Veterinary Syndromic Surveillance: current initiatives and potential for development

Fernanda C. Dórea; Javier Sanchez; Crawford W. Revie

Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, PE, C1A 4P3, Canada.

Corresponding Author

Fernanda Dórea

fdorea@upei.ca**.** Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, PE, C1A 4P3, Canada. Phone: +1(902)566-0969; Fax: +1(902)-620-5053.

Postal address:

Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, 550 University Avenue, Charlottetown, PE, C1A 4P3

Abstract

This paper reviews recent progress in the development of syndromic surveillance systems for veterinary medicine. Peer-reviewed and grey literature were searched in order to identify surveillance systems that explicitly address outbreak detection based on systematic monitoring of animal population data, in any phase of implementation. The review found that developments in veterinary syndromic surveillance are focused not only on animal health, but also on the use of animals as sentinels for public health, representing a further step towards *One Medicine*. The main sources of information are clinical data from practitioners and laboratory data, but a number of other sources are being explored. Due to limitations inherent in the way data on animal health is collected, the development of veterinary syndromic surveillance initially focused on animal health data collection strategies, analyzing historical data for their potential to support systematic monitoring, or solving problems of data classification and integration. Systems based on passive notification or data transfers are now dealing with sustainability issues. Given the ongoing barriers in availability of data, diagnostic laboratories appear to provide the most readily available data sources for syndromic surveillance in animal health. As the bottlenecks around data source availability are overcome, the next challenge is consolidating data standards for data classification, promoting the integration of different animal health surveillance systems, and also the integration to public health surveillance. Moreover, the outputs of systems for systematic monitoring of animal health data must be directly connected to real-time decision support systems which are increasingly being used for disease management and control.

Keywords: Syndromic surveillance; veterinary surveillance; animal health surveillance; emerging diseases; aberration detection; prospective monitoring.

Introduction

The evolution of disease control methods in veterinary medicine from campaigns and mass action to a new phase of surveillance and selective action was defined by Dr. Calvin Schwabe (1982) as an epidemiological revolution, marked by the use of epidemiological intelligence and analysis key tools for diagnosis and decision making. The last decade has witnessed a further step in this revolution, with "epidemiological intelligence" being progressively improved through novel informatics and data mining techniques; these allow analysis to be carried out on an unprecedented quantity of data to identify novel and useful patterns in an automated manner (Chen et al., 2005).

In this new context, providing effective and comprehensive approaches for systematic information management and analysis plays a central role in achieving the goals of disease surveillance (Zeng et al., 2005). While the concepts behind integrating information from multiple sources are not novel (McKendrick et al, 1995), the past decade has seen an increase in research that is focused on developing, "the science and technologies needed for collecting, sharing, reporting, analyzing, and visualizing infectious disease data and for providing data and decision-making support for infectious disease", which Zeng *et al.* (2005) defined as *infectious disease informatics*. This is an interdisciplinary field, taking advantage of a range of information technologies such as data sharing and security, geographic information systems (GIS), data mining and visualization, knowledge management, biostatistics and bioinformatics (Chen et al., 2005; Zeng et al., 2005).

The uptake of these approaches gained momentum when bioterrorist events, such as the anthrax attacks of 2001, and outbreaks of emerging infectious diseases, such as SARS (Bravata et al., 2004) underlined the necessity to recognize patterns indicative of a possible introduction of human pathogens, natural or not, as early as possible. Using the tools provided by infectious disease informatics, real time surveillance systems were developed to make use of pre-diagnosis data already available and automatically collected (Mandl et al., 2004a), such as sales of over-the-counter medicine, absences from work or school, patient's chief complaint upon emergency visit, or laboratory test orders (Wagner et al., 2001; Sosin and DeThomasis, 2004).

Due to the lack of specificity associated with pre-diagnosis data, this new type of surveillance targets general groups of diseases, or syndromes, and is therefore often referred to as "syndromic surveillance". The Centers for Disease Control (CDC, USA) has defined as syndromic surveillance those approaches which make use of "health-related data that precede diagnosis and signal with sufficient probability of a case or an outbreak to warrant further public health response" (Centers for Disease Control and Prevention, 2006). While less specific than confirmatory diagnosis, data used for syndromic surveillance is more timely (Shmueli, 2010), allowing for real-time or near-real-time analysis and interpretation of data (Fricker, 2006). The assumption is not that the data are representative of the disease burden in the population (and usually no attempt is made to estimate such parameters, as various biases are recognized to exist), but that they are sensitive to changes to the level of disease in the population, containing an early, though weak, signature of a disease outbreak (Yahav and Shmueli, 2007). While syndromic surveillance definitions focus on early detection of disease, Henning (2004) highlights the fact that with the continuous use of such systems longitudinal data are being accumulated, allowing for a broader achievement; "the use of existing health data in real time to provide immediate analysis and feedback to those charged with investigation and follow-up of potential outbreaks".

In veterinary medicine the development of systems for early detection of diseases followed a similar path to that taken in public health. Recent focus on the "One Medicine" concept has resulted in an increased awareness that the early detection of outbreaks in animal populations, whether zoonotic or not, can be of great public health importance.

While the past decade has seen a growth in the literature dealing with novel surveillance approaches, including a great increase in the use of cluster detection techniques applied retrospectively to data, to the authors' knowledge there exists no systematic overview of the application of syndromic surveillance to veterinary medicine. This paper reviews the current progress towards developing syndromic surveillance in veterinary medicine, defining as such all those systems that explicitly address outbreak detection based on systematic monitoring of population data. While this review focuses on syndromic surveillance systems that are already operational or are in their implementation phase, we also review studies investigating the potential for early detection of disease using alternative types of data available in animal health, to help the reader gain a sense of potential future developments.

Population coverage and timeliness in syndromic surveillance

A primary assumption of any syndromic surveillance system is that the behavior of the population changes when their health is affected, and that clusters (in space or time) of these behavioral changes can be detected if the population is continuously monitored (Mandl et al., 2004a). Therefore, syndromic surveillance systems can be designed to minimize the main limitations of passive surveillance methods based on laboratory confirmation and disease reports by clinicians (Bravata et al., 2004), namely: chronic under-reporting; a long time lag between outbreak onset and diagnosis; and a low sensitivity as a result of the high specificity of these methods. The low sensitivity of traditional surveillance relates to the focus on one disease or a list of reportable diseases, and the dependence on the ability of the clinician to recognize the clinical signs of specific diseases, a special limitation in case of rare or emerging diseases (Salman, 2003; Shephard, 2006; Shaffer, 2007).

In Figure 1 the timeline and population coverage associated with different surveillance strategies is schematically presented for three different target populations: humans, livestock and companion animals. Syndromic surveillance aims at reducing the time lag associated with passive surveillance by monitoring populations before laboratory confirmation. Under-reporting is also minimized by the systematic, continuous screening of information at earlier stages in the disease process. As illustrated in Figure 1, population coverage is reduced as the timeline of the disease process continues from the general population to laboratory confirmation of diseases. Doherr and Audige (2001) have noted that in this "pyramid of scrutiny" the animal owners and the veterinary practitioners act as a serial testing scheme, and the volume of laboratory submission reflects their judgement on the cost-benefit ratio associated with the laboratory tests.

The scheme in Figure 1 also indicates the loss in timeliness as surveillance is applied further along in the disease process. Timeliness refers to "the difference between the onset of an outbreak and the discovery of the outbreak" (Wagner et al., 2001). Buckeridge (2007) reviewed the determinants of detection in automated surveillance systems in public health, pointing out characteristics of the system and of the outbreak that affect detection. The exact characteristics of the outbreak are unpredictable, but systems should be designed based on the expected characteristics of the disease(s) that it aims to detect (Mandl et al., 2004a). The characteristics of the system listed by Buckeridge were the choice of data source, the sampling strategy of the system, and the detection algorithm choice and settings.

The gain in timeliness as surveillance is applied closer to the top of the scheme shown in Figure 1, in comparison to the reporting of laboratory results, is usually based on the assumption that outbreak discovery closely follows the identification of positive cases (Shaffer, 2007). In reality, this will only be true for the introduction of diseases in previously free zones/countries (any positive case is considered an alarm), and in this special case laboratory confirmation depends on the veterinarian having suspected the disease despite its absence in the region, and the laboratory having the specific test for it. Where the correct tests are not ordered/performed, or the outbreak event represents a sudden increase in the incidence of an endemic disease, its detection would likely occur much later in the disease process, if at all, in a situation where continuous statistical monitoring is not in place.

Syndromic surveillance initiatives in veterinary medicine

Scientific literature was reviewed using the following Medical Subject Headings (MeSH): cluster analysis, disease outbreak/veterinary, biosurveillance, medical informatics applications, and public health informatics. Keyword searches were primarily applied on PubMed and CAB Abstracts. The search was last updated in January 20111. Electronic grey literature was searched using these terms and also “syndromic surveillance” and “early disease warning”. Proceedings of the annual conferences of the International Society for Disease Surveillance (ISDS), symposiums of the International Society for Veterinary Epidemiology and Economics (ISVEE) and Conference of Research Workers in Animal Disease (CRWAD) dated back to 2000 were screened individually. References within the papers found were also scrutinized.

A cursory look at syndromic surveillance initiatives in veterinary medicine reveals that this is an incipient field, and that a clear definition as to which systems should be classified as “syndromic” is hard to achieve. We focused our review on any surveillance systems based on the systematic monitoring of animal populations, using data sources that are timelier than traditional passive surveillance (as indicated in the left-most brackets of Figure 1). For the sake of structuring this review, systems that focus primarily on detection of emerging diseases, registering only atypical cases, are listed separately from systems that target animal health surveillance as a whole. The latter are based on monitoring all clinical cases, aiming at detecting not only disease introduction, but also changes in trends of endemic disease. Systems that monitor animal health with the primary purpose of detecting zoonotic threats for public health protection are also grouped separately. For reference, all the systems are listed in Table 1 (in chronological order by publication date). Peer reviewed papers evaluating the potential of specific datasets for syndromic surveillance, but not reporting the implementation of any system, are listed in Table 2.

<u>Syndromic surveillance based on notification of atypical cases</u>

Vourc’h et al. (2006) presented a list of 14 emergence events associated with animal disease, and claimed that in most of these the key to detection was the observation of unusual signs or an unusual combination of signs. The same authors argue that focusing on solely reporting atypical cases (as opposed to monitoring trends for several unspecific clinical signs) can reduce the reporting load and requirement for disciplined coverage associated with the general syndromic surveillance approach.

The émergence system (Vourc’h and Barnouin, 2003) was developed in France based on two components: a farmer component via routine surveys on farms, and a veterinarian component (Vourc’h and Barnouin, 2003).

The veterinarian participation is based on atypical clinical case notification on a website (INRA - National Institute for Agricultural Research), and follow-ups. Monthly confirmation of vigilance is requested from veterinarians not reporting any atypical cases. The system also tracks diseases with emergence potential and/or known public health importance. The system currently focuses on bovines but it is built to be generic allowing its application to, "any species, any country, any disease".

