Geographic information systems: their application in animal disease control

R.L. SANSON, D.U. PFEIFFER AND R.S. MORRIS *

Summary: Geographic information systems (GIS) are computerised information systems that allow for the capture, storage, manipulation, analysis, display and reporting of geographically referenced data. They have been used in recent years for a wide variety of purposes, including town planning and environmental resource management.

The technology has many features which make it ideal for use in animal disease control, including the ability to store information relating to demographic and causal factors and disease incidence on a geographical background, and a variety of spatial analysis functions.

A number of possible veterinary applications are suggested, and three examples of the use of GIS in New Zealand are discussed.

KEYWORDS: Animal disease control - Computers - Epidemiology - Geographic information system - Spatial analysis.

INTRODUCTION

Geographic information systems (GIS) have been used in recent years for a wide variety of purposes, including urban and regional planning (3, 18) and utility management, land suitability assessment (7), environmental resource monitoring (4, 19), emergency response management (1) and ecological modelling (25). Owing to their inherent ability to manage spatial information, they are suited to any application where geographically referenced data is stored, manipulated and consulted. GIS have developed from purely inventory to management tools (6). They are being used as part of decision support systems or as "intelligent geographic information systems" which allow them to be combined with simulation models and expert systems (5, 16).

This paper will attempt to define the technology and identify possible uses within the broad field of animal disease control, and will then discuss some specific projects involving GIS.
DEFINITION

Geographic information systems (GIS) are computerised information systems that allow for the capture, storage, manipulation, analysis, display and reporting of geographically referenced data (17, 21, 27). Essentially, the technique is a combination of computerised mapping technology and database management systems (DBMS), in which spatial data sets from diverse sources are managed and analysed. The geographic information is organised in the form of various layers of thematic maps with their related attributes. Attributes are the items of data which relate to the map but are not part of it, such as the names of rivers or the type of vegetation in an area. Since the subject has an extensive terminology of its own, a glossary is appended to this paper.

The digital data stored within the GIS are generally derived by digitising (tracing) location information from existing maps, or are captured directly from remotely sensed data, such as aerial photographs and satellite images. Another option used in ecological studies is the direct capture of coordinate locations using radio telemetry. Radio transmitters are attached to the animals whose movements are being studied and locations are determined by radio triangulation or satellite tracking (8). Global positioning equipment can be used to determine exact geographic location directly from the position in question. Attribute information may be entered from the keyboard, or incorporated from existing public or private databases.

Digital maps are stored within the GIS in two basic formats, grid-based and vector-based. In grid- or raster-based systems, spatial information is aggregated by superimposing a grid over the area of interest; the user can specify the dimensions of the grid pattern. Attribute information is associated either with each individual cell, or with groups of cells that are homogeneous with respect to a particular characteristic. In vector-based systems, geographical features are represented as points, arcs and polygons. Points are single locations; arcs (lines) are generally comprised of their respective straight line segments (vectors); polygons are simply areas enclosed by arcs. There are advantages and disadvantages to both raster and vector systems (15). Grid-based systems are convenient for storage and manipulation of region-type features and information from remotely sensed image data is extracted efficiently. However, processing speed can be extremely slow. In order to achieve high resolution, cell size must be very small, and this may result in large data sets which are time-consuming to process. On the other hand, the resolution of vector-based systems is naturally very high because the actual coordinates of features are stored. The drawback of this format is that computer manipulation tends to be much more complex. Vector formats are ideal for processing of line-type features (10). Some GIS software packages use both formats for different functions.

