GeoCREV: veterinary geographical information system and the development of a practical sub-national spatial data infrastructure

Nicola Ferrè¹, Paolo Mulatti², Matteo Mazzucato¹, Monica Lorenzetto¹, Matteo Trolese¹, Dario Pandolfo³, Piero Vio³, Guido Sitta⁴, Stefano Marangon²

¹GIS Office, Veterinary Epidemiological Unit, Istituto Zooprofilattico Sperimentale delle Venezie, Viale dell'Università 10, 35020 Legnaro, Padua, Italy; ²Istituto Zooprofilattico Sperimentale delle Venezie, Viale dell'Università 10, 35020 Legnaro, Padua, Italy; ³Unità di Progetto Sanità Animale ed Igiene Alimentare, Servizio Sanità Animale, Igiene Allevamento e delle Produzioni Zootecniche, Regione Veneto, 30125 Venice, Italy; ⁴Geographics, 44123 Ferrara, Italy

Abstract. This paper illustrates and discusses the key issues of the geographical information system (GIS) developed by the Unit of Veterinary Epidemiology of the Veneto region (CREV), defined according to user needs, spatial data (availability, accessibility and applicability), development, technical aspects, inter-institutional relationships, constraints and policies. GeoCREV, the support system for decision-making, was designed to integrate geographic information and veterinary laboratory data with the main aim to develop a sub-national, spatial data infrastructure (SDI) for the veterinary services of the Veneto region in north-eastern Italy. Its implementation required (i) collection of data and information; (ii) building a geo-database; and (iii) development of a WebGIS application. Tools for the management, collection, validation and dissemination of the results (public access and limited access) were developed. The modular concept facilitates the updating and development of the system according to user needs and data availability. The GIS management practices that were followed to develop the system are outlined, followed by a detailed discussion of the key elements of the GIS implementation process (data model, technical aspects, inter-institutional relationship, user dimension and institutional framework). Problems encountered in organising the non-spatial data and the future work directions are also described.

Keywords: geographical information system, data mart, veterinary sciences, Italy.

Introduction

In the veterinary field, as in many other disciplines, the use of geographical information systems (GIS) for processing and analysing spatial data is widespread and growing (Rinaldi et al., 2006; Wint, 2007). In recent years, an increasing number of veterinary organisations have sought to develop GIS applications to understand and explain disease dynamics, including diffusion patterns, for the early warning of emerging and re-emerging diseases (Pfeiffer et al., 1995, Durr and Gatrell, 2004). Although the adoption of a GIS approach might appear as a routine, almost mechanical, process (Longley et al., 2005), the development of a GIS infrastructure is a long-term process that must tackle a wide

variety of critical issues, i.e. technological requirements, people, institutional frameworks, and inter-intra-institutional relationships. For a GIS to be successful, it is crucial to develop an effective strategy for its implementation and management (Anderson, 1996). Why is a GIS strategy so demanding? The main reason is probably that it requires a superior flow of information and that it cannot be implemented without sustained effort. Moreover, several characteristics differentiate GIS from other technologies and necessitate specialised organisational and management approaches. These features include the characteristics of geographic data, their role in a given organisation's business operations, the relationship of GIS technology with other technologies in the organisation, and the adaptable nature of the approach. The various combinations of these guiding factors define the type of organisational model chosen and thus the type of GIS chosen. In fact, for some organisations, such as local governments, a GIS may constitute the core business product affecting and joining most of the activities, whereas for others it may consist only of a simple tool

Corresponding author:
Nicola Ferrè
GIS Office, Veterinary Epidemiological Unit
Istituto Zooprofilattico Sperimentale delle Venezie
Viale dell'Università 10, 35020 Legnaro, Padua, Italy
Tel. +39 049 8084253; Fax +39 049 8830268
E-mail: crev.nferre@izsvenezie.it

used to complete a single task. Because organisations operate in unique environments and have distinct characteristics, goals and requirements, they must develop their own GIS management strategies drawing on common management components and fitting them into their own environments (Somers, 1998).

