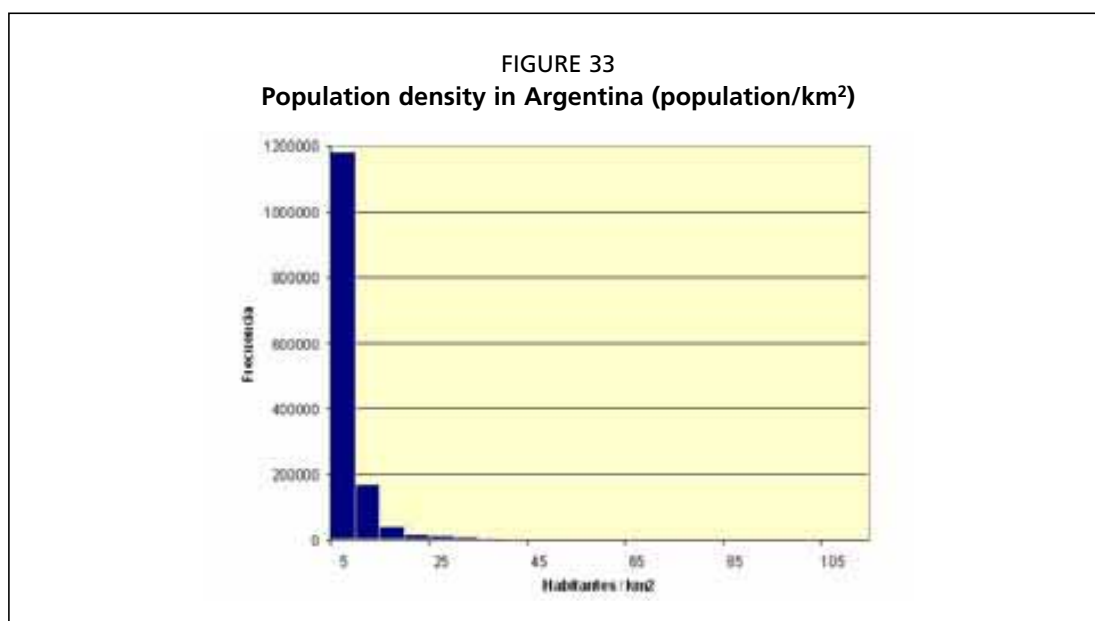
FIGURE 31
Population density in Argentina, expressed as number of persons per 30" latitude by 30" longitude cell.



Source: www.ornl.gov/sci/landscan

FIGURE 32
Distribution of number of persons per home





tion each cell in the grid was assigned a random number of homes, following the distribution previously determined, until the population of each cell was exhausted.

Once the number of homes per cell was determined, the number of homes with yard-fowl was estimated. To estimate this, the probability of a home having backyard-fowl was estimated as a function of population density. In Figure 33 it is possible to see the distribution of cells on the grid over Argentina, as a function of population density (population per km²).

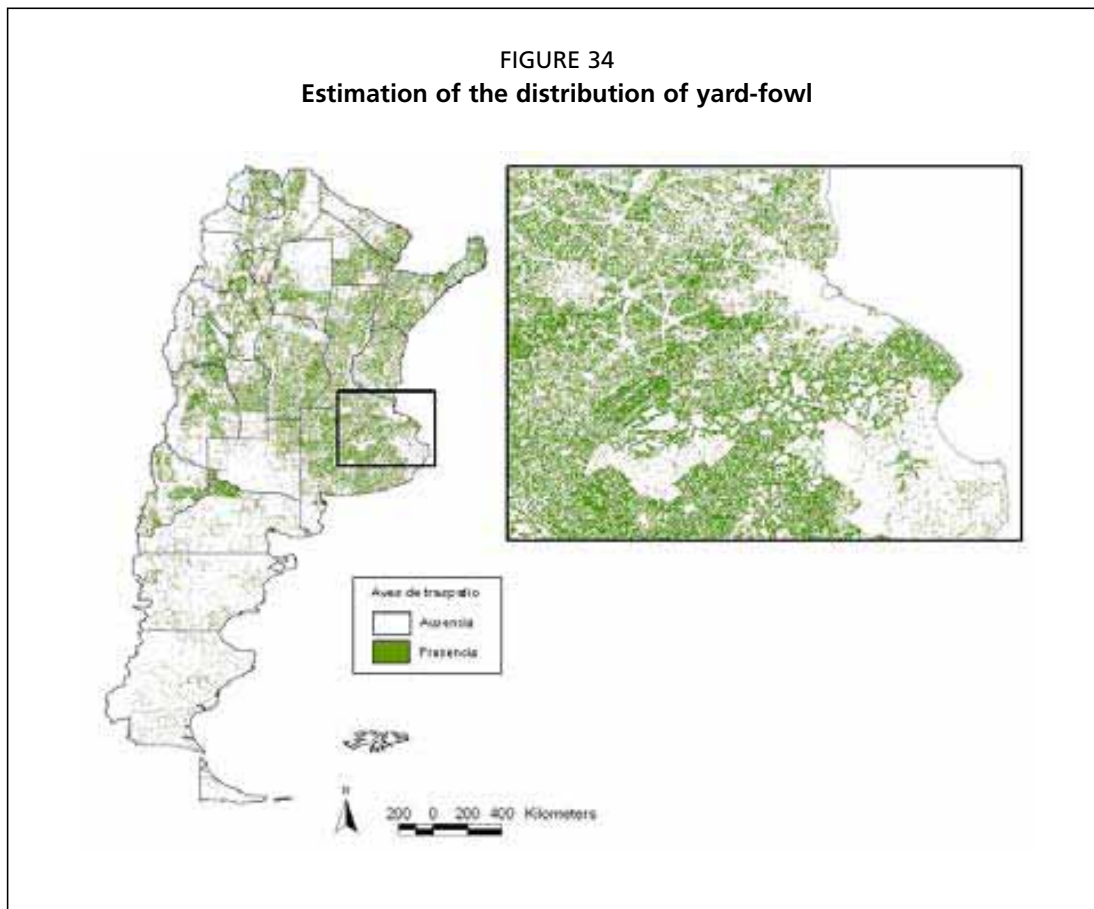
The probability of homes having backyard-fowl was determined, based on the opinions of experts, as a function of population density of the cell they belonged to (Table 4). This estimation can also be carried out based on samples of homes in areas with different population density.