The main computer hardware components of a GIS system are the central computer, a data storage system for holding the data, a high resolution colour display, a digitising tablet for data capture and a hard copy output device, such as a pen plotter. There are numerous options, depending on the purpose for which the GIS is being used, the quantity of data being dealt with and the budget. A typical micro-computer-based system would include an IBM compatible personal computer with an 80286 or 80386 micro-processor, at least 640 KB random access memory (RAM), a hard disk with a minimum size of 30 MB storage, and an EGA or VGA colour graphics card and monitor. It is possible for a GIS system to run on a portable computer.
Traditionally, GIS packages were only available on mini- or mainframe computer systems and tended to be vector-based. With the advent of powerful micro-computers, a range of grid-based and vector-based systems have become available, some of which are scaled down versions of mainframe packages (22). This has put GIS within the reach of many individuals and organisations that would otherwise never have been able to make use of the technology.

GIS FUNCTIONS

Database of geographically referenced data

The database management component provides the environment within which the GIS functions and the means by which the data is controlled. Any information that is coded by location, such as country, province, district or latitude/longitude coordinates, can be stored and manipulated in the GIS. The advantage of using a GIS rather than traditional database management systems (DBMS) is that the data can be viewed, queried and summarised visually through the graphical environment. Moreover, because the data has topology (this means that each feature “knows” its geographical position relative to other features), a variety of spatial processing functions which are not possible on a standard DBMS can be employed to process the information. These functions will be discussed below.

Neighbourhood analysis

This function allows an investigator to find and list all features which meet certain criteria and are adjacent to a particular feature. For example, a disease controller may want to identify all livestock units adjacent to an infected farm. A query of the GIS could give him a list of these farms.

Buffer generation

An extension of the neighbourhood analysis function is the generation of buffer zones around, or along, certain features. These buffers can be of variable width and are used to identify features that meet certain criteria that are within certain specified distances of the particular feature. This function could be used to define all at-risk properties within a given distance of an infected farm or along a transport route where it is known that infected animals have been driven.

Overlay analysis

Overlay analysis is analysis in which two or more maps are superimposed on top of each other and areas of intersection (overlay) of various features are defined. In GIS, each of the feature types are generally stored in individual layers or coverages. For example, the road network would be stored in one layer, streams in another, current land use, soil types and vegetation maps in others. In order to do complicated queries involving several layers — say, to identify areas of land that meet all of four specified criteria — it becomes necessary to overlay the various coverages and perform Boolean or geometrical overlay analysis. For instance, a Government agricultural development programme may be seeking to develop land in Africa where the risk from trypanosomiasis is low. The risk would be defined on the basis of epidemiological
indicators for trypanosomiasis. An overlay analysis of the respective layers would indicate the relative likelihood of the disease in the different areas under consideration.

In northern Australia, as part of the bovine tuberculosis eradication campaign, the degree of difficulty for livestock mustering was estimated based on a combination of scores and weightings for components of the landscape, such as landform, vegetation or availability of watering points (12).

Network analysis

This technique is used to define such things as shortest distance between two locations or response times for services, such as fire appliances or medical services. It can help in the siting of fire stations, schools, hospitals, etc. It can also be used for water-flow analysis along reticulation systems. Essentially, it allows the modelling of networks, whether roads, streams or piped systems. It does have possible applications in the veterinary field for the tracing of animal or product movements from infected properties to other destinations, or the study of the spread of diseases, such as salmonellosis or Johne’s disease, along ground water drainage systems.

Surface area/distance calculations

Accurate measurements of distances between two or more points, or the areas of selected features on a three-dimensional surface, can be obtained within a GIS. These techniques could be used in an epidemiological investigation, such as a case-control study where, for example, areas of certain classes of vegetation and soil types or distances between farm properties are study variables.

Three-dimensional surface modelling

Some GIS provide three-dimensional (3D) modelling capabilities using such techniques as triangulated irregular networking (TIN) or digital terrain models (DTM). These allow construction of 3D surfaces based on contour or point z-values, which can be either real heights (topography) or anything the investigator chooses to represent as z-values (e.g. disease incidence or virus concentrations). Perspective views of such a 3D surface can be used for presenting disease information over a geographical base. Contour maps (isopleths) can then be produced from the surface. Another useful function is the ability to interpolate z-values for intermediate locations, between known points.

