

A Web-based geographic information system for the management of animal disease epidemics

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Summary

Outbreaks of highly contagious animal diseases severely affect the global economy, seriously disrupting domestic economies and the international trade of livestock and animal commodities. Italy has a series of contingency plans for the management of outbreaks of all major animal diseases. Disease control measures are mainly based on a traditional approach and eradication policies range from culling and stamping-out to movement restrictions of animals and commodities. Given the marked terrain differences in Italy, the uneven distribution of farms and animal population, the presence of potential disease hotspots constituted by high-density clusters of farms and animals, etc., maps have always been a common working tool for the Italian veterinary services to identify location of premises, define the perimeter of the infected and control zones, etc. The Italian Ministry of Health has requested an integrated system for the management of veterinary emergencies. One of the main features of the system is an interactive, customisable and user-friendly Web-based geographic information system (GIS). The *Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise 'G. Caporale'* has been entrusted with the development of a system that provides different administrative levels with a spatial decisional and management tool to assist them in case of epidemics. A Web-based GIS has been designed to integrate epidemiological information with the

corresponding geographic component. The system works on a disease basis (disease-specific maps) for fifteen of the most contagious diseases and is accessible through the Web, allowing for real-time recording of new outbreaks.

Keywords

Animal disease, Disease mapping, Epidemic, Emergency, Emergency management, Geographic information system, Notifiable disease, Web.

Un sistema informativo geografico su piattaforma Web per la gestione di epidemie di malattie animali

Riassunto

I focolai di malattie animali altamente contagiose possono disturbare in modo massiccio l'economia globale, provocando gravi lacerazioni nelle economie locali e parimenti nel commercio internazionale degli animali e dei prodotti da essi derivati. Le misure di controllo delle malattie sono principalmente basate su approcci tradizionali, e le strategie di eradicazione variano dall'abbattimento totale dell'effettivo di allevamento al blocco delle movimentazioni di animali e prodotti derivati. Considerate le marcate differenze che caratterizzano il territorio dell'Italia, la distribuzione disomogenea degli allevamenti e della popolazione animale, la presenza di potenziali punti caldi ai fini della diffusione delle malattie costituiti da aree ad elevata

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densità zootecnica, le mappe sono sempre state un comune strumento di lavoro per i Servizi Veterinari italiani che le utilizzano abitualmente per individuare le aziende, definire il perimetro delle zone infette e soggette a controllo, etc. Il Ministero della Salute italiano ha pertanto richiesto di sviluppare un sistema integrato per la gestione delle emergenze. Una delle componenti principali del sistema è un sistema informativo geografico basato sul Web (Web-GIS) interattivo, personalizzabile e user-friendly. L'Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise 'G. Caporale' è stato incaricato dello sviluppo di tale sistema che fornisce ai diversi livelli amministrativi uno strumento spaziale decisionale e gestionale di supporto in caso di epidemie. Il Web-GIS è stato progettato per integrare le informazioni epidemiologiche con le corrispondenti componenti geografiche. Il sistema funziona sulla base di 15 malattie specifiche (mappe specifiche per malattia), selezionate tra le malattie più contagiose ed è accessibile via Web, per la registrazione in tempo reale dei nuovi focolai.

Parole chiave

Emergenze, Epidemie, Gestione delle Emergenze, Malattie animali, Malattie notificabili, Mappatura delle malattie, Sistema informativo geografico, Web.

Introduction

Recent epidemics of highly contagious diseases such as foot and mouth disease (FMD) in the United Kingdom in 2001 or the classical swine fever (CSF) (hog cholera) epidemic that swept the Netherlands in 1997-1998 have massively disrupted the livestock community and all the economic sectors directly and indirectly linked with animal production. The magnitude of the economic impact of such animal diseases is perfectly similar to the adoption of embargo measures: export of animal commodities from affected countries is forbidden and international trade can be suspended for several months, even after the country is declared free, based on the disease-free standards set by the World Organisation for Animal Health (OIE: *Office International des Épizooties*) (24).

Domestic economies are equally affected, the two main causes being the severe restrictive measures prescribed by national legislation and international standards and enforced for long periods of time, and the drop in consumer confidence in regard to the safety of national animal products, which is often the consequence of ambiguous and unclear communication, itself frequently due to partially incorrect and/or incomplete disease reports.

It is therefore obvious that any tool able to help decision-makers and field veterinarians select control measures specifically tailored to epidemiological local conditions, to accelerate emergency response and also to improve the quality of reporting and communication both with trade partners and the general public would be of great value (3, 7, 13, 17, 19). Geographic information systems (GIS) provide such tools; their use as emergency response systems dates back to some years ago, for instance, during the 1997-1998 CSF epidemics in the Netherlands, where they were used mainly as tracking systems (12) or to keep track of West Nile virus spread in the United States (11).