Then the presence or not of yard-fowl was determined for each home, using a random function based on the distribution of the frequencies described in Table 4. In this way, each home in the country was identified as a possessor or not of yard-fowl.

Finally each cell of the grid of the map based on the existence or not of homes with yard-fowl was placed in one of the following categories:

TABLE 4
Probability of a home having backyard-fowl, based on human population density

Density (human population / km ²)	Probability of yard-fowl
<1.5	0.90
1.5 - 4.2	0.50
4.2 - 6.0	0.20
6.0 - 10.0	0.10
>10.0	0.00



- Absence of backyard-fowl: 0
- Presence of backyard-fowl: 1

In Figure 34 it is possible to see the distribution of the grids with and without yard-fowl.

Distribution of Commercial Fowl

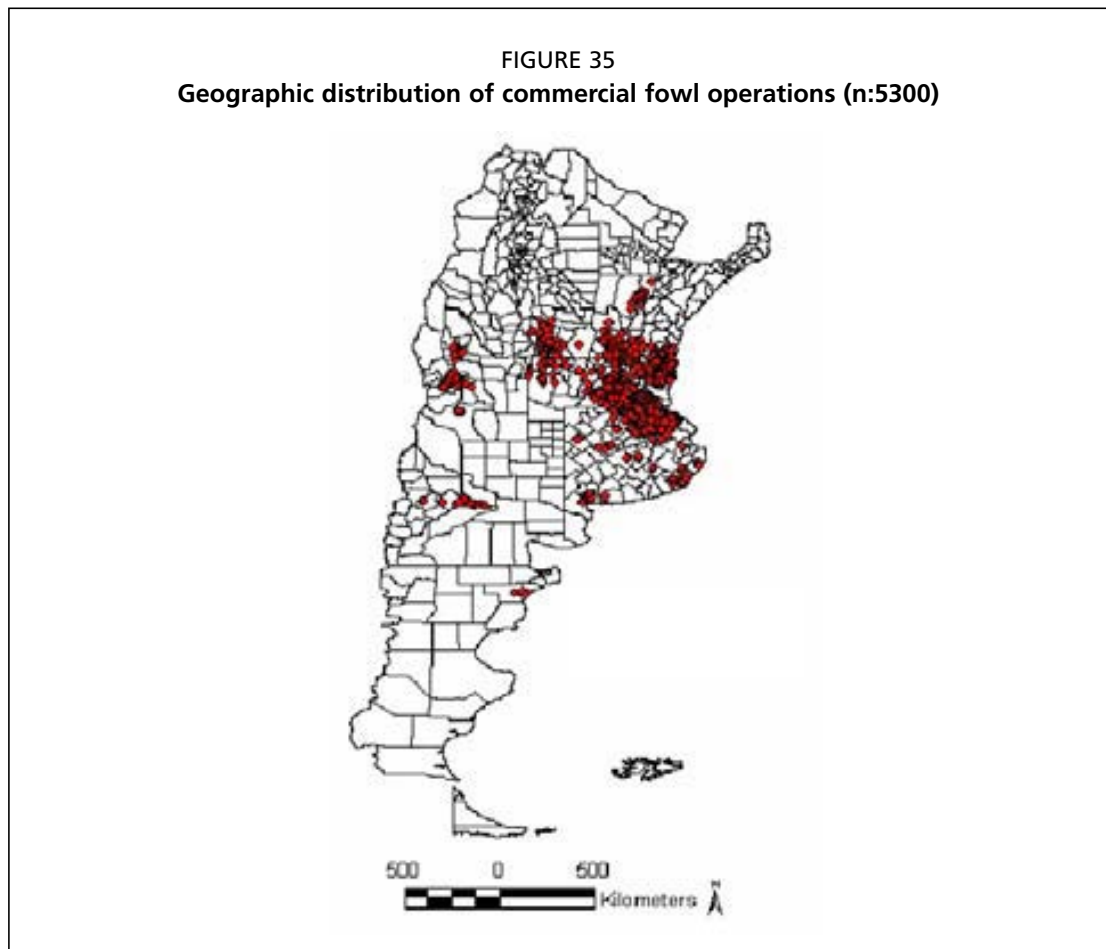
This is the factor of greatest importance in the model. The Official Veterinary Services must obtain, working in cooperation with the private sector, the geographic coordinates of the commercial fowl operations in Argentina. This data must be linked to databases with a description of the most important characteristics of each operation, such as owner's data, productive capacity, type of operation, existent biosecurity measures, etc.