Using a TIN, it is possible to perform 3D surface area, slope and volume calculations and to determine the aspect of TIN triangles. This information could be used as variables in epidemiological studies.

Cartography

One of the strengths of GIS over traditional cartographic (map-drawing) systems is the ability rapidly to produce final maps showing just the features the user wants to display. These can be amended at will to produce new maps. In this respect, different thematic layers (coverages) can be overlaid as if one were combining different transparencies on an overhead projector.
VETERINARY APPLICATIONS

There are a number of possible applications in the veterinary field. One of the most attractive uses is for the recording and reporting of disease information on a geographical basis. This allows for the spatial distribution of disease to be monitored over time. The major issue to be decided is the resolution at which data will be stored; that is, whether the data should be coded by the level of country, region, district or farm. The resolution chosen would be dependent on the availability of the appropriate digital maps and the level of detail of the disease data being supplied.

Historically, disease data has tended to be amalgamated and summarised as reporting procedures have moved the data from district level to national and international levels, simply due to the volume of information that had to be assessed. Usually the spatial units being studied are a priori given and, to a varying degree, aggregated. Analysis of information with different levels of aggregation between or within coverages would lead to problems in interpretation, a situation which is similar to the ecological fallacy in epidemiological analysis (11, 20). With GIS, spatial units can be reasonably small, as it is now possible to process vast amounts of data by computer. However, new forms of communication need to be developed to allow for the transfer of information from district veterinary offices to national and international disease-recording and information centres. Two major forms of communication are the transmission of data electronically along telecommunication links, or the posting of floppy disks or magnetic tapes containing the required information. This avoids re-entry of data at the receiving end and allows for the rapid processing of information.

Another important veterinary application relates to the epidemiological study of specific diseases. The first step is usually to look for clustering of disease cases, as this can be a clue to the presence of risk factors; statistical techniques can be used to test for clustering. The next step is to analyse the relationships between the presence of various determinants of disease and disease incidence, or prevalence, on a geographical basis. The technique used is to overlay the coverages showing the spatial distribution of the variables under study with a map containing information on disease incidence or prevalence. Coverages used in the analysis could contain point information, or take the form of choroplethic (mean values over an area) or isoplethic maps (contours). Areas of overlap of the respective variables with different levels of disease are then calculated; multivariate statistical analysis could be used to identify important factors. Physical proximity of specific determinants to known sites where the disease is present (or absent) can also be studied. Once the causality of disease has been established, the GIS can be used to model disease spread. This would basically entail the overlaying of the various coverages depicting the presence of the disease determinants. The result would be maps showing expected disease incidence. In a study of diseases caused by *Theileria parva* in Africa, the known distribution of the vector (*Rhipicephalus appendiculatus*) was compared with the potential distribution, based on climatic suitability for the tick calculated from an interpolated climate database developed for Africa, and "Normalised Difference Vegetation Indices" derived from remotely sensed data (23). The authors concluded that vast areas of Ethiopia, Zaire and the coastal strip of West Africa, from Cameroon to northern Angola, were suitable for the establishment and maintenance of the tick, and therefore expressed concern over the role animal movements could play in introducing the vector into new areas. It is possible to extend this concept further with the integration of
Simulation models and rule-based expert systems, to allow the prediction of disease incidence in various geographical locations where situations are dynamic rather than static. For example, bluetongue outbreaks in endemic countries are dependent on the geographical distribution of suitable vectors (Culicoides species) which require specific climatic conditions for their establishment and breeding. Furthermore, some Culicoides species require cattle dung for breeding. If vector distribution maps are available and weather data is recorded for the region under consideration, and if this information is combined with cattle density maps, it should be possible to predict areas where outbreaks are likely to occur.