The aim of this paper is to describe the development and implementation of a GIS-based management strategy. In our case, a support system for decision-making (GeoCREV) was created to aid the veterinary services of the Veneto region in north-eastern Italy in accessing and analysing veterinary data integrated with geographical information. It was developed by the Unit of Veterinary Epidemiology of the Veneto region (CREV) at the Istituto Zooprofilattico Sperimentale delle Venezie (IZSVe) with the objective to produce an infrastructure of thematic, sub-national spatial data (Guimet et al., 2004) combining GIS technologies with an advanced database management system (DBMS), allowing users to access veterinary information with the support of computerised mapping technologies (WHO, 1995).

The former veterinary geo-information system of the Veneto region

The regulation that enacts the European Union (EU) Directive on the identification and registration of animals (Anonymous, 1996) and establishes the official database of livestock holdings and individual bovines (Council Directive, 1992), demands the collection and storage of all geographical co-ordinates of registered animal holdings. To map the spatial data and perform spatial analysis to support epidemiological surveillance and disease management, CREV developed a GIS stand-alone application based on ESRI™ (Redlands, CA, USA) products. Most efforts were spent on organising the georeferencing programme dedicated to reading the location of livestock holdings using the "point referencing" method (Durr and Froggatt, 2002). However, the 1999-2000 epidemic of H7N1 subtype of the highly pathogenic avian influenza in north-eastern Italy (Capua et at., 2008) accentuated the need for developing a GIS meeting the demands of decision-makers that could also be used to plan and evaluate field operations. In 2002, a 5-year project to develop a departmental GIS application for epidemiological disease analysis was initiated as part of the emergency response system to epidemic diseases of livestock (Ferrè and Lorenzon, 2004). The key functions of this system were to retrieve and manage spatial outbreak data in the form of reports and maps.

However, an evaluation of this information system in terms of its spatial geo-data assets and related GIS applications, carried out in 2008, revealed a number of problems. The main criticism was lack of organisation of the spatial data, lack of resources such as skilled GIS staff, and non-uniformity of much of the epidemiological information, e.g. redundancy, fragmentation and inability to integrate different information systems. In light of this, it was decided to introduce lasting changes in the GIS management strategy. In particular, it was deemed that the GIS enterprise organisational model (Tomlinson, 2003) would be the best fit for the CREV organisational environment based on the degree of integration of GIS in business operations, the degree of centralisation of GIS operation and use, and the degree of centralisation of management control. The enterprise GIS supports a comprehensive spectrum of user scenarios, the advantage of which is that the information is managed as a common resource that can be accessed and used seamlessly by many users, who may be both geographically and organisationally dispersed. All users can access the same consistent information through local area networks or the Internet, depending on capabilities, functional needs and business practices.

The GIS management strategy design

The key factor in developing a management strategy for the implementation of a GIS in an organisation is the definition of an appropriate model for its operation (Oppman, 1999). The guiding factors include:
(i)   the scope and extent of GIS operations, including the number of users, applications and data availability;
(ii)   the degree to which GIS is integrated into applications already in place;
(iii) the frequency of GIS use; and
(iv)   the complexity of the GIS tools, which determines the size of the GIS resources needed.

In a multi-purpose GIS, such as those used in veterinary organisations, the above factors are often closely related and structured around common core functions and data. Approaching the development of a GIS model through situational analysis of the guiding factors as a single task reduces redundancy, maximises efficiency in software development, and ensures integrity of operations. However, this approach may be difficult to manage due to the involvement of several applications and people, and the various users' requirements. An alternative approach would be to establish a conceptual design of how the guiding fac-

tors fit together within the organisation by basing the conceptual design on the following four components: data and technology, people, institutional framework and inter-institutional relationships.