Passive reporting of atypical cases is one of the components of the national cattle health surveillance system implemented in The Netherlands in 2003 (Bartels et al., 2006). Farmers or veterinarians report incidents not fully understood, motivated by the availability of specialists who visit the farm free of charge, in order to collect detailed information and investigate the problem. The system is complemented by the continuous collection of census data, pathology diagnosis in carcasses, toxicology tests, and periodical prevalence studies. While this represents an innovative system for early disease detection and information collection, the data compilation and analysis is performed by a surveillance team meeting weekly, rather than automated. The team looks for signs of introduction of specific emerging diseases, or analyzes trends of particular diseases, rather than grouping information into syndromes. Quarterly reports are made available to the public.

The Rapid Syndrome Validation Project (RSVP) was first developed for public health, and later applied to cattle populations (RSVP-A) (DeGroot, 2005). Clinical presentations are grouped into six syndromic groups that purposely focus on less common endemic disease presentations, and exclude the most common diseases and production problems. Several forms of data capture are available for veterinarians to report observed cases, as hand-held computers, cell phone, phone and fax lines, and the Internet.

Syndromic surveillance based on analysis of all clinical cases

Because the clinical signs of diseases observed in animals can vary depending on a great number of factors (Davis, 2004b), disease introduction events may initially present as a collection of unspecific signs. Practitioners may therefore fail to diagnose diseases outside their sphere of experience. Alternatively the signs may not be specific enough to allow recognition that a new disease has been introduced (Elbers et al., 2006). Recognizing this, more surveillance systems are designed to monitor general signs, rather than specific diseases or only atypical cases.

In 2003 McIntyre et al. reported on VetPAD, an initiative in New Zealand which aims to take advantage of veterinary practitioner data to improve disease surveillance capability. Understanding that for the system to be sustainable and keep veterinarians engagement it needed to be simple, and offer some advantages for participation, the initiative was based on providing software that would help the practitioner manage her/his practice using a handheld computer, which would electronically transfer data to the surveillance program. The data recorded includes all clinical cases attended by the veterinarian, and goes beyond diagnosis, recording also procedures, treatment, laboratory samples, medications, etc.

Initiatives to collect practitioner data are also being developed in Canada, through the Alberta Veterinary Surveillance Network (Berezowski et al., 2006; Checkley et al., 2006; Checkley et al., 2009) and the Ontario Swine Veterinary-based Surveillance System (OSVS)(Amezcua et al., 2010). In the former veterinarians are encouraged to report all their daily animal health consultations. The veterinary surveillance system is also supported by pathologists and an investigation network, through which producers and other people in contact with livestock can report atypical observations. The OSVS is focused on swine veterinarians, using a variety of recording systems including paper forms and handheld computers, adapted to each clinic's management.

In Australia a system for electronic capture of syndrome data from livestock has been piloted (Shephard, 2006; Shephard et al., 2006a; Shephard et al., 2006b). The Bovine Syndromic Surveillance System (BOSS), a voluntary, producer-driven surveillance system, extends the target audience beyond the veterinarians, including lay observers who are in daily contact with cattle, such as stock inspectors, farmers and stock workers. The method used to engage participation is to provide a generic cattle disease diagnostic program – based on the BOVID system (Brightling et al, 1998) – through which the producers can get a ranked list of differential diagnoses based on the signs observed in their cattle, and be advised of the precautions to take. The information that the producer feeds to the software for decision are exactly those that the surveillance program can take advantage of: animal characteristics, numbers affected, time and place of occurrence, duration of the disease event, and management information regarding the herd.

Recognizing that new or emerging diseases can go undiagnosed due to the lack of specific tests, in Great Britain a system of syndromic surveillance has been developed based on laboratory submissions for which a diagnosis was not reached. Building on the Veterinary Investigation Diagnosis Analysis (VIDA) system, the *FarmFile* system (Gibbens et al., 2008) among other improvements, included statistical monitoring of the ratio of "Diagnosis Not-Reached" (DNR) samples to the total samples processed. Even though this system is not designed to operate in real-time and uses information from the test results phase, a number of syndromic surveillance techniques are adopted by *FarmFile*, including grouping test requests (including DNR) according to the body system affected, and an on-going monitoring of trends. Moreover, the focus on DNR samples represents an innovative initiative, potentially increasing the ability of the current surveillance to account for emerging diseases based largely on what was previously discarded data.

All the systems previously mentioned are focused on livestock. Syndromic surveillance systems targeting companion animals are usually designed with focus on public health, as discussed in the following topic. An exception is Small Animal Veterinary Surveillance Network (SAVSNET) (Tierney et al. 2009; University of Liverpool), in development at the University of Liverpool. Besides monitoring disease trends, the project also aims at making the collected information via reports in a website.

Also in the United Kingdom, the National Animal Disease Information Service (NADIS) (Anonymous, 2010) deserves attention for its support to animal disease monitoring and evidence-based medicine. Even though the system is not syndromic or prospective, it does include a unique network of 60 veterinary practices and 6 veterinary colleges, monitoring diseases in cattle, sheep and pigs, and publishes publicly available reports of disease trends and parasite forecasts.

<u>Syndromic surveillance focusing on public health (animals as sentinels for human diseases)</u>

Ashford et al. (2000) and Davis (2004a) reviewed the role of veterinarians in the preparedness against bioterrorism, based on the fact that almost all the biological bioterrorism agents listed by a group of experts gathered by the CDC in the United States in 1999 are zoonotic. Rabinowitz (2006) reviewed several diseases with bioterrorism potential and the role of animal populations in their detection. This is based on the assumption of one or more of the following factors being true: the 'sentinels' have increased susceptibility, would present with a shorter incubation period, are likely to be exposed sooner or more intensively and continuously through the environment; or simply because the concomitant observation in humans and animals would add confidence to the detection of a natural or introduced disease threat. As Figure 1 illustrates, depending on the disease, the number of sick animals can indeed exceed the number of sick humans. Moreover, domestic animal populations may be easier to observe or test.

Syndromic surveillance systems collecting animal health data for public health surveillance focus mainly on zoonotic diseases. These systems have thus far been largely based on companion animals, due to their proximity to humans, but their choice of targeted animals can also be based on the susceptibility of the different species, and their potential to signal disease before humans. Examples of the latter are the systems based on the higher susceptibility of crows and horses to West Nile virus (Mostashari et al., 2003; Davis, 2004b; Johnson et al., 2006; Shuai et al., 2006; Leblond et al., 2007). One unique initiative highlighted the potential of zoo animals as sentinels, focusing also on West Nile virus detection (McNamara, 2007).

Animal data has been incorporated into a few implemented syndromic surveillance systems for human populations. Those reported in the literature include: the Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) (Babin et al., 2003), the North Dakota Electronic Animal health Surveillance System (Goplin and Benz, 2007) and the Multi-Hazard Threat Database (MHTD), a disaster preparedness project of the North Carolina Department of Agriculture and Consumer Services (2007). Brianti et al. (2007) investigated the potential for improving public health surveillance of leishmaniosis by a retrospective survey which included data from veterinary practitioners and from hospitals.

Glickman et al. (2006) highlighted the gap in our understanding of the dynamics and disease burden in companion animals even though they are in daily contact with humans. The authors were responsible for implementing a National Companion Animal Surveillance Program (NCASP) in the United States in 2004 which took advantage of large amounts of computerized data from a major chain of pet hospitals in that country (450 hospitals), complemented by access to the computerized database from a network of diagnostic laboratories serving 18,000 pet hospitals. The system allows daily data analysis of all clinical visits to the hospital network. Results based on monitoring tick infestation, leptospirosis in dogs and the occurrence of influenza-like illness (ILI) in cats, have demonstrated the feasibility of conducting parallel syndromic surveillance in animals and humans.

Shaffer et al. (2007) evaluated the use of companion animals as sentinels of infectious diseases in humans by the implementation of syndromic detection of diseases using laboratory submission requests, also taking advantage of the already available, electronic database of a laboratory network. Microbiology test orders were transferred daily, and directly mapped into 11 syndromic groups monitored independently. The authors report the positive results in using the system for population surveillance in a timely manner, and highlight the wide geographic coverage given by one single source of data.

Maciejewski et al. (2007) reported the construction of a framework for joint analysis of human emergency room data and veterinary hospital data (mostly pets), called Linked Animal-Human Health Visual Analytics (LAHVA). Human data is processed daily, while animal data is received in batches every 1-3 weeks. The inclusion of animal data is considered to add sensitivity and specificity to the surveillance, and takes advantage of the lower privacy concerns regarding animal data. Besides temporal analyses, the system advantages include the integration of different data sources, and the visual analytic tools that integrate human and animal data. Testing of the system was performed by retrospective analysis using seasonal influenza and wastewater contamination.

Data sources for syndromic surveillance in veterinary medicine

In public health it has been noted that the ultimate choice of target for syndromic surveillance (according to the scheme in Figure 1) depends on the balance between quality and timeliness, and the weight of the costs of false alarms and missed alarms. In animal health the decision is further complicated by the scarce availability of suitable data (Shephard, 2006; Smith-Akin et al., 2007), which for the purposes of syndromic surveillance should be acquired continuously, in an automated routine, be electronically stored and timely available (Mandl et al., 2004a). Moreover, animal data is subject to more non-disease variation than human disease data (Kosmider et al., 2006). The rate of seeking care is not only related to the awareness and severity of diseases, as in humans, but also, especially in livestock, by cost. In turn, the rate of laboratory test submission is not only a result of diagnostic concerns; specimen collection can also take place for a variety of other reasons such as trade certification, food safety monitoring, etc.

Shephard (2006) listed barriers to the development of syndromic surveillance systems in animal health as including the great diversity in species, production and purpose, and the hierarchical structure of animal populations (in food production). Additional barriers relate to the poor availability of data sources in comparison to human medicine, due to less frequent capture, often in a non-computerized format, as well as less well developed data standards. This section will review how some of the initiatives listed in the previous section have dealt with the problem of finding adequate datasets, and their strategies to increase population coverage compared to voluntary notification of confirmed cases.

Voluntary Notification

Coverage of systems based on passive notification can be increased by understanding the behaviour of the reporting entities – veterinarians, animal owners, etc – and designing ways to positively influence them. The challenge is to find a strategy that is not only successful, but also sustainable (Hoinville et al., 2009). As early as 1998 Gobar et al. reported a program for surveillance of causes of death in dogs, using the Internet to survey small animal veterinarians. The novelty resulted in 25 veterinarians actively submitting case materials and promoting discussion, but no report of the sustainability of the system and rate of participation over time was found. Shephard (2006) reported a study to investigate the sustainability of implementing a system based on veterinary voluntary reporting of clinical livestock cases. The results indicated that the system would likely not be sustainable, especially due to veterinarians' perceptions of limited personal value associated with participation, and a view of increased risk of penalty in case of reporting.