In the case of Argentina the National Service of Agrifood Health and Quality (Servicio Nacional de Sanidad y Calidad Agroalimentaria, SENASA) has georeferenced more than 5300 commercial operations in the form of dots (latitude-longitude). Their geographic distribution can be seen in Figure 35.

Preparation of Theme Layers

In the text above the preparation of maps with 8 risk factors was described: borders, airports, highways, bodies of water, rivers, sites where wild birds congregate, yard-fowl and commercial fowl operations. Each of these maps is a theme layer for the risk map.

To unify the format of each theme layer, the map of Argentina was divided into a grid



made up of 3993 rows x 2393 columns. In this way, the size of each pixel is approximately 1 km².

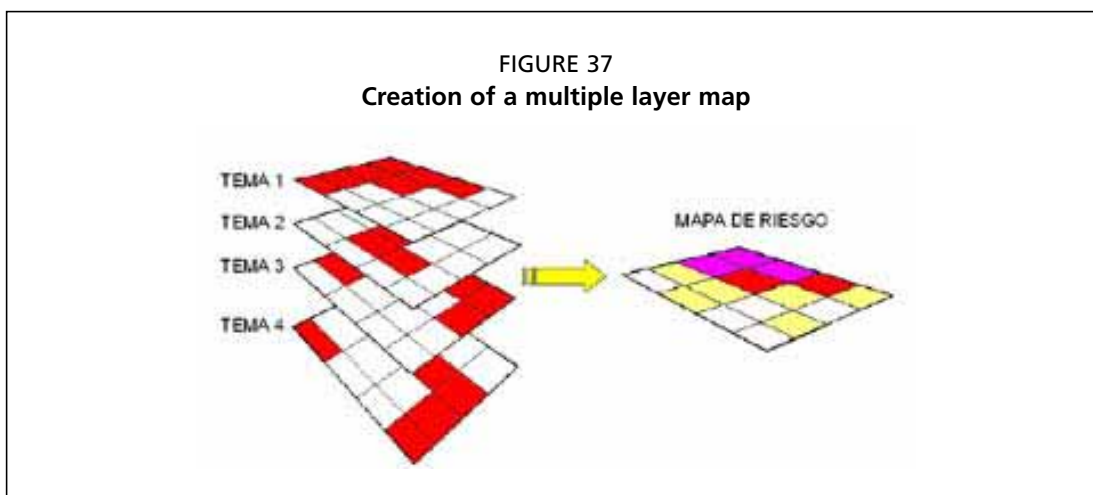
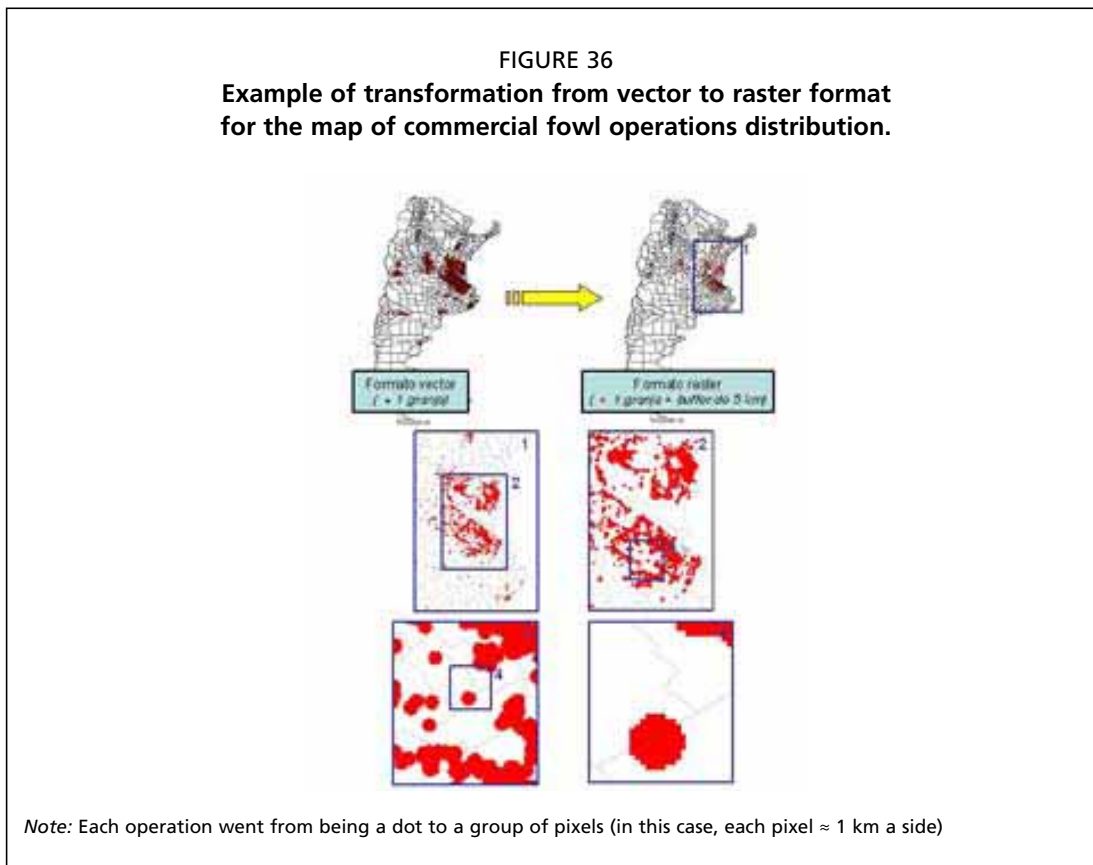
Maps in which the data was expressed in the form of a vector were converted to raster format, with a definition coinciding with the grid (3993 rows x 2393 columns). Maps with the data originally expressed in raster format, such as is the case of the one of yard-fowl, were re-adapted to the definition of 3993 rows x 2393 columns.