Data and technology component – the data mart

To support GIS applications, the GeoCREV business data, collected from various internal and external sources, were integrated with spatial data, to produce a spatially enabled geo-database. Aggregating disparate data sources on a common geographic structure is not an easy task. Given that many current systems are based on closed or proprietary interfaces and formats, it can be difficult to integrate data from one organisation with those from another (Boulos, 2004). While transactional databases are used for the collection, processing and quality assurance of data, they are not optimised for data retrieval. The data mart structure overcomes this deficiency by pulling data from the transactional database and provide them in a format that makes data querying, retrieving and reporting easy and efficient (Scherma and Boliar, 2004; Yeung and Hall, 2006). To support reporting and analysis within a map-based system, data marts are built around a geo-relational data model where subsets of specialised business data (so-called "attributes") are organised in a way that makes integration with related feature entities (polygons, lines or points) easy and efficient. The available information on animal resources was extracted for GeoCREV from the following operational source systems:

(i) the regional livestock holding database, which is an Oracle 10g database based at Vega Park in Venice-Italy (Venice gateway for science and technology - http://www.vegapark.ve.it/en). This database manages information related to livestock holdings of different animal species and their characteristics, e.g. type of production, number of animals, etc.;

(ii) the laboratory information management system (LIMS), which is a Firebird 2.0.6 database (http://www.firebirdsql.org/) based at IZSVe, is designed to manage data generated by the IZSVe diagnostic laboratories;

(iii) the animal diseases notification system (ADNS) is a suite of various CREV databases (some based on Oracle 10g and others on Access Microsoft XP), each used to store outbreak data on a specific disease;

(iv) the national cartographic data warehouse at the Italian Ministry for the Environment, Land and Sea (the National Cartographic Portal (http://www.pcn.minambiente.it/PCN/), provides cartographic support such as web map services (WMS), web feature services (WFS), etc. that can be used as reference; and

(v) the feature data sets, based on Oracle 10g (combined with ESRI SDE as gateway) in Ferrara, Italy, which contain spatial information on specific types of spatial objects, e.g. farms and site traps.

Once the requirements for access and the availability of the database content had been specified, the integration and transformation layer (I&T) was developed. This is a custom programmed module that automatically acquires the available data from different sources through: (i) dblink and web services from Oracle and Firebird databases; (ii) automatic replication from Access databases; and (iii) ArcSDE on Oracle synchronisation. A GIS data mart management module, which processes and integrates I&T data into the geo-relational database by means of specific spatial table-views, was also developed. The geo-relational database is configured as a decision support system with the Oracle server software supporting queries from direct client users and the ArcSDE supporting the application data server for spatial queries. The geo-database can be broken down into three major components: (i) the spatially enabled data, (ii) the Oracle server process, and (iii) the ArcSDE server process.

Both ArcSDE and Oracle cooperatively process GIS application queries. Non-GIS queries, such as data mart requests, are handled by Oracle alone. The relation between the data sources and the data marts is shown in Figure 1. To use the information for micro/macro planning and decision-making (Chen et al., 2003), data were integrated and aggregated properly. Three data marts have been identified:

(i) farms (information on farm characteristics);

(ii) outbreaks (information on outbreaks); and

(iii) health status (information on surveillance and monitoring programmes).

The data marts are structured in logical layers, each based on a table-view that contains attributes (joined with the related spatial features) used to produce cartograms or to extract tabular data. For the "Farms
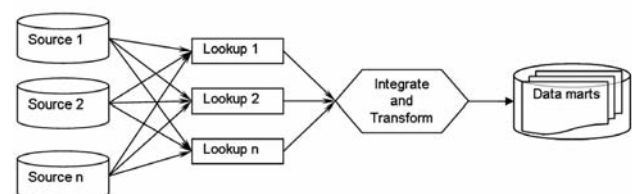

Fig. 1. Relation between data sources and data marts.

data mart", the table-views are categorised according to species, production type and year, while they are categorised by disease, epidemic and year for the "Outbreaks data mart". For the "Health status data mart", they are categorised according to monitoring programmes, diagnostic techniques and disease. This modular structure facilitates the addition of new feature classes. If other internal or external data are accessible, they should first be modelled into I&T constructs, then processed and incorporated into the geo-relational data mart model to produce the cartograms.