Systems that focus only on the reporting of atypical cases, such as RSVP-A (DeGroot, 2005), the national cattle surveillance system in The Netherlands (Bartels et al., 2006), and émergences (Vourc'h and Barnouin, 2003), aim at keeping veterinarians involved by reducing the time demanded of them – the systems provide easy and quick reporting, through handheld computers or websites. The RSVP-A and the national cattle surveillance system in The Netherlands also promote participation by giving information feedback to the public (in the form of publicly available quarterly reports on the latter, but restricted to participating veterinarians in the RSVP-A).. However, maintaining compliance over time remains a great challenge (Mandl et al., 2004a). Reports on evaluations of the sustainability of these systems could not be found in the literature.

Clinical data

In contrast to human medicine, in veterinary clinics the payment is due, in most cases, at the time of service, with no requirement to transfer data to third-party payers, such as insurance companies. This has caused veterinary clinic data recording to be primarily focused on client and invoice management, and there has been little incentive to develop and implement standards for disease coding (Smith-Akin et al., 2007).

Despite these bottlenecks, the use of computerized records is becoming standard practice in companion animal medicine, offering opportunities for the collection of syndromic data. The SAVSNET for instance (Tierney et al., 2009; University of Liverpool), which plans to use practice-based, real-time collected data in its next implementation step, will take advantage of the fact that around 20% of pet clinics in the UK use the same software for practice management. The lack of data standards in veterinary medicine, however, means that data integration among clinics using different software remains problematic.

The opportunities for data integration increase with the growth of corporate veterinary practices (Moore et al., 2004). The Purdue University-Banfield National Companion Animal Surveillance (Glickman et al., 2006) reported a coverage of 2% of the total pet dog and cat population in the United States, by using the centralized database of Banfield, a pet hospital chain widely spread across the country (Maciejewski et al., 2007), and whose demographic and medical information is completely computerized. Data from the same hospital network are also used by the LAHVA initiative (Maciejewski et al., 2007).

Automated collection of clinical data is harder for systems targeting livestock due to the lower level of computerization in large animal practices, compared to companion animal practices. These systems depend on the willingness of the veterinarian to comply and take the extra effort of submitting their routine data to a surveillance system. Engagement is sought by adapting the recording system to the routine recording process of the practice or by offering feedback to the veterinarians and farmers by means of a complete investigation network, as in the Alberta Veterinary Surveillance Network (Berezowski et al., 2006; Checkley et al., 2006; Checkley et al., 2009). Assessments of system sustainability have not been reported.

Robotham and Green (2004) stated that systems that depend uniquely on voluntary transference of routine clinical data by veterinarians are not sustainable without any return to the veterinarian. Proposed methods to increase veterinarian engagement include continuous training, return of the information collected with added value to the practitioners (Bartlett et al., 1986; Bartlett et al., 2010), and financial incentives to reporting (Checkley et al., 2009).

Herd Management Data

Automated monitoring of herd management data and indicators of production quality have been reported and reviewed (Bartlett et al., 2010; De Vries and Reneau, 2010). However no reports on implementations of syndromic surveillance systems based on these data were found. Mork et al. (2009) compared data kept on farmers' records to the data reported by veterinarians to a dairy industry cattle database in Sweden, and showed that only 54% of the disease events registered by farmers were treated by a veterinarian. Even for those events that were reported by both groups, the farmers kept information that was more detailed and specific than that reported by the veterinarians.

The BOSS system (Shephard, 2006), even though based on disease events, can be considered a system based on direct herd information, as it represents an effort to involve farmers directly. Rate of underreporting should theoretically be low, as it targets the population of animals becoming sick, not the population of animals for which veterinary care was sought. However, population coverage will be limited by access to (and willingness to use) a computer. This is becoming less and less of a problem, as an increasing number of herds are already managed with the help of computerized systems.

The increase in the use of computerized herd management tools could offer another opportunity for surveillance. The lack of uniform standards among systems may however complicate integration, and it would suffer from the same problems discussed for capture of computerized clinical data.

Laboratory data

Laboratory test *requests* are a type of syndromic data. They are timelier than *results*, and can be grouped in syndromes according to the nature of the disease and/or symptoms observed by the veterinarian (Pavlin et al., 2003; Buehler et al., 2004; Ma et al., 2005). Stone (2007) investigated the potential of using laboratory test requests for syndromic surveillance in veterinary medicine and reviewed the potential biases associated with this type of data. The author also pointed out the variability in the submission rates year to year, and misclassification biases (veterinarian not submitting the right sample or requesting the correct test), but concluded that the data is suitable for syndromic surveillance.

Laboratory test requests are more often automated and electronically recorded than clinical data (Sintchenko and Gallego, 2009) and therefore these data allow for the construction of a sustainable surveillance system. Laboratories also represent a more centralized source of data, especially in livestock medicine. However, their use depends on the willingness of data owners to share these data (Glickman et al., 2006).

It has been reported that laboratory test orders suffer from the low submission of specimens as part of the diagnostic process in veterinary medicine (Zurbrigg and Blackwell, 2009). However, Shaffer (2007) assessed the potential of microbiology test submissions for syndromic surveillance in companion animals assuming that the consistency of test orders over time allows for the use of these data in prospective monitoring, and that increases in the number of test orders can be used as indicators of an increase in disease burden. The availability of historic data is another advantage of laboratory data in veterinary medicine over other types of data, since some estimation of a baseline of disease burden is needed in syndromic surveillance to compensate for the lack of denominator data.

Laboratory test requests screen a larger proportion of the animal population than sick animals, as animals can be tested for different purposes. Zhang et al. (2005) reported that four different purposes were recorded as reason for test requests in their laboratory data: diagnostic, export testing, government monitoring, and industry monitoring.

The use of laboratory data in veterinary syndrome surveillance appears to be a growing field. The Canadian Animal Health Surveillance Network (CAHSN), part of the Canadian Food Inspection Agency, is establishing a network of federal, provincial and university animal health diagnostic laboratories to implement an early warning system for animal diseases in real-time, especially diseases with zoonotic potential (Canadian Food Inspection Agency, 2009). The website of the Gluck Equine Research Center (Gluck Equine Research Center) reported that the Veterinary Diagnostic Laboratory in the United Kingdom is developing a syndromic surveillance system in near real-time, also based on monitoring sample submissions. Table 2 provides additional examples of investigations of the potential of laboratory data on early disease detection (Kosmider et al., 2006; Odoi et al., 2009).

Others

The limited number of implemented syndromic surveillance systems in veterinary medicine use the sources of data noted above. However, a variety of alternate data sources are being explored for their syndromic surveillance potential.

Egenvall et al. (1998) and Penell et al. (2007) have assessed the quality and completeness of computerized insurance data from dogs and cats, and horses respectively. If the use of health insurance grows in veterinary medicine, these data may provide a source of centralized information, and the use of coding standards may become more widespread.

The work of Van Metre et al. (2009) investigated the use of direct observation in auction markets. The advantage of this method is associated with the opportunity to screen a large number of animals at once, and especially of reaching smaller operations which may be systematically excluded of other surveillance methods due to a lower frequency of veterinary care (Van Metre et al., 2009). Even for the population under veterinary care, observations in auction markets may be timelier than the observation of clinical cases.

Abattoirs represent a unique source of data for veterinary surveillance, compared to public health. Engle (2006) used the condemnation data available through the electronic Animal Disposition Reporting System (eADRS) from the Food Safety and Inspection Services (FSIS) in the USA, and concluded that a swine erysipelas outbreak in Iowa and Minnesota during July 2001 could have been identified up to 10 months earlier if automated analysis of the data had been in place. Weber (2009) also evaluated the potential for using condemnation data to set up an animal health monitoring system. Benschop et al. (2008) provided a thorough temporal and spatial analysis of abattoir data collected by the Danish Swine Salmonellosis Control Programme, and its potential for temporal monitoring and to improve surveillance design.

McNamara (2007) drew attention to the fact that zoos are an often overlooked source of surveillance data. The author highlighted their role as epidemiological monitoring stations, as they “contain a population of known individuals at a point-source location that are followed over time”. Zoos have historical data on animal tests that are performed as animals are received and regularly throughout their life. The author reported the success of a “Surveillance for West Nile Virus in Zoological Institutions” that ran successfully for 4 years, and is now being used as a model for expanding H5N1 surveillance in the United States.

Smith et al. (2006b) presented even more innovative ideas to collect livestock health information that goes beyond clinical, sporadic information. The authors are developing a telemonitoring system that continuously transfers animal health data from devices permanently worn by the animals. Data would be collected and monitored continuously through devices placed in points of animal agglomeration within the farm. Evaluations of the system, especially of its cost-effectiveness, are not yet available.

Implementation of disease aberration detection from animal health data

Figure 2 summarizes the process of using animal health data sources to monitor disease trends and detect temporal or spatial aberrations in the number of cases. Comprehensive reviews of each of the components of a syndromic surveillance system are available elsewhere (Lober et al., 2004; Mandl et al., 2004a; Shephard, 2006;

Shaffer, 2007). The focus of this review is on the particular characteristics of veterinary syndromic surveillance, in livestock and companion animals.

Definition of events and syndromes

Automated disease monitoring systems must make a clear definition of what constitutes one event in the data available, as the statistical analyses are typically based on observed counts. For companion animals each patient entry is usually considered to represent an event, as long as there is no evidence that repeated encounters are associated with the same health event. In the case of livestock, health events are usually enumerated at herd level.

Once the events have been identified, identifying the criteria to be used to group these into specific syndrome(s) and devising reliable/automated data classification protocols are essential components of an early epidemic detection system (Ivanov et al., 2002; Mandl et al., 2004a). The classification protocol must be based on the system goals, but must also relate on the specific data in hand, as the data grouping will likely influence the performance of the alert detection algorithm (Shaffer, 2007).

In public health, clinical data is usually coded for billing purposes using standard nomenclatures, and coding standards for laboratory data are also available, allowing for the integration of multiple sources of data. When clinical or laboratory data are coded, classification can often be performed by directly mapping codes into syndromes. When data are not coded, automated classification algorithms must be trained to recognize relevant medical information on the data, and determine the syndrome associated with each event/unit. A common example is the use of text mining algorithms to extract information from text entered by nurses during triage in emergency rooms (*chief complaint* data) (Ivanov et al., 2002).

Vocabularies and standards for data classification are not as unified in animal health (Smith-Akin et al., 2007) as is the case for human health. Wurtz and Popovich (2002) reported on the range of codes that do exist, but noted that these are not widely used in clinics. Numerical codes are available through the Standardized Nomenclature for Veterinary Diseases and Operations (SNVDO), and the National Animal Health Reporting System (NAHRS). In addition veterinary input has been incorporated into more general health ontologies such as HL7, LOINC, and SNOMED (which has been renamed the "Systematized Nomenclature of Human and Veterinary Medicine). Bartlett et al. (2010) reported that the Veterinary Medical Data Base (VMDB), created in 1964 to store all clinical cases seen in veterinary teaching hospitals across North America, is not up to date because several schools are behind in coding their cases for upload to the database; a problem that would not exist if hospitals already coded their cases routinely under a standard system. None of the surveillance systems presented in this paper reported using a standard classification system.