Within the scope of the research project entitled 'Implementation of an information system for the management of epidemic emergencies', the *Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise 'G. Caporale'* (IZS A&M) has developed a Web-based service called STEM (*Sistema Telematico per la gestione delle Emergenze epidemiche*: telematic system for the management of epidemic emergencies). STEM was initially designed as a decisional and management tool to be used by the different organisational levels of national veterinary services (local health units, i.e. field veterinarians, regional government and the Ministry of Health) in case of outbreaks of major diseases (4). The system basically works as an early response and reporting system, in line with principles of emergency management (7, 17); its key functions are the retrieval and management of outbreak data and the creation of reports and interactive maps to visualise them.

STEM is linked to the IZS A&M laboratories information system (SILAB: *Sistema Informativo dei Laboratori*: laboratory information system), from which it is able to select, extract and visualise a pre-defined set of information, such as laboratory results for samples collected on farms. Presently, STEM is farm/outbreak-based and laboratory results are currently visualised only for infected farms (i.e. the outbreak). However, software is widely able to extend the display functions to include other results (sero-surveillance, abattoir-surveillance, transport data, etc.), thus transforming it into a true disease mapping system, rather than a mere outbreak mapping/reporting system.

STEM is also linked to the Italian national databank the national data bank (BDN: *banca dati nazionale*) for animal identification, that presently includes cattle, swine, poultry, sheep and goats. Identification criteria vary according to the species: cattle are identified both at farm (farm coding, latitude/longitude coordinates, etc.) and individual levels (single head identification). The same criteria also apply to sheep and goats, the only difference being in the completion stage of the individual head databases, with the cattle databank completed, while sheep and goats are still in progress; 100% cattle and sheep/goat farms are coded and geo-referenced. Swine and poultry populations are identified only at the farm level and not as single individuals; both databanks are complete; only poultry farms with more than 250 animals have been geo-referenced and entered in the BDN to date. Finally, about 60% of all Italian equine premises have been identified and geo-referenced.

STEM has been subjected to field trials, both simulating the occurrence of an epidemic of FMD (1) and during a recent epidemic of swine vesicular disease (SVD), involving different swine farms in the pilot region (Abruzzo). These initial trials resulted in a series of changes to the original design, for instance, in the display of the boundaries of the movement restriction zones

Some potential applications of GIS-response systems is the description and optimisation of routes, such as patrolling routes during post-

outbreak surveillance, optimisation of truck routes when moving animals from a restricted zone to a free one, etc. (19, 20). STEM was used in this way during the recent SVD epidemics with the aim of mitigating the effects of some of the restriction measures on local facilities (sheep abattoir). In particular, local veterinary services have used STEM to identify, optimise and record an itinerary that specially authorised vehicles coming from SVD-free zones can follow when transporting slaughter sheep to an abattoir located inside the surveillance zone of one of the SVD outbreaks. The Commission of the European Union (EU) has approved the procedure.

Report functions are another important feature of the prototype, designed and modified according to various past experience (1, 4, 5, 6) and considerations (3, 9, 10, 13, 15, 25). The system has been used for instance to generate the mandatory reports that have to be submitted monthly to the EU Commission to keep member countries informed on the evolution of the epidemics.

The authors describe the Web-GIS section of STEM and its key functions.

Materials and methods

The Web-GIS section can be accessed through an electronic authentication procedure and a generic browser.

The system is user-friendly and interactive; users can surf dynamic maps and use system data to perform tailored epidemiological analysis, without having to install any GIS software on their PCs. The map services were created using the Environmental Systems Research Institute (ESRI) internet map server technology (ArcIMS™ 9.0); the geographic layers were shaped and are currently managed with ArcGIS™ desktop 9.0 and ArcSDE™ 9.0. The geo-database used to collect spatial and epidemiological data is a relational data base management system (RDBMS) based on Oracle® 8.1.7. The Web-GIS architecture and the data flow are shown in Figure 1.

The Web-GIS is developed using an html viewer that enables the customisation of maps to be published.

The geodetic datum is World Geodetic System 1984 (WGS 84) in accordance with the International Organization for Standardization (ISO) standard (ISO 19115 Geographic information) and the geographic projection (ED 1950 UTM Zone 33N) to visualise maps on the Web is created directly on the fly in ArcXML™ programming language used to communicate between the Web server and ArcIMS™ spatial server. The geographic coordinates derived from geographic positioning system (GPS) observations can be inserted directly online by an apposite procedure as a spatial database engine (SDE) point on the SDE-layer and directly visualised on the map. The system is able to localise hotspots in the event of rapidly expanding epidemics.