Subsequently, for each of the 8 maps the following procedure was followed: each cell of the grid (3993 rows x 2393 columns) was assigned a value of 0 or 1, according to whether the event of interest existed or not.

In Figure 36 it is possible to see, as an example, how the map of distribution of commercial fowl operations, originally expressed in vector format (each dot = 1 farm) was transformed. Furthermore, in this case the pixel of the location of each operation was identified plus a buffer zone with a 5 km diameter.

Unifying theme layers

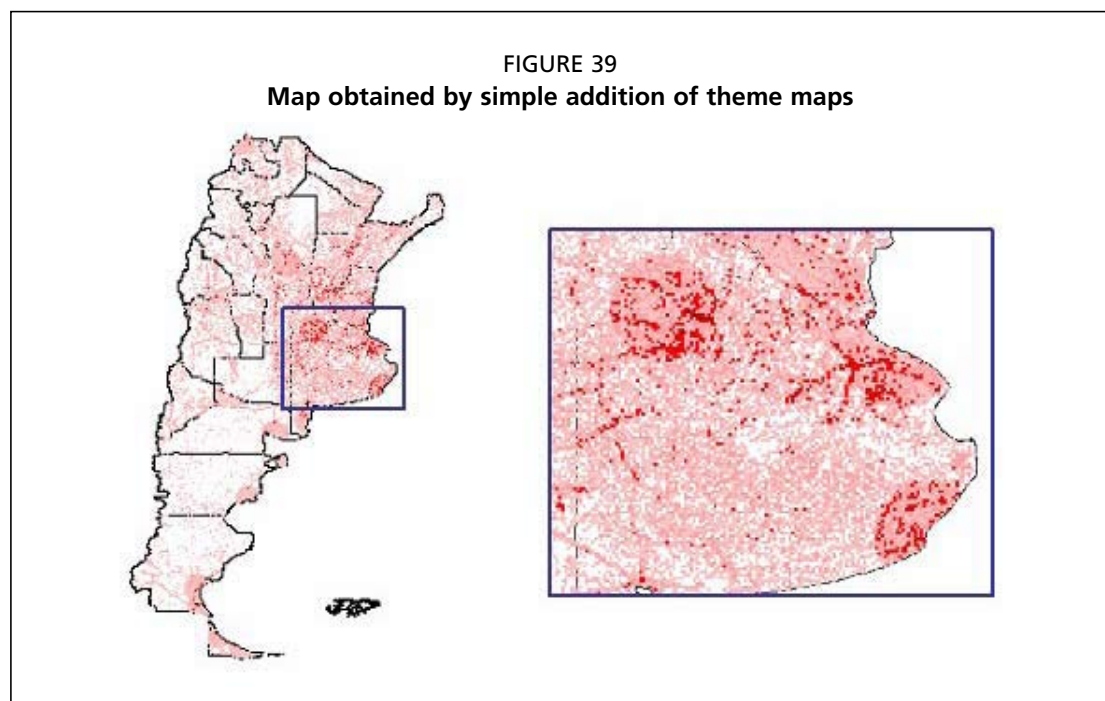
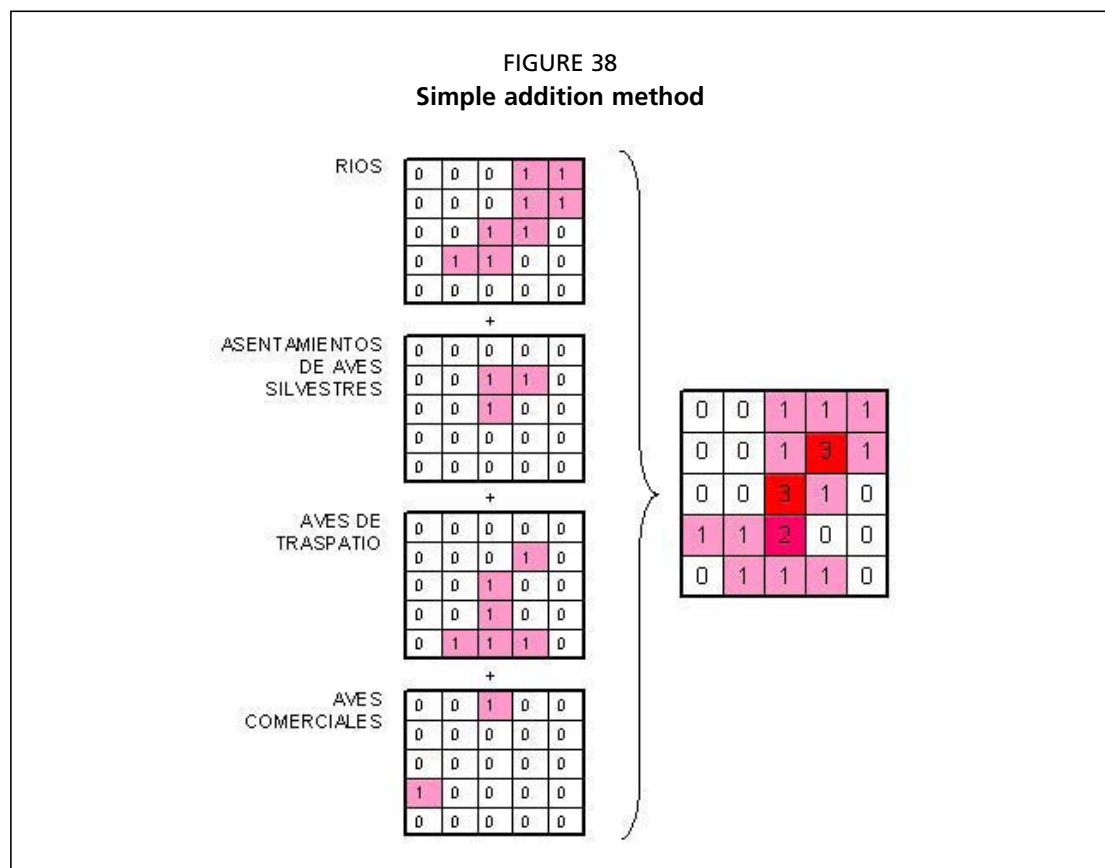
Once the theme layers had been determined and standardized to a common format, as is explained above, they must be unified. To achieve this, all the theme layers must be superimposed, so as to form a single map in which it is possible to see a synthesis of all the theme layers, similar to the diagram in Figure 37.