Data and technology component – the GIS operational model

To publish and share data managed by the above-described, geo-relational database, a spatial data infrastructure was developed. The SDI was designed to support a comprehensive spectrum of user scenarios, ranging from a desktop application to webGIS services with a large number of geographically dispersed users. All users can access the same information handled by the data marts, either through the local area networks or through the Internet. From a technical perspective, the infrastructure is organised according to function (data, services, and internal and external applications) as seen to the right in Figure 2 as well as according to the institutional organisation of the IZSVe (Fig. 2, left side). One module, referred to as the desktop module, was developed to operate at the intranet level and is therefore configured as a desktop section dedicated to managing activities for epidemic emergencies and surveillance, while another was developed as a WebGIS platform and dedicated to data collection and publication.

The desktop module was designed to be a management framework for decision-making and for use at different organisation levels (CREV, reference laboratories, crises units, etc.) in the event of disease out-

breaks. The framework module is based on a set of procedures and GIS models developed with the ESRI model builder (ESRI, 2006). Its key functions are: (i) the retrieval and management of data on outbreaks; (ii) the creation of tabular reports (e.g., list of premises falling within the restriction zones, health status of at-risk holdings); and (iii) the publication of interactive maps to visualise the business data.

The WebGIS platform is based on the ArcGIS (ESRI) server architecture, the components of which are shown in Figure 3. The solution adopted includes: (i) the enterprise data server; (ii) the web server; (iii) application servers; (iv) client applications (presented below); and (v) the network infrastructure. The ArcGIS server components, located between the web servers and the data server, broker the incoming web application requests, while requests that require GIS services are passed from the web server to the ArcGIS server, which processes these and obtains the necessary GIS data from ArcSDE – Oracle on the data server or from other web services belonging to the geography network. The application server also provides a set of web services, implemented according to the web service paradigms (ISO, 2004, 2005), which resolve (in particular the WFS) horizontal integration problems (for other public organisations external to the veterinary organisations, such as the environmental agency and the Department of Urban and Regional Planning) and vertical integration problems (for other veterinary organisations such as the Ministry of Health and local health units) that appear when dealing with sub-national veterinary GIS applications. For example, the system is used to solve problems related to the submission of spatial epidemiological data through the hierarchy of the entire veterinary organisation. In this project, the relationships were set up downwards to local health units and upwards to regional veterinary services and the Ministry of Health or national reference laboratories.
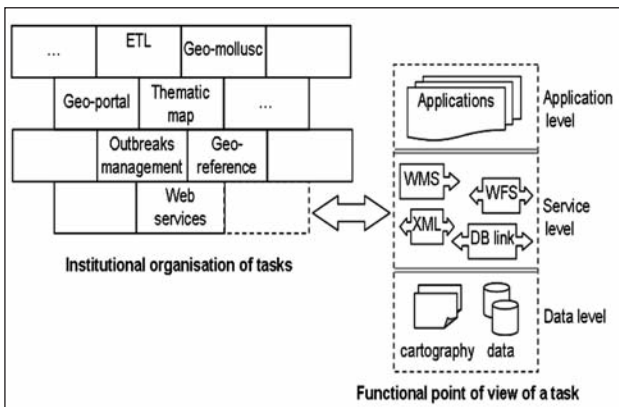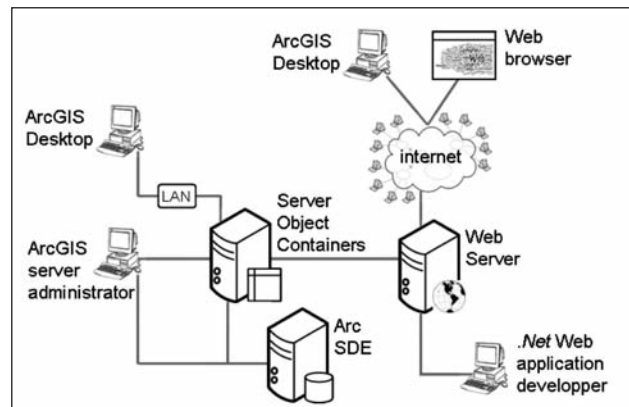

Fig. 2. The SDI architecture.