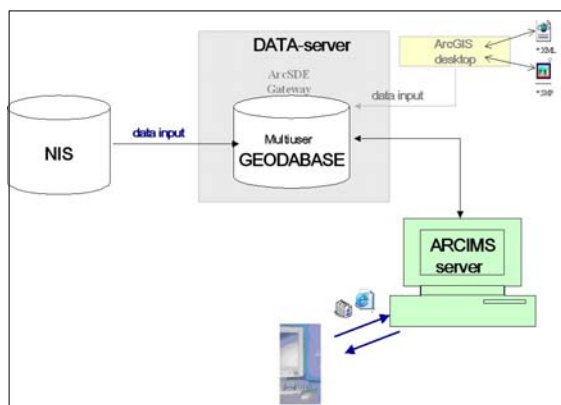


Figure 1
Web-based geographic information system:
architecture of the system

SDE-layers relevant to specific epidemic emergencies are automatically updated overnight; a db-link ensures the smooth data flow between the National Information System (NIS) and the geo-database: both systems are always completely aligned (a detailed description of the epidemiological data recorded, data flow and NIS update may be found in a paper by Colangeli *et al.*) (4).

The farm is the geographic unit of the system; the following data are recorded for each unit:

- demographics (ownership, number and species of farmed livestock, health status)
- localisation (longitude and latitude)
- surveillance data.

Each map consists of multiple layers and is provided with a topographic raster map layer (source: *Istituto Geografico Militare Italiano*, scale: 1:250.000) for the early recognition and evaluation of the epidemiological and environmental characteristics of an outbreak, and subsequently for the improvement of prevention and control measures.

Results

Fifteen different ArcIMS™ projects were developed (Table I).

The interactive thematic maps are equipped with several standard ArcIMS™ tools (zoom in/out, pan etc.) and query functions (identify, query, find, select etc.) (Fig. 2). Additional tools, such as html/Excel® print options, developed in JavaScript language and print view, are available as shown in Figure 3.

Each diseases map is characterised by the following features, specifically requested by users':

- outbreak specific features managed by STEM-GIS: outbreak demographics, outbreak confirmation date and outbreak extinction date (Fig. 4)
- list of premises falling within the restriction zone (protection zone and surveillance zone), including the individual farm code, animal species reared, address and owner's name
- the health status of each farm can be visualised directly on the Web as a health form, containing the following information: farm code, identification of the single farm units (a farm can have more than one premises), laboratory results and in case of arthropod-borne diseases, the entomological situation (Fig. 5).

Web services connect STEM to the BDN which enables the retrieval of all relevant information for each farm, i.e. identification of animals currently present on the farm, type of animal, gender, birth date and movements into and/or out the farm (Fig. 6).

Other information retrievable from the NDB includes the list and location of livestock markets, abattoirs and hatcheries, animal movements to and from pastures

Table I
Diseases included in the Web-based geographic information system

| Disease | Notes |
|-----------------------------------|--|
| Foot and mouth disease | Not present in Italy; geographic and farm demographics data, no epidemiological information |
| Swine vesicular disease | Present in Italy; geographic data and epidemiological data |
| Vesicular stomatitis | Not present in Italy; geographic and farm demographics data, no epidemiological information |
| Classical swine fever | Present only in Sardinia |
| African swine fever | Present only in Sardinia |
| Rinderpest | Not present in Italy; geographic and farm demographics data, no epidemiological information |
| Peste des petits ruminants | Not present in Italy; geographic and farm demographics data, no epidemiological information |
| Contagious bovine pleuropneumonia | Not present in Italy; geographical and farm demographics data, no epidemiological information |
| Lumpy skin disease | Not present in Italy; geographical and farm demographics data, no epidemiological information |
| Rift Valley fever | Not present in Italy; geographical and farm demographics data, no epidemiological information |
| Sheep and goat pox | Not present in Italy; geographical and farm demographics data, no epidemiological information |
| Bluetongue | Present in central-south Italy (including Sardinia and Sicily); eradication and monitoring plan |
| African horse sickness | Not present in Italy; geographic and farm demographics data, no epidemiological information |
| Highly pathogenic avian influenza | Not currently present in the Abruzzo region of Italy; geographic and farm demographics data; historic epidemiologic data (wild birds and surveillance) |
| Newcastle disease | Not present in Italy; geographic and farm demographics data, no epidemiological information |
| West Nile virus | Surveillance system (wild birds, sentinel chicken and horses): geographic and epidemiological data |