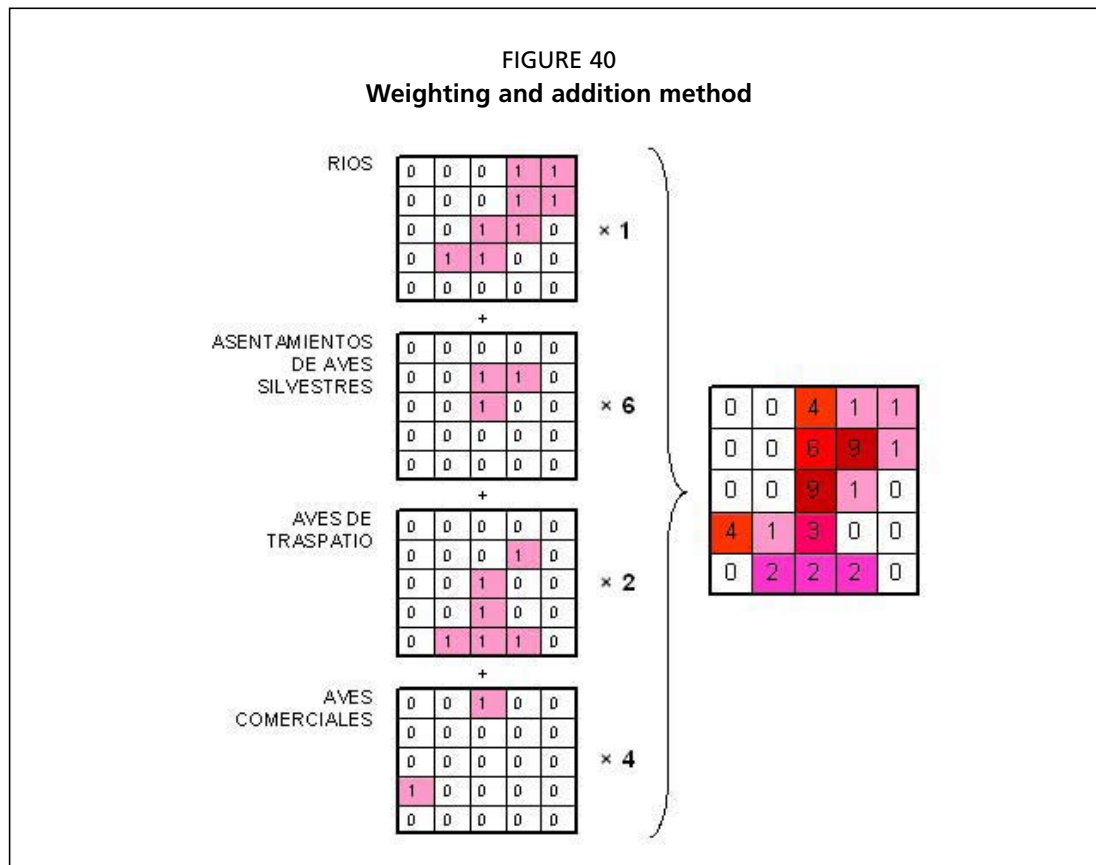
The unified map can be made using different procedures, each has advantages and disadvantages. Amongst these procedures are: a – simple addition; b – weighting and addition; c – comparison of pairs. The 3 methods are described below.

Simple Addition

This is the simplest procedure. Based on theme layers in raster format, in which each cell has a value of 0 or 1, a new map is created in raster format in which each cell has a value corresponding to the sum of all the theme layers. In Figure 38 it is possible to see a diagram of this procedure.