Another example would be the development of control policies for rabies in foxes. Using computer simulation modelling, Tinline (26) identified six different factors which affect the persistence of rabies in southern Ontario. Among them were the existence of distinct spatial and temporal clusters of endemic disease of at least 4,000 km$^2$ (rabies units) and with heterogeneity of the habitat. Based on these criteria, a GIS would allow identification of existing or potential rabies units and improve the efficiency of control measures by targeting high risk areas. Epidemiological information incorporated in a GIS can have major implications in the planning of production systems and disease control strategies.

The following three projects are described as examples of the potential applications of GIS technology to veterinary science.

**Tuberculosis control programme in New Zealand**

For the development of effective strategies in national disease control and the monitoring of the effect of these control efforts, accurate and up-to-date information on the disease situation in the country is needed. In New Zealand, a GIS is being developed which has the capacity to operate in future as part of a decision support system for the national bovine tuberculosis control scheme. The GIS will be used to produce maps describing the past, current and simulated future disease situation in the country.

In the New Zealand national cattle tuberculosis database, information (including tuberculin test reactor incidence and movement control status) is being stored for each cattle herd in the country. This information can be summarised at county level and integrated into the GIS through geographical cross references. Three-dimensional maps depicting problem areas in the country can be produced (Fig. 1). Series of maps in conjunction with map overlay analysis of sequential years can describe the spatial dynamics of average tuberculosis reactor incidence and numbers of herds on movement control over time (2). Clustering of disease in space and time can be analysed (24, 28). Multivariate statistical analyses can be used to identify potential risk factors, such as cattle population density or tuberculosis infection status of feral animal populations associated with bovine tuberculosis incidence in cattle. Separate overlays describing the spatial occurrence of these risk factors can be aggregated using weighted map overlay analysis to compose a map of risk areas for the country (13). On the basis of these tuberculosis risk maps, it would be possible to develop more effective control strategies for each risk level.

Possums (*Trichosurus vulpecula* Kerr) are a significant reservoir for tuberculosis reinfection in cattle. The size of the areas with endemic *Mycobacterium bovis* infection in the feral possum population has increased over the last ten years despite extensive
A GIS allows the descriptive and quantitative analysis of spatial and temporal dynamics of the spread of infection in possum populations (Fig. 2) (P. Livingstone, personal communication).

**FIG. 1**

Spatial distribution of number of tuberculin test reactors in cattle in New Zealand, 1988-1989

**EpiMAN – Epidemic management system**

A computerised disease recording and information system for use during an exotic disease emergency (EpiMAN) is being developed at the Department of Veterinary Clinical Sciences, Massey University, on behalf of the New Zealand Ministry of Agriculture and Fisheries (MAF). The system incorporates a GIS, a simulation model of foot and mouth disease (FMD) and expert system elements. The system will allow the rapid integration of important information specific to the geographical setting where the emergency is occurring. This information will be sourced from various public databases and will include property boundary maps, topography, individual farm profiles, locations of all dairy and meat-processing plants, saleyards and other animal congregation points, and feral animal distribution maps. Once this descriptive information has been compiled, the system would be capable of mapping a potential epidemic of a major exotic disease (such as foot and mouth disease) as it develops, presenting epidemiological reports to the Emergency Headquarters (EHQ) controller, easing some of the work load in various sections of the EHQ and acting as a decision support tool by permitting the effects of various proposed control options to be simulated. GIS is ideally suited to such a task. EpiMAN will make use of many of the GIS functions outlined above. Integration of spatially referenced data,
FIG. 2

Areas with endemic tuberculosis infection in possum populations in New Zealand, 1981-1990
neighbourhood analysis, buffer generation, networking of bulk raw milk transport routes, 3D modelling of foot and mouth disease virus (FMDV) plumes, overlay analysis and cartographic map output will be utilised by the management system. Two examples of maps are presented, one showing a simulated FMDV-plume overlaying a farm distribution map (Fig. 3), the other showing the location of currently infected properties (Fig. 4).