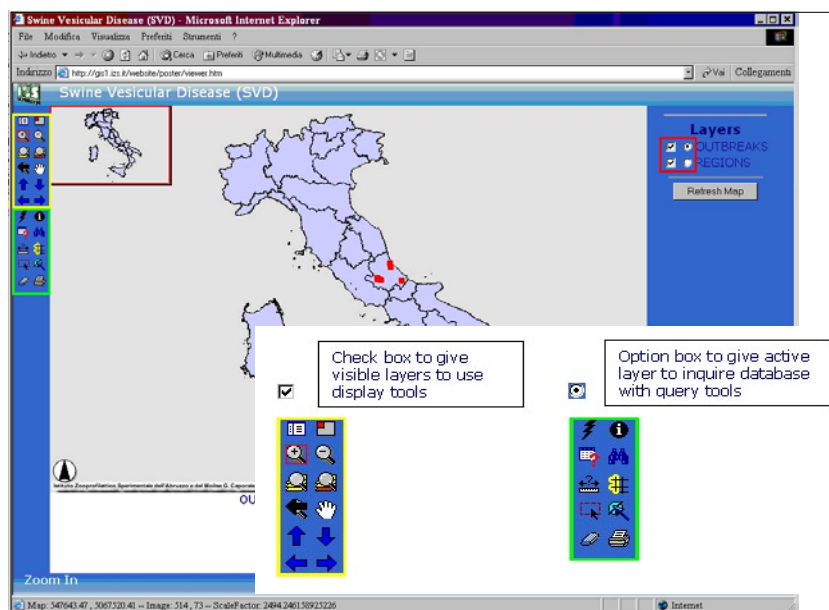


Figure 2
The interactive thematic maps are equipped with several standard ArcIMS™ tools (zoom in/out, pan etc.) and query functions (identify, query, find, select etc.)

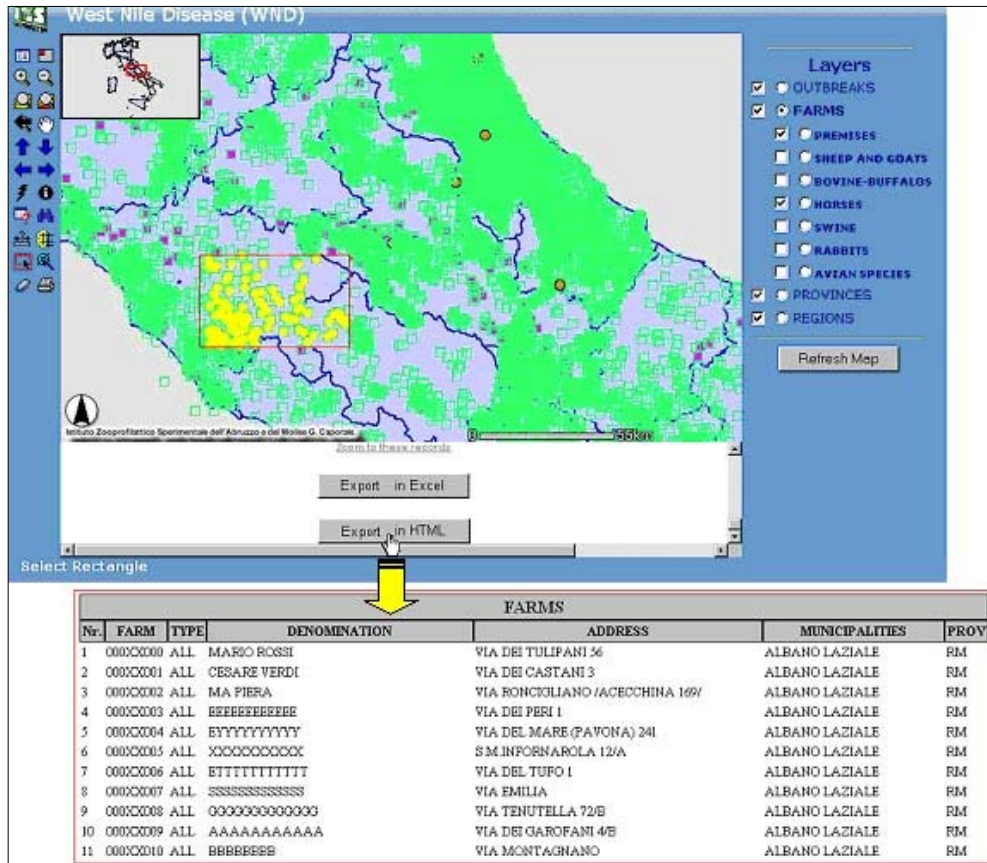


Figure 3 Additional tools including an html/Excel® export option to create the html or Excel® file with the information relative to selected features (ex. farms)