Fig. 3. The SDI components.

People

To refine and detail the GeoCREV operations and procedures, it was essential to understand the types of users and scenarios (De Smith et al., 2007). The identification of user types is based on the analysis of the former veterinary geo-information system of the Veneto region. This system had approximately 200 housing and community users, while the number of users is expected to increase to about 300 with the new WebGIS system, which permits as many as six simultaneous users. Grouped below are the four types of system users:

(i) casual user, who accesses the system through the Internet in search of ready-to-use thematic maps (e.g. animal health status and spatial distribution of animal holdings);

(ii) standard users (e.g. field veterinarians - the system's principal customers), who typically provide and access information needed in their daily work;

(iii) research/analysts users (largely IZSVe staff), who undertake the combination and custom analyses of existing data. Their work support policy-making, geo-statistical analysis and the development of sophisticated custom applications; and

(iv) data managers (mainly information-system professionals responsible for the maintenance and upgrading of the system), who also perform special custom applications and are supposed to address technical problems.

Depending on criteria such as, for example, permission level, responsibility and department, each user is provided with a different set of applications and data. GeoCREV recognises seven different profiles organised in a data/applications matrix in order to produce a cohesive user-management tool set that can be easily customised and maintained. A simplified version of a user profile is shown in Figure 4.

Institutional framework

The institutional framework defines the policy for building, maintaining and accessing the system. In CREV's previous geo-information system, a cohesive framework for effectively coordinating spatial activities was lacking. To develop a new institutional framework, two workgroups were created, one dealing with spatial data and one with infrastructure. The spatial data working group developed recommendations regarding data (formats, precision and quality) and procedures (acquisition, integration and consistency maintenance), while the infrastructure working group established GIS policies (definition of responsibilities, sharing policies, data security and technical aspects such as hardware, software and platforms) for developing the WebGIS platform. When a consensus had been reached for the formation of the IZSVe geographic information institutional framework, the following elements were adopted:

(i) standardised thematic and digital information offering a comprehensible data structure for users and developers;

(ii) general-purpose and open data structure design facilitating the integration of data (in thematic and

Profile table

Code: nnnn
Name: Xxxx Yyyy
Organisation: Zzzzz
Type: **User***

			Applications				
			Geo-portal	Geo-mollusc	Thematic map	Geo-reference	Web services
Data mart	Farm	Sensible data				X	
		No sensible data	X		X	X	
		Aggregate data	X		X	X	
	Outbreak	Sensible data					
		No sensible data			X		
		Aggregate data			X		
	Health status	Sensible data					
		No sensible data			X		
		Aggregate data			X		

Fig. 4. Example of a user profile schema.

logical terms) with other veterinary institutions;

(iii) use of legal or recognised data sources, which define the data quality, liability and reliability; and

(iv) extensive capabilities for operating the database to facilitate data access and management.

The defined policies also consider aspects such as user and administrator training since any system, with more than one user at more than one level of technical competence and with different roles within the system, requires sustained, continuous training to function over the long term.

Inter-departmental and inter-institutional relationships

The arguably most important aspect of an SDI is that its structure be the result of a shared interest in developing the system. Indeed, the main challenge of this project was to improve relationships between the IZSVe and the data providers. This was achieved through the following three steps:

(i) motivation, which aims to develop awareness of the stakeholders and emphasising the need for partnership in reaching shared goals. At this level, roles, capabilities and resources are documented by asking the other organisations to present GIS activities already in place, discussing the domain and giving reasons for which they should be interested in collaborating with the IZSVe. This was developed by holding *ad hoc* meetings, courses and conferences oriented towards the exchange of know-how;

(ii) coordination, in which the organisations identify existing opportunities and examine how these may be further developed. This is also the level at which the format for data access is decided and exchange of information is explored with the support of information technology and GIS experts; and

(iii) outcome, in which solutions to common problems are targeted. Several meetings were held to study and propose projects for implementing the necessary GIS infrastructure and maintaining the established relations with the involved organisations.