Epidemiological study of bovine tuberculosis in Australian brush-tailed possum (Trichosurus vulpecula Kerr) populations in New Zealand and development of a computer simulation model of the dynamics of M. bovis infection within possum populations

In a longitudinal study of the epidemiology of bovine tuberculosis in possums, a GIS is being used to produce maps of the distribution of den sites and possum population density (Fig. 5). The GIS produces geographically referenced data on catch occurrence and/or radio telemetry fixes for individual animals; this can be used for home-range calculations (29). Map overlay analysis will be used to assess the extent of areal overlap between home ranges of tuberculous and non-tuberculous animals. Time series of maps can be drawn depicting the spatial dynamics of clusters of tuberculosis infection based on den-site location and/or home-range information of tuberculous animals.

A computer simulation model with geographical input from a GIS will be developed to simulate the effect of different control strategies on spread of M. bovis infection within possum populations in various geographical locations of the country.

CONCLUSION

GIS represent a new technology in veterinary epidemiology for the reporting of animal disease information and the study and modelling of specific disease problems. However, the technology is not a panacea in its own right and any adoption of such a system must be preceded by a careful evaluation of information needs. A fully featured GIS software package, the necessary hardware and the digital maps needed to run a complete system can be relatively expensive, when all that may be required is a standard database management system and an additional graphical package that can display coloured maps with a certain amount of text or numeric information appended. This would not provide any sophisticated spatial analysis functions, but may suffice as a reporting system. As needs grow and resources become available, an investment in a more complete system could be made. There are three situations in veterinary science where it is suggested that GIS will play an increasingly important role in the future: the need to solve epidemiologically complex disease problems, the need rapidly to monitor highly contagious diseases that might cross international boundaries, and the need to deal with politically sensitive diseases for which prompt and accurate reporting is essential.
FIG. 4

Map of foot and mouth disease infected premises
FIG. 5

Descriptive analysis of a longitudinal study of tuberculosis in possums in New Zealand
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Arc</td>
<td>Line</td>
</tr>
<tr>
<td>Attribute Data</td>
<td>Textual information associated with map feature</td>
</tr>
<tr>
<td>Buffer Analysis</td>
<td>Analysis conducted on features found within user-definable distance of a particular object</td>
</tr>
<tr>
<td>Choroplethic</td>
<td>A map showing areas with equal values for a certain variable</td>
</tr>
<tr>
<td>Coverage</td>
<td>Synonym for digital version of a map. Generally refers to one particular “layer” of geographical information, such as the topographical information, road network, site names, etc.</td>
</tr>
<tr>
<td>Database Management System (DBMS)</td>
<td>A computerised filing and cross-referencing system with inbuilt analytical capacity</td>
</tr>
<tr>
<td>Digital Map</td>
<td>A computer representation of a map. Geographic features are stored internally as a series of vectors or x,y points, while attribute information is stored as text</td>
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<tr>
<td>Digitising Tablet</td>
<td>An electronic board and pointing device that allows the copying of information from a paper map or drawing into a digital representation of the map within a computer, while maintaining precise agreement between the two representations</td>
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<tr>
<td>Digital Terrain Model (DTM)</td>
<td>Allows for processing of topographical features, such as slope, aspect and perspective views</td>
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<tr>
<td>EGA</td>
<td>Graphics standard for computers that allows for 16 colours at a resolution of 640 x 350</td>
</tr>
<tr>
<td>Expert System</td>
<td>A computerised system that has coded within it the knowledge and expertise of one or more human experts in a particular field. Using this knowledge, the system can reach conclusions about problems within the relevant field, and present both the conclusions and (if necessary) the logic supporting the conclusions to the user</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System. A computerised information system that allows for the creation, storage, manipulation, display and reporting of digitised maps, including user-selected attributes associated with the map features</td>
</tr>
<tr>
<td>Interpolation</td>
<td>A mathematical technique of smoothly joining data points by a line, so that values of a variable can be estimated between measured points</td>
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<tr>
<td>Isoplethic</td>
<td>A map formed by joining all points with equal values (e.g. contour lines).</td>
</tr>
<tr>
<td>Neighbourhood Analysis</td>
<td>Conducted on all land parcels bordering a selected land parcel, or set of land parcels</td>
</tr>
<tr>
<td>Network Analysis</td>
<td>Permits optimal routing along networks of line features, such as roads or water lines, and allocation of resources</td>
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Overlay Analysis