In the absence of standard nomenclature, a key element in the implementation of any syndromic surveillance system is the definition of syndrome groups and the rules to assign events membership. Shaffer (2007) reported a consultation with a group of seven veterinarians, together with staff from the diagnostic laboratory who handle data regularly, to determine which laboratory test orders should be mapped into which syndromes. The final syndromic groups identified during this consultation were: respiratory, GIT, neurologic, dermal, reproductive, endocrine, hepatic, infectious, febrile, renal, and non-specific. Stone (2007) also mapped laboratory data into groups based mainly on organ systems. After some standardization of the data these records were grouped into the following categories: reproductive system, abortion, alimentary system/oral, anorexia/depression/malaise, circulatory/oedema/anaemia; diarrhoea/dysentery, lymphoreticular, mastitis, musculoeskeletal, nervous system, perinatal losses, respiratory system, skin/photosensitivity, sudden death, and urinary/renal. Samples for which a diagnosis was not reached in the *FarmFile* system (Gibbens et al., 2008) were mapped into syndromes based on body system together with the information given by the veterinarian at submission concerning observed clinical signs. The final syndromic groups in that system were: systemic, digestive, respiratory, urinary, musculoskeletal, nervous, skin, circulatory, reproductive, other, disease type unknown, mastitis and fetopathy. The implementation of this syndrome mapping within *FarmFile* generated feedback which improved the data collection forms. The list of clinical signs to be used by veterinarians when submitting samples was revised, in order to improve syndromic classification of the data.

For most of the systems based on clinical data listed in this review the protocol for classifying data into syndromic groups could not be found in the literature, or none had yet been implemented. A number of the systems are still being piloted using one or a few specific syndromes, and these have so far been identified retrospectively. The RSVP-A system uses six syndromic groups, but classification is decided and entered by the veterinarian reporting the atypical cases observed; this is also the case of the Alberta Veterinary Surveillance Network. In the BOSS system (Shephard, 2006) the BOVID software, a rule-based diagnostic program designed to identify the most probable diagnosis based on clinical signs reported, classifies the reported cases into syndromic groups (based on organ system) to deliver counts by syndrome. The syndrome groups used within BOSS/BOVID are: body; ears/eyes; airways; GIT; genital and urinary system; nervous; skin; cardio-vascular; death or reduced production; and muscle, bone or gait abnormal.

Aberration detection algorithms

Monitoring of time series data in surveillance can be retrospective or prospective. Retrospective surveillance is used to explain temporal and spatio-temporal patterns in data, and is therefore used in the generation of hypothesis. In syndromic surveillance, where the focus is outbreak detection, statistical analysis is prospective, aiming at detecting meaningful changes from the expected range of data values, which are referred to as “aberrations” (Buckeridge et al., 2005; Hohle et al., 2009). Mandl et al. (2004b) summarized the methodological stages to process data for outbreak detection, once events have been classified into syndromic groups, as: evaluation of historical data to establish a baseline model for the expect number of cases; comparison of observed values to baselines, to detect abnormal activities if occurring; culminating in an evaluation of the alert and a decision as to whether notification and investigation should take place.

The choice of algorithm to detect abnormal activities is based on the type of data (number of time series to monitor, whether rates or counts are monitored, rare versus frequent counts, temporal or spatio-temporal data); the availability of historical data to construct baselines; the nature of the disease being monitored (whether outbreaks are expected to occur as ‘spikes’, a sudden or slow increase); and an assessment of the desired balance between sensitivity (ability to detect true alarms) and specificity (ability to avoid false alarms). Algorithms for outbreak detection have been thoroughly reviewed elsewhere (Ward and Carpenter, 2000a; Ward and Carpenter, 2000b; Carpenter, 2001; Buckeridge et al., 2005; Fricker, 2006; Shephard, 2006; Moore et al., 2004). The goal here is to list the methods that have been cited in the veterinary syndromic surveillance systems covered in this review. However, as many of the systems are still in their initial implementation phase, the types of algorithms being used were often not identified; and a column detailing this information could not added in Table 1.

For temporal analysis, control charts (such as cumulative sums and exponentially weighted moving averages) are the most commonly employed algorithms (Shephard, 2006; Goplin and Benz, 2007; Shaffer, 2007; Checkley et al., 2009; Weber, 2009). This is not surprising, as for most of the data sources used there is limited availability of historical data. Control charts require limited baseline data, using a small number of previous observations to establish thresholds of expected values, based on the assumption that those observations came from a pre-specified parametric distribution. New observations are compared to the thresholds, and the system is determined to be “out-of-control” if the observations fall beyond the calculated expected limits (Benneyan, 1998). Performance is not optimal, since these methods do not exploit the full information content of the data, and because health data often violates the basic assumptions of control charts – that events are independent, stationary and normally distributed (Lotze et al., 2007). However, the popularity of these methods in public and animal health surveillance attest for they usefulness, especially when historical data is limited.

When historical information is available regression methods can be used. Published work on regression methods applied to veterinary data have thus far focused on retrospective analyses, as a means of assessing their potential for prospective modeling. For instance the work of the Purdue University-Banfield National Companion Animal Surveillance (Glickman et al., 2006) with clinical data, the analysis of the Danish Salmonella Control Programme data (Benschop et al. (2008), and the work of Kosmider et al.(2006) based on laboratory detection of Salmonella in British livestock, are all examples which adopt this approach.

Geographical information is often used to aggregate data into demographic areas, after which temporal analysis is applied to these areas independently (Shaffer, 2007). Public health systems are usually restricted by privacy concerns regarding address information from patients (Maciejewski et al., 2007), while in animal health systems the problem is the lack of geo-location data relating to health events. Often the only geographical information in the system refers to the practitioner location or postal code (Shaffer, 2007). This represents a challenge for use in spatial analysis of animal surveillance, since the geographical radius of clients attended by each practitioner is not usually determined and may vary greatly, particularly in regions of low farm and/or practitioner density.

Where spatial cluster analyses were performed in the systems reviewed here, the most commonly reported method was the scan-statistic (Odoi et al., 2009; Perez et al., 2009), which can be performed with the freely-available software *SaTScan* (Kulldorff, 1997; Kulldorff, 2006). Spatial cluster detection using algorithms available within the R statistical package was reported in the case of the Alberta Veterinary Surveillance Network (Checkley et al., 2009).

Evaluation

The “framework for evaluating public health surveillance systems for early detection of outbreaks” was reviewed in 2004 by a working group promoted by the CDC (Buehler et al., 2004). The document contains an operations checklist to review system-wide issues, data sources, data processing, statistical analysis, and epidemiological analysis, interpretation and investigation. It sets out a framework for description and evaluation of any system as a whole, including: usefulness, flexibility, acceptability, portability, stability and costs. In a similar way, Stone (2007) stated that a veterinary syndromic surveillance system should be evaluated for: population coverage, automation of data capture and transfer, value to users, detection efficiency of programmed algorithms, and contribution to claims of disease freedom.

More quantitative evaluation methods have been proposed to specifically evaluate the performance of various detection algorithms, using real or simulated data; and thus to evaluate the system's performance at the population level in the similar way to which test diagnostic performance is evaluated for individual testing. This includes the measurement of sensitivity, and specificity (Buckeridge et al., 2008). Kleinman and Abrams propose methodologies which also include an evaluation of the timeliness of a system (Kleinman and Abrams, 2006) and the number of lives saved (Kleinman and Abrams, 2008), based on the traditional Receiver Operating Characteristic (ROC) curves used for diagnostic tests evaluation.

Ultimately, the factors that affect the ability of any system to detect outbreaks also depend on the nature of the outbreak (Buckeridge, 2007). Evaluation of outbreak detection algorithms based on simulated data has been suggested in the literature. These evaluations may use wholly simulated data sets or may superimpose various patterns of simulated outbreaks onto authentic data. An overview of these approaches can be found in Buckeridge et al. 2005. A holistic evaluation of how all system components operate in real time is only possible once the system has been implemented. None of the systems listed in this review have been formally evaluated using the metrics described above; this is not surprising as most of them are still in development and few are fully operational. However, various authors have attempted to assess the quality of different system components. In those cases where any, even limited, evaluation was reported, notes have been added to Table 1 and Table 2.

The Ontario Swine Veterinary-based Surveillance System (OSVS) (Amezcua et al., 2010) was the only system for which an evaluation of the characteristics of data acquired through practitioners' reports was performed. The authors estimated the level of compliance by comparing the data provided by practitioners against the submissions made by the same veterinarians to Ontario's Animal Health Laboratory. Completeness of data (measured in terms of the completion of each form field), coverage of the program, and timeliness for reporting were evaluated. Completeness actually increased from the first to the second year of the study, as well as coverage of farms in the province.

The émergences system was not formally evaluated, but in 2003 Vourc'h and Barnouin reported that over a period of six months the system received 33 notifications, two of which were considered atypical. Shaffer (2007) reported that during the pilot study of the described syndromic surveillance system based on microbiological test requests nine clusters were detected. Follow-up investigations were able to link two of these to a true increase in the incidence of disease. Assessing sensitivity and specificity was not considered viable due to the lack of a gold standard for determining when outbreaks were really happening. The BOSS system was also not evaluated due to the lack of a standard against which the completeness of the data received from producers could be assessed (Shephard, 2006). Retrospective analysis of the data on LAHVA indicated that respiratory symptoms in dogs occur approximately 10 days earlier than is the case for humans, and that detection of eye-inflammation in dogs would also have served as a sentinel for humans in a case of wastewater contamination (Maciejewski et al., 2007). Also retrospectively, Odoi (2009) showed that an outbreak of abortion in mares could have been detected 6 days earlier.

Discussion

A pre-conference workshop at the ISVEE meeting in 2009 discussed the development and application of methods for effective surveillance in livestock populations (Hoinville, et al., 2009). Syndromic surveillance systems can meet several of the surveillance goals proposed during that meeting, including: comprehensive coverage of many diseases within a single monitoring system, detection of emerging diseases, maximizing the value of existing data sources, integration of public health with veterinary data, development of new analytical methods, technological innovation, flexibility in the type of data available and desired system outcome, encouraging stakeholder participation, and an increase in negative reporting. This paper has discussed how syndromic surveillance in animal populations can help meet many of these goals.