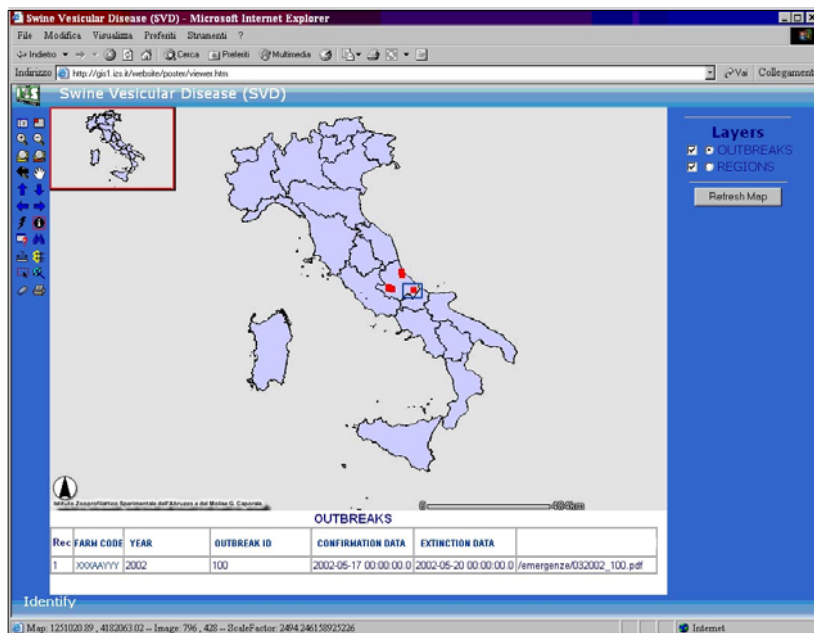


Figure 4 Outbreak-specific features managed by the *Sistema Telematico per la gestione delle Emergenze epidemiche* (STEM: telematic system for the management of epidemic emergencies)-geographic information system: demographics of the outbreak, farm, outbreak confirmation date, outbreak eradication date, etc.