To carry out this procedure in ArcView 3.2, the function “MAP CALCULATOR” in the “ANALYSIS” menu is used (with the Spatial Analysis extension activated). In Figure 39 it is possible to see a map obtained in this way, with a magnified detail of the Province of Buenos Aires.



The main advantage of this method is its simplicity, as well as the fact that it shows a clear differentiation between areas at risk and those that are not at risk. Its main disadvantage is the lack of consistency with reality, since in practice it is difficult to find situations in which all risk factors have the same relative importance.

Weighting and Addition

In this procedure, the value of each cell of the theme maps (0 or 1) is multiplied by the weighting factor, according to the relative importance of each risk factor. This weighting, of a semi-quantitative type, is the critical step in this method, and must be based on a detailed analysis of each element, a careful study of the literature and consultations with experts on the subject. It is possible to see a diagram of the procedure in Figure 40.

The procedure consists in determining a score for each risk factor between 1 and 10, according to its relative importance, with relation to the introduction of HPIA. In Table 5 it is possible to see, as an example, the scores given to each risk factor.

Subsequently, using the "ANALYSIS - MAP CALCULATOR" function, a new map may be generated based on the following equation:

$$[(Fron \times 3) + (Aerop \times 4) + (Rut \times 7) + (Espej \times 9) + (Rios \times 6) + (ASilv \times 9) + (ATras \times 7) + (ACom \times 5)] / 50 *$$

* Fron = Border; Aerop = Airports; Rut = Highways; Espej = Bodies of water ; Rios = Rivers; ASilv = Sites where wild birds congregate; ATras = Yard-fowl; ACom = Commercial fowl

TABLE 5
Score for each risk factor

Name of the map	Risk Factor	Score
Fron	Border	3
Aerop	Airports	4
Rut	Highways	7
Espej	Bodies of water	9
Rios	Rivers	6
ASilv	Sites where wild birds congregate	9
ATras	Yard-fowl	7
ACom	Commercial fowl	5
	TOTAL	50

With this procedure a map in raster format will be obtained in which each cell of the grid has a value between 0 and 1. In Figure 41 (a) it is possible to see a map of Argentina obtained in this way.

This method has the advantage of producing more realistic results than the simple addition method. Its disadvantage lies in the determination of the weighting factors. This must be done objectively, and therefore requires a greater level of knowledge, both of epidemiological aspects of the disease and of the risk factors involved.

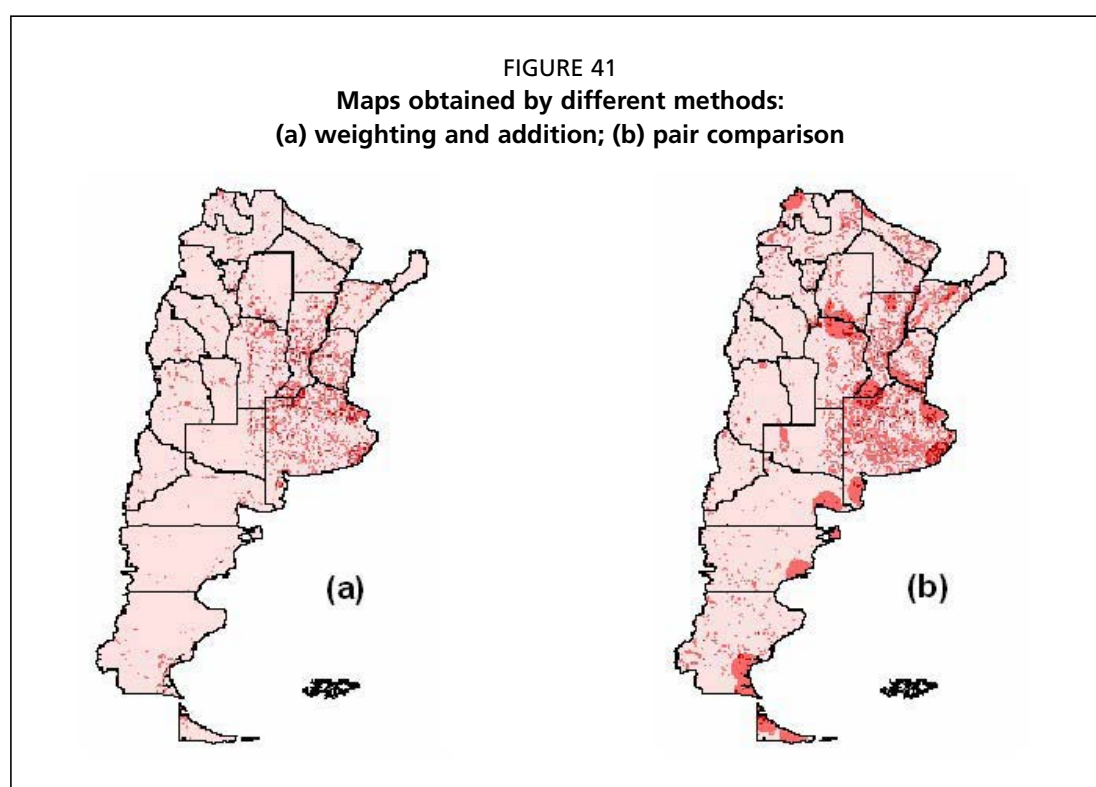


TABLE 6
Possible values obtained for the comparison of risk factors

Less important				1	More important			
1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely strong	Very strong	Strong	Moderate	Equal	Moderate	Strong	Very strong	Extremely strong