Only systems that explicitly address outbreak detection based on systematic monitoring of animal population data have been included in this review. However, there is little doubt that disease control capabilities have also been enhanced by systems for disease monitoring which adopt novel approaches to data sharing, integration and visualization. The authors recommend the following examples to those readers interested in exploring the broader application of information systems to veterinary surveillance: the Michigan equine monitoring system (Kaneene, 1997); the Pathman project (Durr and Estland, 2004); the Rapid Analysis & Detection of Animal-related Risks (RADAR) (Smith, et al., 2006a; Paiba, et al., 2007); the FMD BioPortal System (Perez et al., 2009); geographical information systems for the surveillance of bluetongue in Australia (Cameron, 2004) and Italy (Conte et al., 2005); the swine industry initiative for disease data sharing in Minnesota (Davies et al.,2007); GLiPHA (Clements et al.; 2002); and the papers of Egbert (2004) and Durr & Estland (2004).

The initiatives reviewed have made use of several sources of clinical and diagnostic data in order to implement syndromic surveillance system in veterinary medicine.

Due to the lack of commonly adopted data standards, each syndromic surveillance system implemented in veterinary medicine to date has tended to develop and validate their own classification system. As long as common standards are not adopted, new systems will have limited capability to take advantage of the progress made by existing systems. While each method may be valid within its own architecture, the use of standards would enable data integration across heterogeneous datasets, and allow comparisons among geographical locations and veterinary practices over time (McIntyre, et al., 2003).

As a result of the current limitations, most efforts to date have been directed towards developing animal health data collection strategies, analyzing historical data already available for their potential to support syndromic surveillance, or solving problems of data classification and integration; rather than focusing on the development of automated syndromic analysis. The concentration of effort on these early stages of development is evident when one considers the relatively plentiful supply of papers dealing with potential data sources, in contrast to those reporting the use of various aberration detection algorithms, illustrating systems outputs or evaluating operational syndromic surveillance systems. In fact, none of the listed initiatives contain all the components which characterize the more mature systems for early disease detection in public health. In consequence, the term “syndromic surveillance” has been applied throughout this review in a rather loose manner, since the term has been coined in reference to early disease detection systems based on the systematic monitor or large amount of pre-diagnosis data. Not all of the systems reviewed here are strictly based on the classification of data into syndromes.

Despite differences in structure, all of the initiatives reviewed are making efforts to improve the quantity, quality and speed of information extraction from animal health data, and the lessons learned will support further advances in the development of the field of syndromic animal surveillance.

Many of the systems developed in veterinary medicine have attempted to solve data limitations by encouraging passive notification of cases or transfer of clinical data, directly from farmers, or by enrolling private veterinarians in the system. All these systems are dealing with sustainability issues. Information feedback or financial incentives to participating veterinarians have been used as strategies to sustain participation, but in general the lesson learned is that if data transfer demands extra effort from participants, long term sustainability may not be possible.

Given the current barriers, diagnostic laboratories appear to provide a readily available source of data for syndromic surveillance in animal health. The less timely nature of laboratory data is compensated, in veterinary medicine, by its greater specificity when compared to clinical data. In addition there is reasonable availability of current and historical laboratory data in digital format, both for companion and livestock animals. In companion animal medicine, where computerization of records is already common, investments in the use of data standards will increase the value of clinical data for syndromic surveillance use. In livestock health, however, the use of laboratory data remains the most readily available and reliable source of electronic, continuously recorded data. Laboratories are typically centralized and can cover large geographical areas. However, it is also important that investment be made in data standardization within the livestock laboratory sector as this would allow for the integration of databases across broader geographical areas.

The expansion of syndromic surveillance in public health has fomented great improvements in the development and adaptation of aberration detection algorithms for use in health data, as demonstrated for instance by the work of several teams within the BioALIRT project, which has been sponsoring research on improving the timeliness of outbreak detection since 2001(Wagner, et al., 2006). Implementation of syndromic surveillance in public health has also resulted in the expansion of the field of infectious disease informatics. Several teams have documented their experiences in creating information systems and provided guidelines on the architecture necessary to conduct prospective, real-time surveillance (Tsui, et al., 2003; Lombardo and Buckeridge, 2007; Zeng, et al., 2011). Therefore, as quality animal health data become more readily available, the development of veterinary syndromic surveillance will be able to take advantage of the statistical and computational advances made in the public health field.

In all syndromic surveillance systems the primary output is some form of alarm in the event of aberration detection. However, syndromic surveillance is not a replacement for traditional surveillance (Pavlin, et al., 2003), and therefore once an alarm is triggered by the detection algorithm it must be reviewed by epidemiologists (Buehler, et al., 2004). The design of the system should take into account the information that will be needed when making subsequent decisions and the outputs of the system, in case of any alarm, should contain all the information available from the syndromic dataset that may be of value (Wagner, 2003). The investment in syndromic surveillance may be wasted if, once a decision is made, the epidemiologist cannot count on an investigation team ready to respond to an alarm; the process for aberration follow-up should therefore be described as part of the syndromic surveillance system design (Stone, 2007).

Syndromic surveillance systems can confer benefits which go beyond the detection of true alarms (Ward and Carpenter, 2000b). They can support additional goals associated with animal health surveillance, such as: monitoring disease trends; facilitating the control of disease or infection; supporting claims for freedom from disease or infection; providing data for use in risk analysis, for animal and/or public health purposes; and substantiating the rationale for sanitary measures (OIE, 2010). In practice most systems designed for early detection of disease, due to the longitudinal nature of their data collection, will also contribute to situational awareness, building a foundation for epidemiological research and hypotheses generation and testing, and thus provide support for evidence-based medicine. A number of the systems reviewed here intend to deliver the information extracted from the syndromic surveillance process to the public (Tierney, et al., 2009) or to participating veterinarians (McIntyre, et al., 2003; DeGroot, 2005; Glickman, et al., 2006).

The development of the field of syndromic animal surveillance progressively enhances the animal health community's ability to detect and to respond to outbreaks. The automated and continuous collection of animal health data also facilitates the integration with public health systems, and represents a further step towards *One Medicine*. A recent review (Vrbova et al, 2010) noted that there have been on-going efforts to integrate human and animal data in surveillance initiatives since 2000. However, as pointed out in that review, none of the integrated systems have yet been evaluated and there are several barriers to data sharing between the two domains. Ethical and privacy concerns are not as restrictive in animal health data, as they can be in public health. Nevertheless, barriers to data sharing, mainly related to data ownership and proprietary information, and barriers to data integration due to the lack of commonly adopted standards continue to impair the communication within and between animal and public health data sources.

The longer experience of public health systems with syndromic surveillance has indicated that the cost of system maintenance and response to false alarms can only be justified by the system's contribution to more than event detection (Chretien, et al. 2009). In veterinary medicine, the progress in the development of early warning systems has stimulated the review, improvement and expansion of data collection methods in animal health, though sustainability issues are now evident for systems based on voluntary notification or passive data transfer from veterinarians.

While in public health, syndromic surveillance can be based on sales of over-the-counter medicine, or emergency visits, in animal health the earliest type of syndromic data available is clinical. Several initiatives have shown that there is potential for clinical data to be used in the continuous monitoring of animal populations, but implementations in real-time still depends primarily on finding sustainable ways to collect and process clinical data from practitioners. To achieve this, investment is needed in systems which enable information flow from livestock practitioners to surveillance teams, and financial incentives are often necessary to guarantee practitioner engagement. Clinical data from companion animal medicine is more often computerized, and offers greater potential, but authors have indicated problems concerning data sharing, and unreliable flow of data from providers to the surveillance teams.

Until investments have been made to solve these issues, laboratory data continues to offer the greatest potential for syndromic surveillance in veterinary medicine. Similar problems to those associated with clinical computerized data such as the need for data sharing agreements and investments in data classification to allow integrations across different plataforms, apply to laboratory data. However, until data integration problems are solved, monitoring each single source of laboratory data may still offer geographical coverage greater than any single source of clinical data. Systems implemented directly with the data provider will minimize data flow issues.

This review has illustrated that the field of syndromic surveillance in veterinary medicine is incipient, but fast growing. As syndromic animal surveillance systems have developed over the past decade, limitations in the data available on animal health have become apparent. The lack of automated data collection limited opportunities for implementation of systematic monitoring systems; lack of computerized records limited automated analysis;

and the lack of standards limited the integration across multiple databases. The costs of overcoming these barriers and implementing real-time monitoring systems are justified by their utility. Syndromic surveillance systems offer opportunities that go beyond early detection of diseases, providing information to aid planning and policy development.

Acknowledgements

This work was supported by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) through an Animal Health Strategic Investment (AHSI) grant.

Conflict of Interest

No conflict of interest to declare.

References

________. National animal disease information service. UK veterinary sentinel practice network. 2010. Accessed on September 4th, 2010. Available at: http://www.nadis.org.uk.

Amezcua, M.R., Pearl, D.L., Friendship, R.M., McNab, W.B., 2010. Evaluation of the Ontario swine veterinary-based surveillance system implemented for swine. Can. J. Vet. Res., 74:241-251.

Ashford, D.A., Gomez, T.M., Noah, D.L., Scott, D.P., Franz, D.R., 2000. Biological terrorism and veterinary medicine in the united states. J. Am. Vet. Med. Assoc. 217, 664-667.

Babin, S.M., casper, J., Witt, C., Lewis, S.L.H., Wojcik, R.A., Magruder, S.F., Burkom, H.S., Weitzel, J., Lombardo, J., 2003. Early detection of possible bioterrorist events using sentinel animals. The 131st Annual Meeting of APHA, November 15-19, San Francisco, USA.

Bartels, C.J.M., Kock, P., Middelesch, H., Wouda, W., van Wuijckhuise, L., van der Zwaag, H. 2006. Cattle Health Surveillance in the Netherlands; How to Interpret Anedoctal and Census Data. Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia

Bartlett, P.C., Kaneene, J.B., Kirk, J.H., Wilke, M.A., Martenuik, J.V., 1986. Development of a computerized dairy herd health data base for epidemiologic research. Prev. Vet. Med. 4, 3-14.

Bartlett, P.C., Van Buren, J.W., Neterer, M., Zhou, C., 2010. Disease surveillance and referral bias in the veterinary medical database. Prev. Vet. Med. 94, 264-271.

Benneyan, J.C., 1998. Statistical quality control methods in infection control and hospital epidemiology, part I: Introduction and basic theory. Infect. Control Hosp. Epidemiol. 19, 194-214.

Benschop, J., Stevenson, M.A., Dahl, J., Morris, R.S., French, N.P., 2008. Temporal and longitudinal analysis of danish swine salmonellosis control programme data: Implications for surveillance. Epidemiol. Infect. 136, 1511-1520.

Berezowski, J., Checkley, S., Clarke, R., Patel, J., Renter, D., 2006. The Alberta veterinary surveillance network : Part 2, veterinary practice surveillance. Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia.

Bravata, D.M., McDonald, K.M., Smith, W.M., Rydzak, C., Szeto, H., Buckeridge, D.L., Haberland, C., Owens, D.K., 2004. Systematic review: Surveillance systems for early detection of bioterrorism-related diseases. Ann. Intern. Med. 140, 910-922.