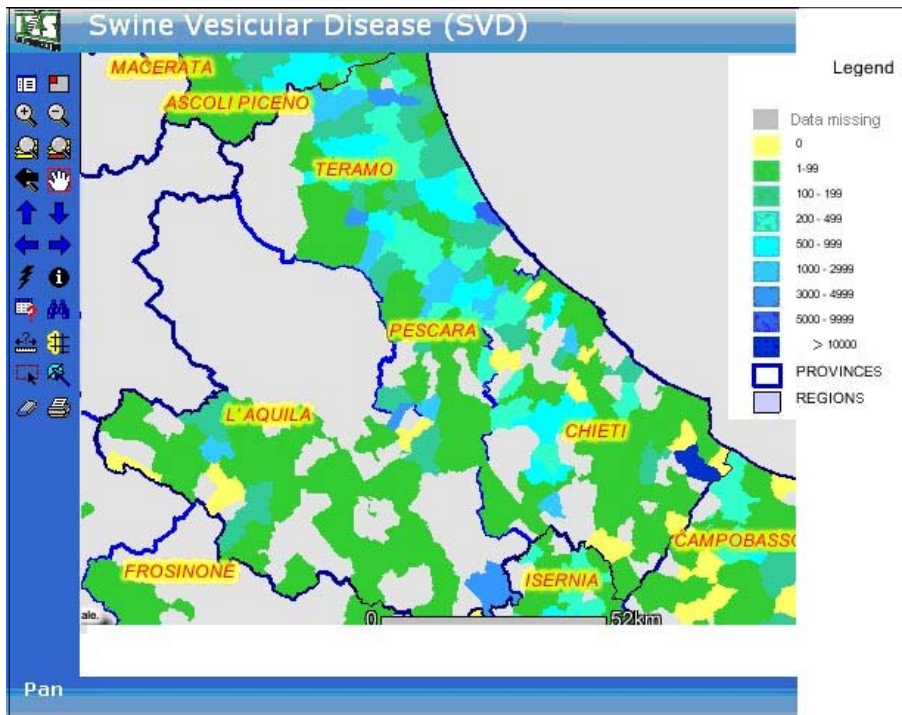


Figure 5
Pig density in Abruzzo by administrative unit

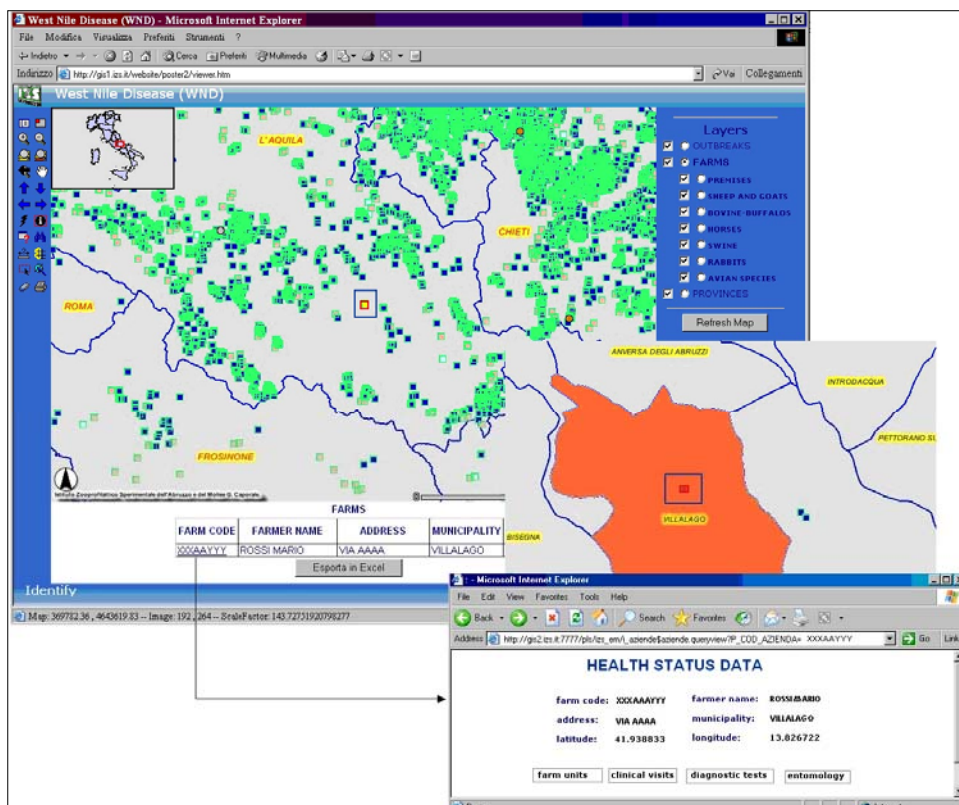


Figure 6
Distribution of premises surrounding an outbreak classified according to animal species
The health status of each farm can be visualised directly on the Web as a health form
The form contains the following information: identification of the single farm units, laboratory results and, for arthropod-borne diseases, the entomological situation

(transhumant herds), the health status of farms subjected to disease surveillance financed by the Italian government, etc.

The system provides helpful tools (buffer, select by line/polygon) that veterinary services can use to draw and define risk areas (protection zones, surveillance zones, etc.) as a simple buffer around an infected farm (Fig. 7) or as a polygon drawn by the user, based on specific criteria, for instance, taking into account actual terrain features, such as roads, rivers, etc. (Figs 8 and 9). A system function identifies and lists all geographic units within the defined buffer zone or polygonal zone, complete with the relevant epidemiological data, thus allowing veterinary services to obtain timely and useful information to control disease spread.

Discussion

STEM is a prototype designed to support the management of diseases outbreaks starting in the early stages of the emergency and providing a spatial background for the assessment of measures to be implemented. The first pilot version, released at the end of March 2006, has developed a number of descriptive applications, especially in the form of farms and farm-attributes mapping.

STEM functions have been tested mainly within the framework generated by a recent SVD epidemic. For each outbreak, spatial attributes (location, coordinates, distance from other farms) and other characteristics (general farm data, laboratory results, epidemiological profile according to the epidemiological