Web applications

This section describes briefly how the four components of the institutional framework mentioned above were combined to develop the GeoCREV applications. Based on the user profiles, the applications described below were organised into different web pages accessible by field veterinarians, IZSVe staff or users interested in veterinary information (thematic portals).

The GeoCREV Web portal

In addition to the applications generally available in any veterinary geo-portal, e.g. the interactive interface that shows outbreak distribution, disease incidence and other spatio-temporal epidemiological events portrayed at the administrative level, or shown as smoothed maps, there is also a "create your own map" application, which allows exploration and visualisation of the available epidemiological layers provided by GeoCREV. The home page of the GeoCREV and the "create your own map" interface are illustrated in Figure 5.

The "geo-mollusc" application

One of the objectives of GeoCREV is to facilitate and coordinate the exchange of spatial assets among stakeholders of the regional veterinary services. In this context, an application was developed for managing the data generated by the ongoing surveillance programme on the presence of contaminants in the Venice Lagoon, e.g. polychlorinated biphenyls (PCBs), dioxins, heavy metals, algal toxins and food-borne pathogens capable of generating mollusc disease. Areas of the lagoon where molluscs are reared for consumption are mapped in the system, and the topology of this information is checked by the system according to a set of defined rules (e.g. no overlapping of different areas). Each geographical area is described by a set of attributes acquired from a set of specific table-views of the data marts. The system also allows managing data regarding laboratory results and samples collected by field veterinarians in the framework of the programme. Three main outcomes are generated (the printed screen is presented in Fig. 6):

(i) the tools for data retrieval to be used by field veterinarians;

(ii) weekly updated spatial analyses (e.g., kriging diagrams, kernel distributions, etc.) of data on the distribution of the contaminants; and

(iii) data web services (WFS and XML) to guarantee the interoperability with other information systems.

The "geo-reference" application

For spatial, epidemiological analysis, the critical event is the location where the disease occurs. This application simplifies the task of locating and georeferencing multiple elements (e.g. farms, trap sites, sample
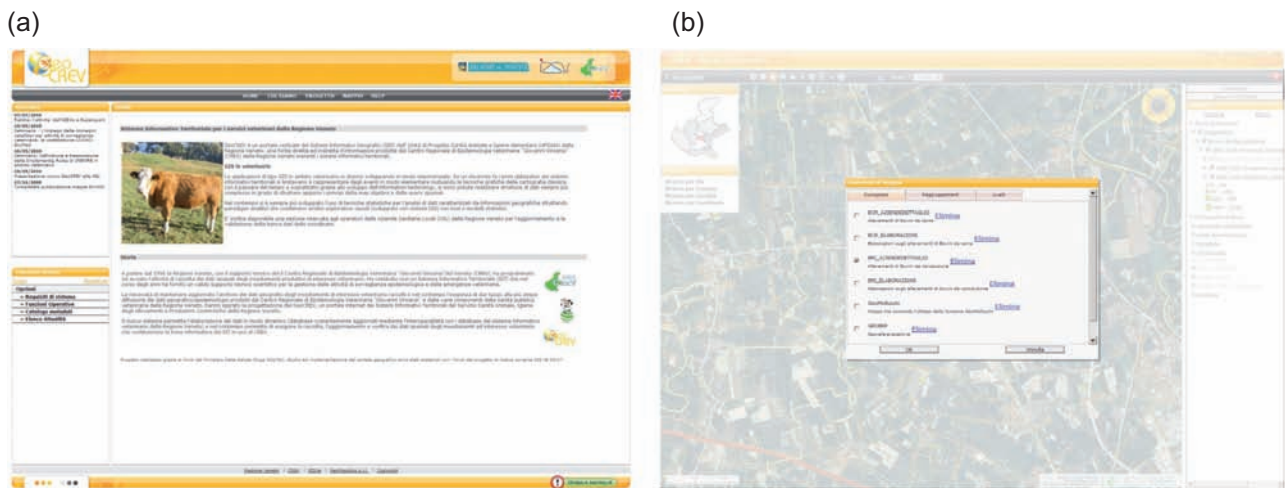
(a)   (b)

Fig. 5. The GeoCREV portal (a) and the "*create your own map*"(b) interface.