Analysis performed when different map layers (coverages) are superimposed onto each other. Typically, new coverages are produced based on the geometrical intersection of map features from the parent maps. For example, overlaying a soils coverage with a land use coverage could reveal such information as the location of residential areas built on unstable soils.

Polygon

Closed shape based on the intersection of lines. For example, a surveyed land parcel, a lake or an area of a particular soil type.

Raster

A grid system made up of cells or pixels in such a way that the information pertaining to a single cell and feature is uniform.

Stochastic Simulation Model

A computer model which achieves biological realism by incorporating a chance element into the simulation process. It is thus "stochastic" rather than "deterministic"; in the latter case, there is no chance element and the model will always behave identically if given the same starting assumptions.

Theme

An association of spatial layer(s) and textual attribute data.

Triangulated Irregular Network (TIN)

A sophisticated technique of analyzing topography. It is a method of conducting Digital Terrain Modeling (DTM).

Topology

The definition of the relationships of individual map features to each other in a geographical sense, as on a traditional cartographic map.

Transformation

Allows transformation of one map projection system or coordinate system to another.

Vector

A line and point system. A series of points connected by arcs can designate a zone or polygon.

VGA

Graphics standard for computers that allows for 16 colours at a resolution of 640x480.

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**LES SYSTÊMES D'INFORMATIONS GÉOGRAPHIQUES : APPLICATION À LA PROPHYLAXIE DES MALADIES ANIMALES. - R.L. Sanson, D.U. Pfeiffer et R.S. Morris.**

**Résumé:** Les systèmes d'informations géographiques sont des systèmes informatisés qui permettent le recueil, le stockage, la manipulation, l'analyse, la visualisation et la transmission d'informations assorties de références géographiques. Ces systèmes sont utilisés depuis quelques années pour un large éventail d'objectifs, entre autres dans les domaines de l'urbanisme et de la gestion des ressources naturelles.
La technologie offre de multiples possibilités dont l'exploitation apparaît idéale en matière de prophylaxie des maladies animales. On peut citer notamment l'enregistrement dans leur contexte géographique des informations relatives à l'incidence d'une maladie à ses caractéristiques démographiques et étiologiques, et l'utilisation de diverses fonctions d'analyse spatiale.

Les auteurs proposent un certain nombre d'applications possibles dans le domaine vétérinaire et analyser trois exemples d'utilisation de systèmes d'informations géographiques en Nouvelle-Zélande.

MOTS-CLÉS : Analyse spatiale - Epidémiologie - Informatique - Prophylaxie des maladies animales - Systèmes d'informations géographiques.


Resumen: Los sistemas de informaciones geográficas son sistemas computarizados que permiten capturar, almacenar, manipular, analizar, visualizar y editar datos con referencias geográficas. Estos sistemas se utilizan desde hace varios años en campos muy diversos, incluidos, por ejemplo, el urbanismo y la gestión de recursos naturales.

La tecnología ofrece posibilidades múltiples, cuya utilización parece ideal en materia de control de enfermedades animales. Se puede citar la posibilidad de registrar en su contexto geográfico datos relativos a la incidencia de una enfermedad, sus características demográficas y etiológicas, así como la aplicación de una variedad de funciones de análisis espacial.

Los autores proponen varias aplicaciones veterinarias posibles y analizan tres ejemplos de utilización de sistemas de informaciones geográficas en Nueva Zelanda.

PALABRAS CLAVE: Análisis espacial - Control de enfermedades animales - Epidemiología - Informática - Sistemas de informaciones geográficas.

REFERENCES