Brianti, E., Drigo, M., Zirilli, V., Poglayen, G., Giannetto, S., 2007. Use of a health information system (HIS) for the epidemiological surveillance of leishmaniasis in urban areas. Vet. Res. Commun. 31 Suppl 1, 213-215.

Brightling, P, Larcombe, MT, Blood, BC & Kennedy, PC 1998, 'Development and use of BOVID-3, an expert system for veterinarians involved in diagnosis, treatment and prevention of diseases of cattle', Bovine Practitioner, vol. 32, no. 2, pp. 46-49

Buckeridge, D.L., 2007. Outbreak detection through automated surveillance: A review of the determinants of detection. J. Biomed. Inform. 40, 370-379.

Buckeridge, D.L., Burkom, H., Campbell, M., Hogan, W.R., Moore, A.W., 2005. Algorithms for rapid outbreak detection: A research synthesis. J. Biomed. Inform. 38, 99-113.

Buckeridge, D.L., Okhmatovskaia, A., Tu, S., O'Connor, M., Nyulas, C., Musen, M.A., 2008. Predicting outbreak detection in public health surveillance: Quantitative analysis to enable evidence-based method selection. AMIA. Annu. Symp. Proc. 76-80.

Buehler, J.W., Hopkins, R.S., Overhage, J.M., Sosin, D.M., Tong, V., CDC Working Group, 2004. Framework for evaluating public health surveillance systems for early detection of outbreaks: Recommendations from the CDC working group. MMWR Recomm Rep. 53, 1-11.

Cameron, A.R., 2004. Data management and analysis systems for bluetongue virus zoning in Australia. Vet. Ital. 40, 365-368.

Canadian Food Inspection Agency, 2009. The Canadian Animal Health Surveillance Network (CAHSN). Accessed on August 23rd, 2010. Available at: http://www.inspection.gc.ca/english/anima/surv/cahsnrcsze.shtml.

Carpenter, T.E., 2001. Methods to investigate spatial and temporal clustering in veterinary epidemiology. Prev. Vet. Med. 48, 303-320.

Carpenter, T.E., Chriel, M., Greiner, M., 2007. An analysis of an early-warning system to reduce abortions in dairy cattle in denmark incorporating both financial and epidemiologic aspects. Prev. Vet. Med. 78, 1-11.

Centers for Disease Control and Prevention (CDC), 2006. Annotated bibliography for syndromic surveillance. Accessed on March 26th, 2010. Available at: http://www.cdc.gov/ncphi/disss/nndss/syndromic.htm.

Checkley, S., Berezowski, J., Annett, C., Bystrom, J., Clarke, R., Miller, B., Patel, J., Perry, A., Renter, D., Snyder, C., 2006. The Alberta Veterinary Surveillance Network : Part 1, general Description/Overview. Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia

Checkley, S., Berezowski, J., Patel, J., Clarke, R., Peters, D., Keenliside, J., Miller, B., Bystrom, J., Annett, C., Jamal, I., Qu, Y., Turner, S., Herntier, T., 2009. Emerging disease surveillance of livestock through the alberta veterinary surveillance network. Proceedings of the 12th International Symposium on Veterinary Epidemiology and Economics, 2009. Durban, South Africa.

Chen, H., Fuller, S.S., Friedman, C., Hersh, W., 2005. Knowledge Management, Data Mining, and Text Mining in Medical Informatics. In: Chen, H., Fuller, S.S., Friedman, C., Hersh, W. (Eds.), Knowledge Management and Data Mining in Biomedicine. Springer.

Chretien, J.P., Tomich, N.E., Gaydos, J.C., Kelley, P.W. 2009 Real-Time Public Health Surveillance for Emergency Preparedness. Am J Public Health. 99(8):1360-3.

Clements, A.C., Pfeiffer, D.U., Otte, M.J., Morteo, K., Chen, L., 2002. A global livestock production and health atlas (GLiPHA) for interactive presentation, integration and analysis of livestock data. Prev. Vet. Med. 56, 19-32.

Conte, A., Colangeli, P., Ippoliti, C., Paladini, C., Ambrosini, M., Savini, L., Dall'Acqua, F., Calistri, P., 2005. The use of a web-based interactive geographical information system for the surveillance of bluetongue in Italy. Rev. Sci. Tech. 24, 857-868.

Davies, P.R., Wayne, S.R., Torrison, J.L., Peele, B., de Groot, B.D., Wray, D., 2007. Real-time disease surveillance tools for the swine industry in Minnesota. Vet. Ital. 43, 731-738.

Davis, R.G., 2004a. The ABCs of bioterrorism for veterinarians, focusing on category A agents. J. Am. Vet. Med. Assoc. 224, 1084-1095.

Davis, R.G., 2004b. The ABCs of bioterrorism for veterinarians, focusing on category B and C agents. J. Am. Vet. Med. Assoc. 224, 1096-1104.

De Vries, A., Reneau, J.K., 2010. Application of statistical process control charts to monitor changes in animal production systems. J. Anim. Sci. 88, E11-24.

DeGroot, B., 2005. The rapid syndrome validation project for animals - augmenting contact with the network of accredited veterinarians. NAHSS Outlook April.

Doherr, M.G., Audige, L., 2001. Monitoring and surveillance for rare health-related events: A review from the veterinary perspective. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 356, 1097-1106.

Durr, P.A., Eastland, S., 2004. Use of web-enabled databases for complex animal health investigations. Rev. Sci. Tech. 23, 873-884.

Egbert, M., 2004. Web-based disease tracking: A West Nile virus example. 2010, Accessed on August 23rd. Available at: http://proceedings.esri.com/library/userconf/proc04/docs/pap1131.pdf.

Elbers, A.R.W., Loeffen, W.L.A., Dekker, A., Koch, G., Van Rooij, E.M.A., 2006. Substantial improvement of early detection of notifiable animal diseases: A call for unorthodox changes. Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia

Engle, M., 2006. The value of an "early warning" surveillance system for emerging diseases. accessed at: http://www.pork.org/NewsAndInformation/News/docs/MEngle.pdf. in: Weber, W.D. development of an animal health monitoring system based on slaughter condemnation data. Proceedings of the 8th conference of the international society for disease surveillance, 2009. Miami, USA.

Fricker, R.D., 2006. Syndromic surveillance. an article for the encyclopedia for quantitative risk assessment. draft. Accessed on April 23rd, 2010. Available at: http://faculty.nps.edu/rdfricke/docs/SyndromicSurveillance.pdf.

Gibbens, J.C., Robertson, S., Willmington, J., Milnes, A., Ryan, J.B., Wilesmith, J.W., Cook, A.J., David, G.P., 2008. Use of laboratory data to reduce the time taken to detect new diseases: VIDA to FarmFile. Vet. Rec. 162, 771-776.

Glickman, L.T., Moore, G.E., Glickman, N.W., Caldanaro, R.J., Aucoin, D., Lewis, H.B., 2006. Purdue university-banfield national companion animal surveillance program for emerging and zoonotic diseases. Vector Borne Zoonotic Dis. 6, 14-23.

Gluck Equine reseacrh Center, Research in the department of veterinary science. 2010, Accessed on August 8th, 2010. Available at http://www.ca.uky.edy/Gluck/ResearchDVS.asp.

Gobar, G.M., Case, J.T., Kass, P.H., 1998. Program for surveillance of causes of death of dogs, using the internet to survey small animal veterinarians. J. Am. Vet. Med. Assoc. 213, 251-256.

Goplin, J., Benz, M., 2007. North dakota electronic animal health surveillance system. Advances in Disease Surveillance 4.

Henning, K.J., 2004. What is syndromic surveillance? MMWR 53 Suppl, 5-11.

Hohle, M., Paul, M., Held, L., 2009. Statistical approaches to the monitoring and surveillance of infectious diseases for veterinary public health. Prev. Vet. Med. 91, 2-10.

Hoinville, L., Ellis-Iversen, J., Vink, D., Watson, E., Snow, L., Gibbens, J., 2009. Discussing the development and application of methods for effective surveillance in livestock populations - report of a workshop held prior to the ISVEE conference, Durban, South Africa, August 2009.

INRA (National Institute for Agricultural Research), Context for studying emerging animal diseases. Accessed on August 13th, 2010. Available at: http://www.inra.fr/maladies-emergentes.

Ivanov, O., Wagner, M.M., Chapman, W.W., Olszewski, R.T., 2002. Accuracy of three classifiers of acute gastrointestinal syndrome for syndromic surveillance. AMIA. Annu. Symp. Proc. 345-349.

Johnson, G.D., Eidson, M., Schmit, K., Ellis, A., Kulldorff, M., 2006. Geographic prediction of human onset of West Nile virus using dead crow clusters: An evaluation of year 2002 data in New York state. Am. J. Epidemiol. 163, 171-180.

Kaneene, J.B., Saffell, M., Fedewa, D.J., Gallagher, K., Chaddock, H.M., 1997. The Michigan equine monitoring system. I. design, implementation and population estimates. Prev. Vet. Med. 29, 263-275.

Kleinman, K.P., Abrams, A.M., 2006. Assessing surveillance using sensitivity, specificity and timeliness. Stat. Methods Med. Res. 15, 445-464.

Kleinman, K.P., Abrams, A.M., 2008. Assessing the utility of public health surveillance using specificity, sensitivity, and lives saved. Stat. Med. 27, 4057-4068.

Kulldorff, M., 1997. A spatial scan statistics. Communications in Statistics - Theory and Methods 26, 1481-1496.

Kulldorff, M., 2006. SaTScan(TM) user guide. 2010. Accessed on August 2nd, 2010. Available at: http://www.satscan.org/.

Leblond, A., Hendrikx, P., Sabatier, P., 2007. West nile virus outbreak detection using syndromic monitoring in horses. Vector Borne Zoonotic Dis. 7, 403-410.

Lober, W.B., Trigg, L., Karras, B., 2004. Information system architectures for syndromic surveillance. MMWR 53 Suppl, 203-208.

Lombardo, J.S., Buckeridge, D.L., 2007. Disease Surveillance - a Public Health Informatics Approach. John Wiley & Sons, New Jersey.

Lotze, T., Murphy, S.P., Shmueli, G., 2007. Preparing biosurveillance data for classic monitoring. Advances in Disease Surveillance 2, 55.

Ma, H., Rolka, H., Mandl, K., Buckeridge, D., Fleischauer, A., Pavlin, J., 2005. Implementation of laboratory order data in BioSense early event detection and situation awareness system. MMWR 54 Suppl, 27-30.

Maciejewski, R., Tyner, B., Jang, Y., Zheng, C., Nehme, R., Ebert, D.S., Cleveland, W.S., Ouzzani, M., Grannis, J., Glickman, L.T., 2007. LAHVA: Linked animal-human health visual analytics. Advances in Disease Surveillance 4.