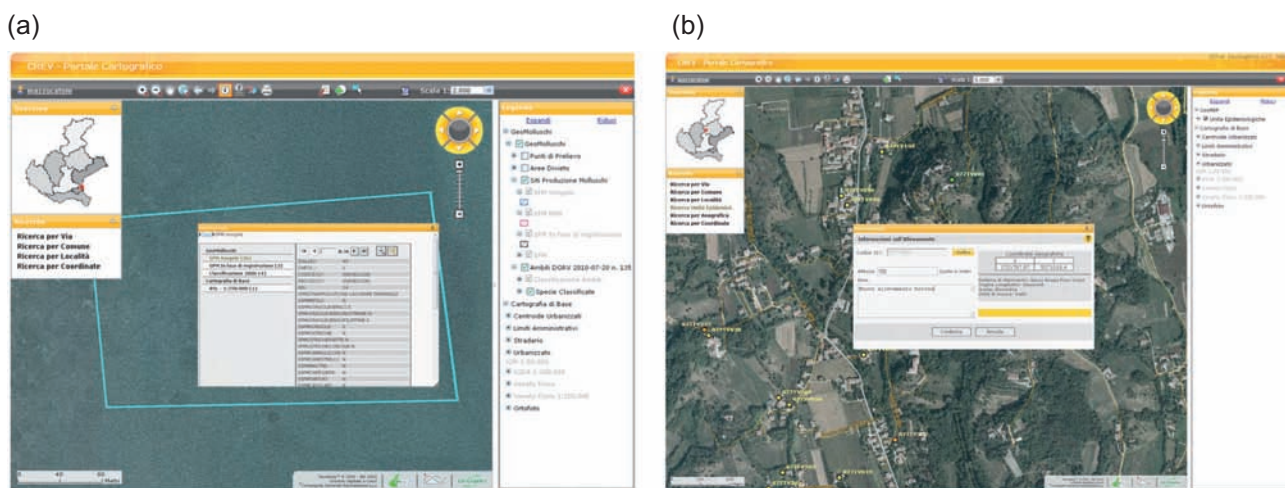(a)   (b)

Fig. 6. The "print screen" of the geo-mollusc (a) and geo-reference (b) applications.

collection sites, etc.) by means of a point feature using different types of location finders. The conversion of the output into data for GeoCREV is automated and consists of three phases: an initial phase, which identifies the area where the spatial object is located by means of a gazetteer process, followed by one or more web services (based on the type of spatial object geo-referenced), which allows all available, relevant information on the spatial object in question to be retrieved (e.g., farm characteristics, laboratory data, etc.) and, finally, calculation of the altitude of the spatial object based on interpolation with a DTM file (Fig. 6).

Implementation

The GeoCREV became operative only recently (January 2011). Therefore, only early findings (originating from the testing procedure) can be described here. A series of gaps in two areas were identified:

technology gaps (hardware and network infrastructures) and organisational gaps (staffing, skills and/or support procedures). A set of recommendations have been identified to address the gaps identified during the implementation phase.

Technology gaps

Currently there are no separate environments for the development, test and production of GeoCREV. These are necessary for the creation and practise of new procedures, applications and databases to avoid the interruption of existing business processes. Further, in order for the standard users to access the SDI functionalities, a relatively efficient Internet connectivity is required. Some user sites might have (i) an insufficient network bandwidth, (ii) restrictive firewall policies, or (iii) an inefficient proxy structure. These constraints could weaken the efficiency of the web connection.