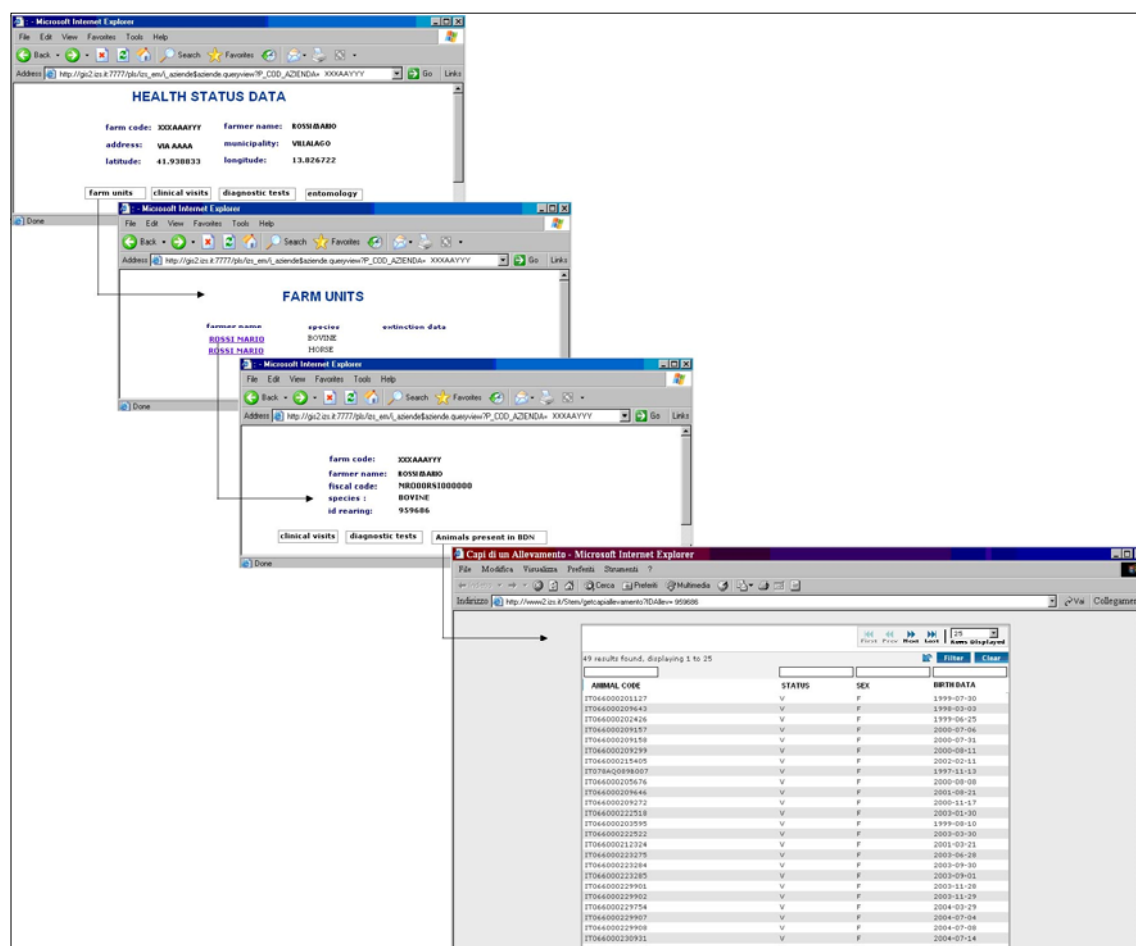


Figure 7

An additional feature of the system enables a connection to the national data bank (BDN: *banca dati nazionale*) and to retrieve all data (identification of animals on the farm, animal condition, sex and data of birth) on the animals of a selected farm, when present in the databank