Mandl, K.D., Overhage, J.M., Wagner, M.M., Lober, W.B., Sebastiani, P., Mostashari, F., Pavlin, J.A., Gesteland, P.H., Treadwell, T., Koski, E., Hutwagner, L., Buckeridge, D.L., Aller, R.D., Grannis, S., 2004a. Implementing syndromic surveillance: A practical guide informed by the early experience. J. Am. Med. Inform. Assoc. 11, 141-150.

Mandl, K.D., Reis, B., Cassa, C., 2004b. Measuring outbreak-detection performance by using controlled feature set simulations. MMWR Morb. Mortal. Wkly. Rep. 53 Suppl, 130-136.

Marshall, M.J., Roger, P.A., Bashiruddin, J.B., 2006. Making better use of technological advances to meet stakeholder needs. Rev. Sci. Tech. 25, 233-251.

McIntyre, L.H., Davies, P.R., Alexander, G., O'Leary, B.D., Morris, R.S., Perkins, N.R., Jackson, R., Poland, R., 2003. VetPAD - veterinary practicioner aided disease surveillance system. Proceedings of the 10th Symposium of the International Society for Veterinary Epidemiology and Economics, 2003. Vina del Mar, Chile.

McKendrick, I.J.; Gettinby, G.; Gu, Y.; Peregrine, A.; Revie, C. (1995) Hybrid Information Systems for Agriculture: The Case of Cattle Trypanosomiasis in Africa. Outlook on Agriculture, 23: 261-267.

McNamara, T., 2007. The role of zoos in biosurveillance. International Zoo Yearbook 41, 12-15.

Moore, G.E., Ward, M.P., Dhariwal, J., Wu, C.C., Glickman, N.W., Lewis, H.B., Glickman, L.T., 2004. Development of a national companion animal syndromic surveillance system for bioterrorism. Proceedings of GISVET 2004. Guelph, Canada.

Mork, M., Lindberg, A., Alenius, S., Vagsholm, I., Egenvall, A., 2009. Comparison between dairy cow disease incidence in data registered by farmers and in data from a disease-recording system based on veterinary reporting. Prev. Vet. Med. 88, 298-307.

Mostashari, F., Kulldorff, M., Hartman, J.J., Miller, J.R., Kulasekera, V., 2003. Dead bird clusters as an early warning system for west nile virus activity. Emerg. Infect. Dis. 9, 641-646.

Nebraska Department of Agriculture, Livestock emergency disease response system. Accessed on August 18th, 2010. Available at: http://www.agr.state.ne.us/division/bai/ledrs.htm.

North Carolina Department of Agriculture and Consumer Services, Multi-hazard threat database (MHTD). Accessed on August 18th, 2010. Available at: http://www.ncagrgis.com/ncmhtd_app/default.aspx.

Odoi, A., Carter, C.N., Riley, J.W., Smith, J.L., Dwyer, R.M., 2009. Application of an automated surveillance-data-analysis system in a laboratory-based early-warning system for detection of an abortion outbreak in mares. Am. J. Vet. Res. 70, 247-256.

OIE. World Organization for Animal Health. 2010. Terrestrial Animal Health Code. Accessed on August 18th, 2010. Available at: http://www.oie.int/eng/normes/en_mcode.htm?e1d10.

Paiba, G.A., Roberts, S.R., Houston, C.W., Williams, E.C., Smith, L.H., Gibbens, J.C., Holdship, S., Lysons, R., 2007. UK surveillance: Provision of quality assured information from combined datasets. Prev. Vet. Med. 81, 117-134.

Pavlin, J.A., Mostashari, F., Kortepeter, M.G., Hynes, N.A., Chotani, R.A., Mikol, Y.B., Ryan, M.A., Neville, J.S., Gantz, D.T., Writer, J.V., Florance, J.E., Culpepper, R.C., Henretig, F.M., Kelley, P.W., 2003. Innovative surveillance methods for rapid detection of disease outbreaks and bioterrorism: Results of an interagency workshop on health indicator surveillance. Am. J. Public Health 93, 1230-1235.

Perez, A.M., Zeng, D., Tseng, C.J., Chen, H., Whedbee, Z., Paton, D., Thurmond, M.C., 2009. A web-based system for near real-time surveillance and space-time cluster analysis of foot-and-mouth disease and other animal diseases. Prev. Vet. Med. 91, 39-45.

Rabinowitz, P., Gordon, Z., Chudnov, D., Wilcox, M., Odofin, L., Liu, A., Dein, J., 2006. Animals as sentinels of bioterrorism agents. Emerg. Infect. Dis. 12, 647-652.

Robotham, J., Green, L.E., 2004. Pilot study to investigate the feasibility of surveillance of small animals in the UK. J. Small Anim. Pract. 45, 213-218.

Rolka, H., Burkom, H., Cooper, G.F., Kulldorff, M., Madigan, D., Wong, W.K., 2007. Issues in applied statistics for public health bioterrorism surveillance using multiple data streams: Research needs. Stat. Med. 26, 1834-1856.

Salman, M.D. (Ed.), 2003. Animal Disease Suvrveillance and Survey Systems: Methods and Application. Blackwell Publishing Professional, Iowa, USA.

Schwabe, C., 1982. The current epidemiological revolution in veterinary medicine. part I. Prev. Vet. Med. 1, 5-15.

Shaffer, L., Funk, J., Rajala-Schultz, P., Wallstrom, G., Wittum, T., Wagner, M., Saville, W., 2007. Early Outbreak Detection using an Automated Data Feed of Test Orders from a Veterinary Diagnostic Laboratory. In: Zeng, D. (Ed.), BioSurveillace 2007. , pp. 79-90.

Shaffer, L.E., 2007. Using pre-diagnostic data from veterinary laboratories to detect disease outbreaks in companion animals. PhD dissertation. Ohio State University, USA.

Shephard, R.W., 2006. The development of a syndromic surveillance system for the extensive beef cattle producing regions of australia. PhD Dissertation. University of Sidney, Australia.

Shephard, R.W., Toribio, J.A., Cameron, A.R., Thomson, P., Baldock, F.C., 2006a. Development of the bovine syndromic surveillance system (BOSSS). Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia.

Shephard, R.W., Toribio, J.A., Cameron, A.R., Thomson, P., Baldock, F.C., 2006b. Incorporating the bovine syndromic surveillance system (BOSSS) within an animal health surveillance network. Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia.

Shmueli, G.B., H., 2010. Statistical challenges facing early outbreak detection in biosurveillance. Technometrics 52, 39-51.

Shuai, J., Buck, P., Sockett, P., Aramini, J., Pollari, F., 2006. A GIS-driven integrated real-time surveillance pilot system for national west nile virus dead bird surveillance in canada. Int. J. Health. Geogr. 5, 17.

Sintchenko, V., Gallego, B., 2009. Laboratory-guided detection of disease outbreaks: Three generations of surveillance systems. Arch. Pathol. Lab. Med. 133, 916-925.

Smith, L., Paiba, G., Lysons, R., Gibbens, J., 2006a. UK surveillance: Rapid analysis & detection of animal-related risks (RADAR) - from concept to reality. Proceedings of the 11th International Symposium on Veterinary Epidemiology and Economics, 2006. Cairns, Australia.

Smith, K., Martinez, A., Craddolph, R., Erickson, H., Andresen, D., Warren, S., 2006b. An integrated cattle health monitoring system. Conf. Proc. IEEE Eng. Med. Biol. Soc. 1, 4659-4662.

Smith-Akin, K.A., Bearden, C.F., Pittenger, S.T., Bernstam, E.V., 2007. Toward a veterinary informatics research agenda: An analysis of the PubMed-indexed literature. Int. J. Med. Inform. 76, 306-312.

Sosin, D.M., DeThomasis, J., 2004. Evaluation challenges for syndromic surveillance--making incremental progress. MMWR 53 Suppl, 125-129.

Stone, M., 2007. The potential for exotic disease syndromic surveillance within veterinary laboratory submissions data. Proceedings of the Epidemiology and Animal Health Management Branch of the NZVA 2007. 91-102.

Tierney, A., Coyne, K.P., Dawson, S., Gaskell, R.M., Bryan, J., Newton, R., Radford, A.D. 2009. SAVSNET. Accessed on August 23rd, 2010. Available at: http://www.bsava.com/News/CongressNews/SAVSNET/tabid/270/Default.aspx.

Tsui, F.C., Espino, J.U., Dato, V.M., Gesteland, P.H., Hutman, J., Wagner, M.M., 2003. Technical description of RODS: A real-time public health surveillance system. J. Am. Med. Inform. Assoc. 10, 399-408.

University of Liverpool, The SAVSNET surveillance project. At: http://www.liv.ac.uk/savsnet/The_Project/index.htm

Van Metre, D.C., Barkey, D.Q., Salman, M.D., Morley, P.S., 2009. Development of a syndromic surveillance system for detection of disease among livestock entering auction market. J. Am. Vet. Med. Assoc. 234, 658-664

Vourc'h, G., Barnouin, J., 2003. How to improve the detection of animal emerging diseases? A two-level (veterinarian/farmer) approach based on an internet-oracle database. Proceedings of the 10th Symposium of the International Society for Veterinary Epidemiology and Economics, 2003. Vina del Mar, Chile.

Vourc'h, G., Bridges, V.E., Gibbens, J., De Groot, B., McIntyre, L., Poland, R., Barnouin, J., 2006. Detecting emerging diseases in farm animals through clinical observations. Emerg. Infect. Dis. 12, 204-210.

Vrbova, L; Stephen, C.; kasman, N.; Boehnke, R.; Doyle-Waters, M.; Chablitt-Clark, A.; Gobson, B.; FitzGerald, M.; Patrick, D.M. 2010. Systematic review of Surveillance Systems for Emerging Zoonoses. Transbound. Emerg. Dis, 57: 154-161.

Wagner, M.M., Tsui, F.C., Espino, J.U., Dato, V.M., Sittig, D.F., Caruana, R.A., McGinnis, L.F., Deerfield, D.W., Druzdzel, M.J., Fridsma, D.B., 2001b. The emerging science of very early detection of disease outbreaks. J. Public Health Manag. Pract. 7, 51-59.

Wagner, M.M., 2003. Models of computer-based outbreak detection. The Reference Librarian 38, 343.
Wagner, M.M., Moore, A.W., Aryel, R.M., 2006. Handbook of Biosurveillance. Elsevier Academic Press.

Ward, M.P., Carpenter, T.E., 2000a. Analysis of time-space clustering in veterinary epidemiology. Prev. Vet. Med. 43, 225-237.

Ward, M.P., Carpenter, T.E., 2000b. Techniques for analysis of disease clustering in space and in time in veterinary epidemiology. Prev. Vet. Med. 45, 257-284.

Weber, W., Development of an animal health monitoring system based on slaughter condemnation data. Proc of the 8th Annual Conference of the International Society for Disease Surveillance, 2009. Miami, USA.