TABLE 7
Matrix of score assignment

	Fron	Aerop	Rut	Espej	Rios	ASilv	ATras	ACom
Fron	1	3.03	3.03	0.33	0.33	0.14	5	5
Aerop	0.33	1	1	0.33	0.33	0.14	5	10
Rut	0.33	1	1	0.33	0.33	0.14	5	10
Espej	3	3	3	1	1	0.14	5	10
Rios	3	3	3	1	1	0.14	5	10
ASilv	7	7	7	7	7	1	3.03	5
ATras	0.2	0.2	0.2	0.2	0.2	0.33	1	3.03
ACom	0.2	0.1	0.1	0.1	0.1	0.2	0.33	1
TOT	15.06	18.33	18.33	10.30	10.30	2.24	29.36	54.03

Pair Comparison

This is another weighting method, in which the value of each cell of the theme maps (0 or 1), is multiplied by a semi-quantitative weighting factor which arises from the comparison of the importance of each risk factor in relation to the others, pair by pair. The calculation of the weighting factor begins by giving each risk factor a score that indicates the relative importance in relation to the other risk factors. This score has a value as indicated in Table 6.

To determine the score of each risk factor, it is necessary to use a matrix (table of 2 x 2) with the risk factors as headers of the columns and rows (Table 7). As a first step the cells in the lower part of the diagonal (where rows and columns intersect, must be completed. For example, in the first column of Table 7 it was indicated that airports and highways are moderately less important (1/3) for the risk of introduction of HPAI than borders, bodies of water and rivers which are moderately more important (3), wild birds are strongly more important (7) and yard-fowl and commercial fowl are very strongly less important (1/5). Subsequently the cells of the lower part of the diagonal are completed, with the inverse of the value of the reciprocal cell in the lower part. For example, the cell Aerop x Fron was assigned a value of 0.33, and the cell ASilv x Espej a value of 7. Therefore, to complete the upper part of the table, the cell Fron x Aerop will be assigned an inverse value to 0.33 (1/0.33 or 0.33⁻¹), that is 3.03, and the cell Espej x ASilv will be assigned the inverse value of 7 (1/7 or 7⁻¹), that is 0.14. Once all the cells in the matrix are complete the total of each column must be calculated.

TABLE 8
Score divided by the total of the column. And the mean value of each row

	Fron	Aerop	Rut	Espej	Rios	ASilv	ATras	ACom	Media
Fron	0.07	0.17	0.17	0.03	0.03	0.06	0.17	0.09	0.10
Aerop	0.02	0.05	0.05	0.03	0.03	0.06	0.17	0.19	0.08
Rut	0.02	0.05	0.05	0.03	0.03	0.06	0.17	0.19	0.08
Espej	0.20	0.16	0.16	0.10	0.10	0.06	0.17	0.19	0.14
Rios	0.20	0.16	0.16	0.10	0.10	0.06	0.17	0.19	0.14
ASilv	0.46	0.38	0.38	0.68	0.68	0.45	0.10	0.09	0.40
ATras	0.01	0.01	0.01	0.02	0.02	0.15	0.03	0.06	0.04
ACom	0.01	0.01	0.01	0.01	0.01	0.09	0.01	0.02	0.02

TABLE 9
Weighting factor for each risk factor, calculated by pair comparison method

Name of the map	Risk Factor	Score
Fron	Border	0.10
Aerop	Airports	0.08
Rut	Highways	0.08
Espej	Bodies of water	0.14
Rios	Rivers	0.14
ASilv	Sites where wild birds congregate	0.40
ATras	Yard-fowl	0.04
ACom	Commercial fowl	0.02

Subsequently, each score is divided by the total of its column. Once this is done, the arithmetic mean of the new values is calculated for each row. An example of these steps can be seen in Table 8.

In Table 9 it is possible to see the weighting factor for each risk factor, which is the mean calculated in the previous step.