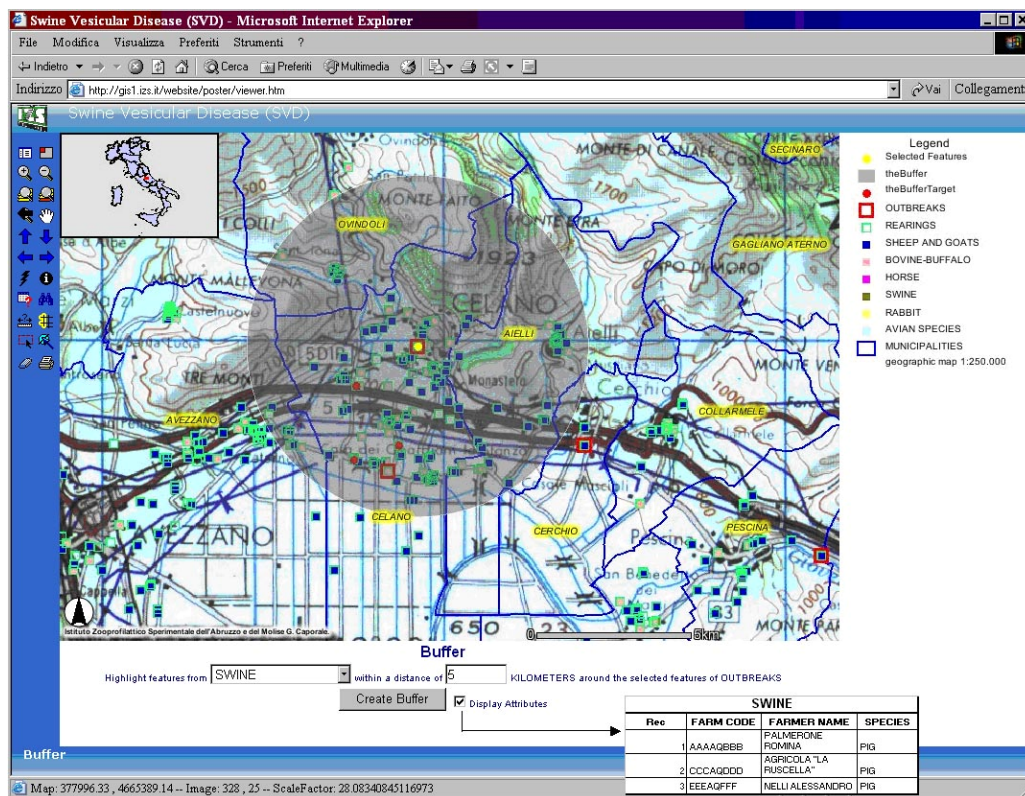


Figure 8
All swine farms within a 5-km radius of the outbreak

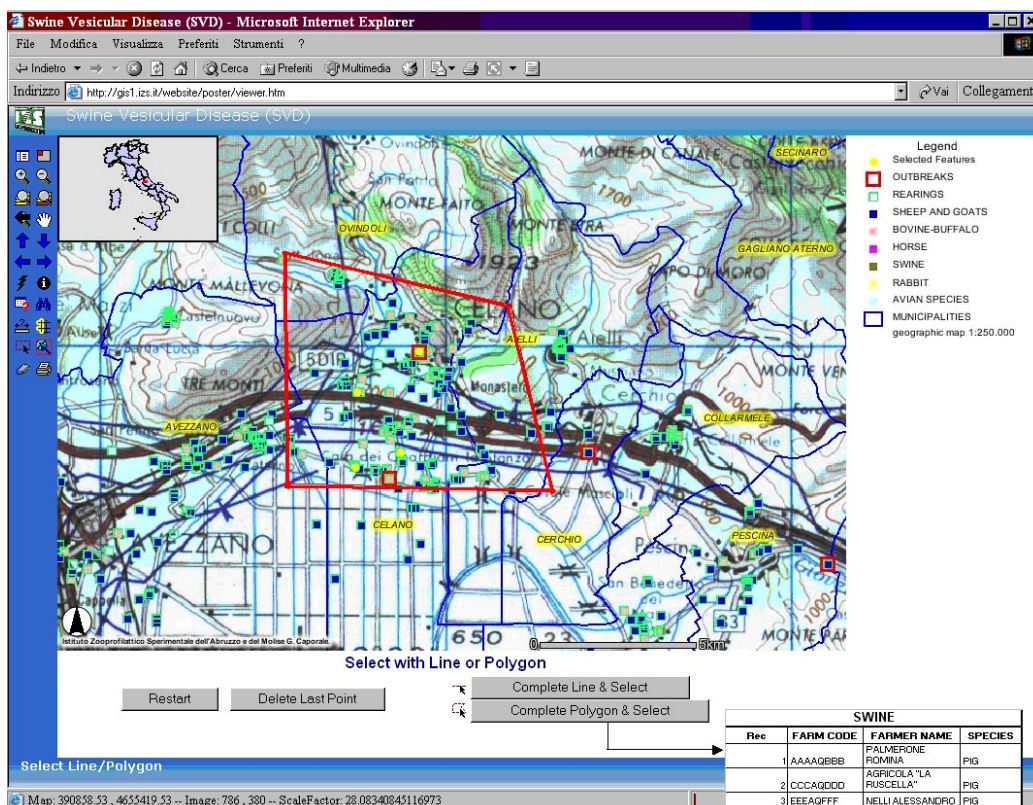


Figure 9
All swine farms present in a defined polygonal area

investigation, etc.) have been defined by linking STEM with a series of databases (Abruzzo Swine Farms Regional Databank, SILAB, Abruzzo Veterinary Epidemiology Centre, etc.).

During the trial, STEM functions were also of use to non-GIS users. The system supported field veterinarians providing a variety of services, such as downloadable files of the contingency plan for SVD and its operational manual, maps of the restriction zones generated automatically (buffers) were used by the veterinary services as a blueprint to design the official restriction zones, etc. A particularly useful function was the link of STEM with SILAB: field veterinarians were able to access the system on the Web and could promptly ascertain the health status (infected/not infected) of the farms sampled within the framework of the surveillance activities, which considerably accelerated all operations aimed at re-gaining freedom-from-disease status.

The spatial characterisation of risk areas is a pre-requisite for more effective disease control planning. Veterinary authorities will be able to allocate adequate human, material and equipment resources in the most effective way. Another advantage is the rationalisation and optimisation of the general emergency management system, especially as far as the organisation of complex operations, such as multi-farm stamping-out, destruction and/or transport of carcasses and infected material, etc.) (8, 16, 17, 22, 23).

The current version of STEM is already linked to a series of Web-enabled databases, containing comprehensive and detailed lists of all the material and human resources required to rapidly and successfully eradicate a major outbreak that are presently available in the Abruzzo region (excavators, fuel depots, personnel and material for the organisation and supervision of pyres, abattoir personnel, rendering plants, authorised vehicles for the transport of animals or at-risk material, etc.).

Most data are spatially characterised. For instance, abattoirs are geo-referenced so that, in the event of the adoption of test-and-move or pre-emptive slaughter strategies, veterinary services will be able to readily evaluate the feasibility of moving animals from overcrowded farms located in the surveillance zones to the nearest abattoirs along optimised routes as far as possible from other establishments hosting susceptible animals (19) or, alternatively, to identify easily and quickly the best sites for burial or burning of carcasses.

Disease surveillance networks are currently being reviewed in Italy, and STEM which was initially a separate entity, will be integrated into a larger project. In particular, the new STEM will manage a large part of disease information spatially, enabling not only access to disease data in emergency situations, but also to routine activities.

The integrated GIS, including both qualitative and quantitative data, will be a powerful tool for the evaluation and the adoption of health policies, greatly simplifying cost/benefit analysis and the evaluation of different control options (2, 3, 13, 18).

Moreover, the integration and analysis of a wealth of health-relevant data into a single system will open up many new research opportunities (4, 15, 18, 21). The new GIS will also be developed keeping research in mind, to investigate and characterise disease behaviour in local conditions, to spatially simulate the effect of disease events and of the measures taken to control them and to generally enhance the spatial epidemiology approach to disease control in Italy (10, 14, 15, 19).

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