Organisational gaps

GIS roles, including viewing/editing privileges, need to be defined for the local health units where the standard users operate. These roles should be coordinated with the GeoCREV office to avoid gaps or duplication of responsibilities. Further, professional training on the use of GIS software and geo relational database administration is needed for the data managers to efficiently and effectively do their work. For data maintenance activities, policies and procedures must be defined. As part of the responsibility of data maintenance shifts from the electronic data processing (EDP) office to the GIS staff, these procedures need to be clearly defined to ensure that the enterprise geo relational databases are properly maintained.

Most standard users have limited knowledge of GIS and its application to the veterinary field. Efforts are needed to expand the knowledge-base on GIS applications for public health issues within the veterinary community.

Notes on costs involved

IZSVe implemented the GeoCREV as a capital project based on a feasibility study and a strategic implementation plan. The start-up phase (including hardware and software for about 60,000 Euros) was sponsored by the Veneto region and the Italian Ministry of Health. Management, operational and maintenance costs were charged to IZSVe, which also provided the ongoing strategic direction.

The IZSVe staff involved in the design and implementation phases of the GeoCREV project consisted of a GIS manger, a networking administrator, a database administrator and two programmers for a total of six man-months. Maintenance of the system and the update of data were estimated to require a total of 15 man-hours per month.

Conclusions

The management matters related to the implementation of a GIS in an organisation are fundamental and often more important than the technological issues. GIS work requires specific organisational and management approaches, including the characteristics of geographic data, the current state of GIS technology, the relationship of GIS technology with other technologies in the organisation and the flexible nature of GIS data (Somers, 1998). GIS approaches in a veterinary organisation should ideally support a wide range of activities and

applications (Pfeiffer et al., 1995; Durr and Eastland, 2004; Kroschewski et al., 2006). The experience at CREV suggest that the development of an optimal GIS capable of serving a wide range of users and business functions is time-consuming and difficult to economically justify and sustain. A "first-cut" GIS, developed quickly to meet short-term targets and the immediate needs of priority users, is recommended. It can be achieved by adopting a modular and scalable implementation strategy focusing on a core system design that encompasses the important characteristics of data, applications to be supported, software functionality and people who will use and run the system. While the technical tasks involved in system design are developed, the organisational issues that facilitate the design and affect the implementation and adoption of the GIS must also be addressed, including strategic planning, user education and training. The latter should involve users in system planning and design, transitions, organisational changes, support services, the organisational environment and the GIS development process as a whole.

In general, the public, veterinary service could improve the workflow of geospatial information in order to provide field veterinarians with epidemiological information and applications to be used for their daily activities. A GIS infrastructure is a good way to achieve this objective, but it should be kept in mind that it requires significant investments and organisational changes. Based on our experience in implementing the GeoCREV project, it appears that it is a long-term process that must tackle a wide set of critical issues, such as people, technological proposals, institutional frameworks and inter- intra-institutional relationships. In particular, two elements should be highlighted:

(i)   field veterinarians need sustainable services, based on a reliable GIS environment and up-to-date epidemiological information to be able to apply adequate measures for the control of infectious livestock diseases, which can result in huge economic loss to the livestock sector (Capua et al., 2008; Cottam et al., 2008); and

(ii) veterinary services require spatial data, especially in cases of the emergence of epidemic diseases (Kroschewski et al., 2006), but the budget for developing a GIS is often limited. Decision-makers must be convinced of the economic benefits of a spatial infrastructure and shown that it can provide better management of available data (http://inspire.jrc.ec.europa.eu/).

The challenges faced by GeoCREV in the near future are those of accessing "new" spatial data or epidemiological datasets for the development of new use-

ful applications. It is important to continue the internal and external promotion of the infrastructure and to integrate mobile platforms and technologies into the system architecture (e.g. for the development of an epidemiological survey application based on personal digital assistant (PDA) devices.

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