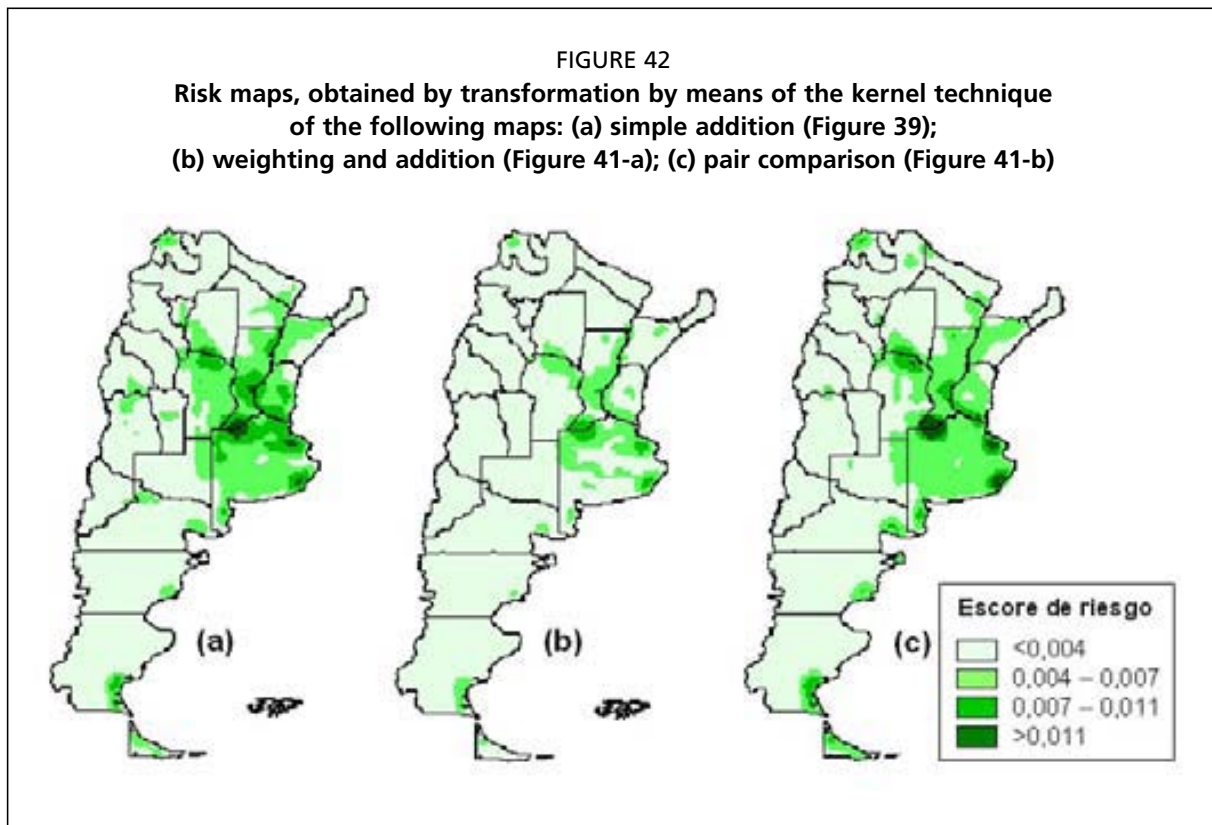
Finally using the function "ANALYSIS - MAP CALCULATOR", the map may be obtained using the equation:

$$(Fron \times 0.10) + (Aerop \times 0.08) + (Rut \times 0.08) + (Espej \times 0.14) + (Rios \times 0.14) + (ASilv \times 0.40) + (ATras \times 0.04) + (ACom \times 0.02)$$

In this way a raster format map will be obtained in which each cell will have a value between 0 and 1. In Figure 41 (b) it is possible to see the map of Argentina obtained using this procedure.

The advantage of this approach, compared with the two methods already described, is that it simplifies the process of scoring each HPAI risk factor: instead of numerically scoring each factor, experts are asked to estimate how much more (or less) important one factor is compared to another.

For further technical details the reader is referred to Eastman *et al.* (1995).



Risk Map

Using the procedure described above it is possible to obtain maps in raster format in which the intensity of the color of the cells is associated with the risk of introduction of HPAI. However, these maps are difficult to interpret and not appropriate for the identification of large areas of risk since they have an irregular cell distribution. For these reasons they must be adjusted.

To achieve this, it is advisable to use 'Kernel Smoothing'. The aim is to identify areas with different levels of risk, based on cell density with an equal or similar risk score. For example, an area will be identified as of high risk if there are many cells in it with a high score and these are very close together spatially.

To carry out this technique first it is necessary to create a dot map based on a unified raster map (presenting the information in several theme layers, as was explained in the previous text). This is achieved by loading the Spatial Analyst and Spatial Tools extensions and using the function "GRID TO POINT" of the "TRANSFORMATION" menu. Two forms will open consecutively, in the first OK must be clicked and in the second it is necessary to indicate Kernel in "Density type".

In Figure 42 it is possible to see 3 maps obtained in this way. Large areas may be identified in them with different risks for the introduction of HPAI. This makes it possible to use different surveillance strategies in each area.

CONCLUSION

The proposed system, based on the identification of areas of potential risk for the introduction of HPAI, allows and favors the implementation of epidemiological surveillance strate-

gies based on risk assessment, thus allowing the concentration of efforts and investments in areas in which the probability of an event is greater.

It must be kept in mind that the success of this method depends largely on the fact that risk assessment is the result of the participation of experts in different fields who jointly define the risk scores (Elliott *et al.*, 2005).

This type of HPAI epidemiological surveillance is recommended by the OIE in Annex 3.8.9. of the Health Code for Terrestrial Animals (OIE, 2007).

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This manual provides, in the first part, an introduction to the use of Geographic Information Systems (GIS) in veterinary epidemiology. The second part describes how a GIS can be used to develop a surveillance strategy for Highly Pathogenic Avian Influenza (HPAI). The approach allows users to identify locations 'at risk' for avian influenza incursion and spread. Informed by appropriate data, this methodological approaches described in this manual provide Official Veterinary Services with a useful set of tools to support the development of surveillance strategies based on risk.

Este manual presenta en su primera parte una introducción a los Sistemas de Información Geográfica (SIG) y sus usos en Vigilancia de las enfermedades animales. En la segunda parte se describe un modelo para la Vigilancia de la Influenza Aviar de Alta Patogenicidad (IAAP) que permite estimar, en base a una serie de datos georreferenciados, las áreas de mayor riesgo potencial para la introducción y difusión del virus de la IAAP en países libres del mismo. El modelo puede ser aplicado por los Servicios Veterinarios Oficiales de los países que dispongan de los datos necesarios, y constituye una herramienta de apoyo para la adopción de medidas de Vigilancia basadas en la estimación del riesgo.