Wurtz, R., Popovich, M., 2002. Animal disease surveillance: A framework for supporting disease detection in public health.Accessed on August 16th, 2010. Available at: http://www.stchome.com/media/white_papers/WHP027A.pdf.

Yahav, I., Shmueli, G., 2007. Algorithm Combination for Improved Performance in Biosurveillance Systems. In: Zeng, D. (Ed.), BioSurveillace 2007. , pp. 79-90.

Zeng, D., Chen, H., Lynch, C., Eidson, M., Gotham, I., 2005. Infectious Disease Informatics and Outbreak Detection. In: Chen, H., Fuller, S.S., Friedman, C., Hersh, W. (Eds.), Knowledge Management and Data Mining in Biomedicine. Springer.

Zeng, D., Chen, H., Castillo-Chavez, C., Lober, W.B., Thurmong, M., 2011. Infectious Disease Informatics and Biosurveillance. Springer.

Zhang, X., McEwen, B., Mann, E., Martin, W., 2005. Detection of clusters of salmonella in animals in Ontario from 1991 to 2001. Can. Vet. J. 46, 517-9, 522-3.

Zurbrigg, K., Blackwell, T., Do submissions to a veterinary diagnostic laboratory accurately reflect incidence or prevalence in the catchment area? Proceedings of the 8th Annual Conference of the International Society for Disease Surveillance, 2009. Miami, USA.

Table 1. Published initiatives in veterinary syndromic surveillance.

System/Ref	Location	Data	Focus	Animal type	Syndromes	Additional Notes
VetPAD (McIntyre et al., 2003)	New Zealand	Clinical data from practitioners	Surveillance of animal diseases	Livestock	Not aggregated (all clinical cases)	Use of handheld computers. Engages participation by providing software that contributes to practice management
Émergences (Vourch and Barnouin, 2003; INRA website)	France	Clinical data from practitioners	Early detection of emerging diseases	"Any species, any country, any disease" – focus on atypical cases and "model diseases"		Access through website, information includes follow-ups
Rapid Syndrome Validation Project for Animals (DeGroot, 2005)	United States	Clinical data from practitioners	Early detection of emerging diseases	Livestock	Focus on 6 groups of non-routine clinical syndromes	Various options for electronic transfer of data.
National cattle health surveillance system (Bartels et al. 2006)	The Netherlands	Unsolved cases by farmers or veterinarians	Early detection of emerging diseases	Cattle	Focus on individual diseases.	Data compilation and analyses is done weekly by a surveillance team, not auromated.
BOSS (Shephard, 2006)	Australia	Observations from producers and stock workers	Surveillance of animal diseases	Livestock	Software (BOVID) receives input concerning disease signs, and groups episodes into organ systems	Takes advantage of audience in daily contact with animals; Software to help producer with diagnosing the problem engages participation.
Purdue University-Banfield National Companion Animal Surveillance (Glickman et al., 2006)	United States	Clinical and laboratory data, direct transfer	Sentinels for zoonotic diseases; portal for evidence-based medicine	Companion Animals	Retrospective pilot: tick and flea vector activity; leptospitosis and ILI. Plan to focus on other syndromes	Makes use of already computerized and centralized database, allowing for daily automated analysis and great geographical coverage
Using pre-dx data from vet. lab. to detect disease outbreaks in companion animals (Shaffer, 2007)	United States	Laboratory microbiology tests submissions	Sentinels for zoonotic diseases	Companion Animals	Direct map of test orders into 11 syndromic groups	Makes use of already computerized database, allowing for daily automated analysis. Use of test orders is timelier than results.
LAHVA: Linked Animal-Human Health Visual Analytics (Maciejewski et al., 2007)	United States	Clinical data from human and pet hospitals	Sentinels for zoonotic diseases	Companion animals	Pilot: seasonal flu and wastewater contamination	Links in one tool the surveillance in public and animal health
FarmFile (Gibbens et al., 2008)	United Kingdom	Laboratory results	Surveillance of animal diseases	Livestock	Focus on "Diagnostic Not Reached" events to assess the	Not real-time, post-result based, but the focus on non-diagnosed

					risk of new diseases emergence	is innovative and adds values to the current surveillance
SAVSNET (Tierney et al., 2009)	United Kingdom	2 steps: 1) laboratory results; 2) real-time practice-based	Surveillance of animal diseases	Companion animals	Piloted using GIT	Focus on information sharing to benefit not only population medicine, but also individual, evidence-based medicine
Syndromic surveillance among livestock entering an auction market (Van Metre et al., 2009)	United States	Animal observations by veterinarian during auction market days	Surveillance of animal diseases	Livestock	Syndromic groups	Conceptually, can be implemented in handheld computers and give immediate feedback
Alberta Veterinary Surveillance Network (Checkley et al., 2009)	Canada	Disease and non-disease events from practitioners	Surveillance of animal diseases	Livestock	Syndromic groups	Part of a network supported also by pathologists and an investigation network
Ontario Swine Veterinary-based Surveillance System (OSVS) (Amezcua et al., 2010)	Canada	Clinical data from practitioners	Surveillance of animal diseases	Livestock	Summarized by body system and production effects	Formally evaluated to assess compliance, completeness, coverage and timeliness. Results show good acceptance.

Table 2. Peer reviewed publications investigating the potential of different datasets in implementing veterinary syndromic surveillance systems.

Study	**Location**	**Type of data**	**Goal**	**Animal type**	**Syndromes**	**Evaluation**
Salmonella outbreaks detection (Kosmider et al., 2006)	United Kingdom	Laboratory results	Public and animal health surveillance	Livestock	Salmonella Typhimurium cases	Assess the improvements needed in the data collection process to allow for the implementation of early detection systems
Laboratory data use for syndromic surveillance (Stone, 2007)	New Zealand	Laboratory submissions	Animal disease surveillance	Livestock	Test orders directly mapped into syndromic groups	Discusses the potential of the data for use in syndromic surveillance, and the inherent biases.
West Nile virus outbreak detection (Leblond et al., 2007)	France	Clinical data from practitioners	Sentinels for humans	Horses	Neurological clinical cases	Retrospective analysis of an outbreak: alarm could have been 4 weeks earlier
Early-warning system to reduce abortions in dairy cattle (Carpenter et al, 2009)	Denmark	Clinical data from practitioners	Animal disease surveillance	Livestock	Abortion	Evaluation of the system included costs of false alarms versus the cost of operating the system
Detection of abortion in mares (Odoi et al., 2009)	United States	Laboratory submission	Animal disease surveillance	Horses	Abortion	Retrospective analysis of an outbreak: Would have detected 1 week earlier

Figure 1. Schematic representation of the disease continuum in a population, and the surveillance opportunities according to population targeted, and type of data used. The scheme illustrates the proportions of subjects in each step of the disease process, for each of the three populations, in comparison to their initial population. The absolute number of livestock, companion animals and humans exposed to any given disease is not likely to be equal, and the top bars should be interpreted as the scaled total population. Proportions are illustrative only. Similarly, icons are not intended to represent a true count, but to illustrate comparative abundance.

Figure 2. Process of monitoring disease trends and detecting clusters using animal health data sources. Synd = Syndrome.

Figure 1

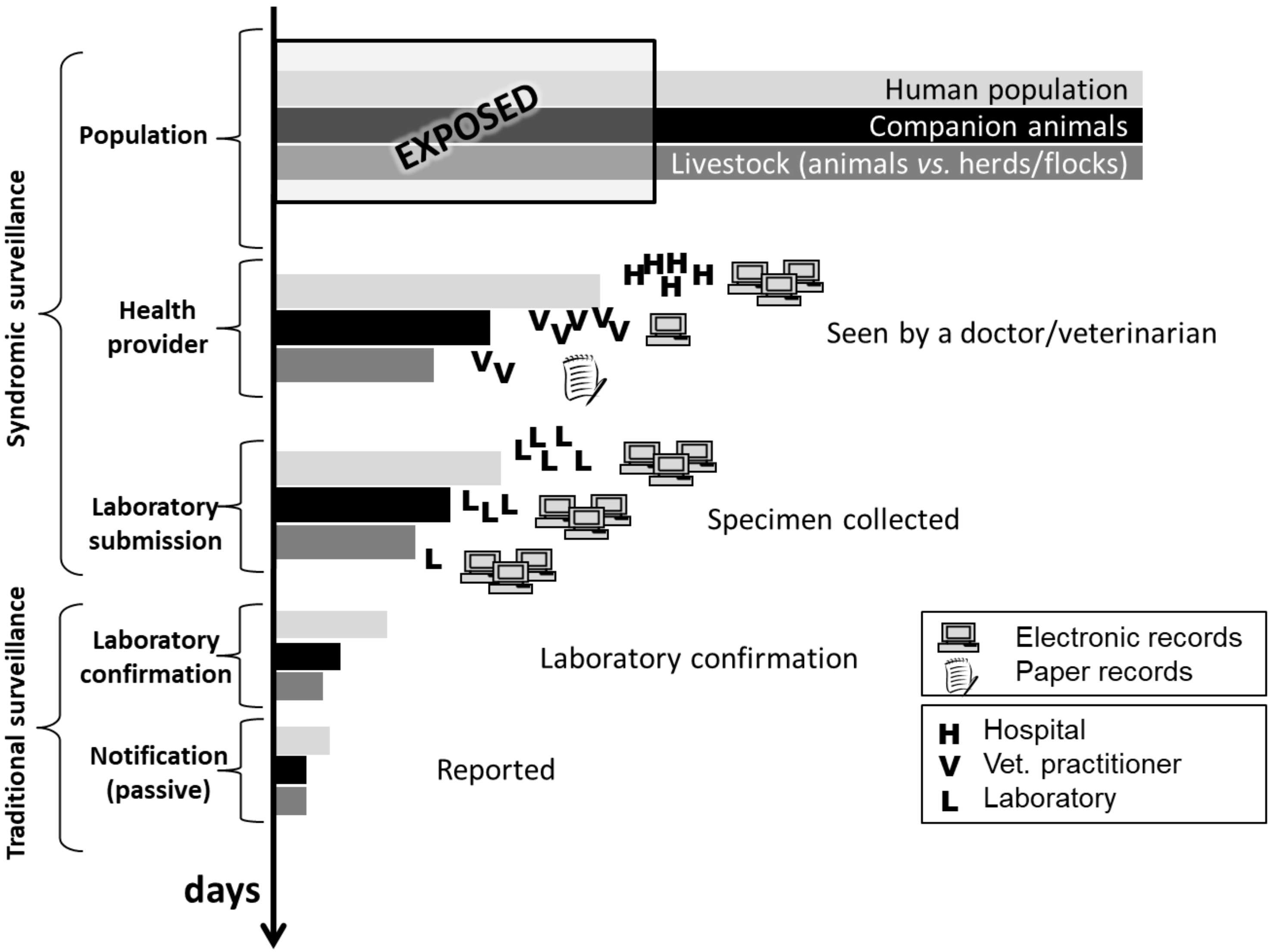
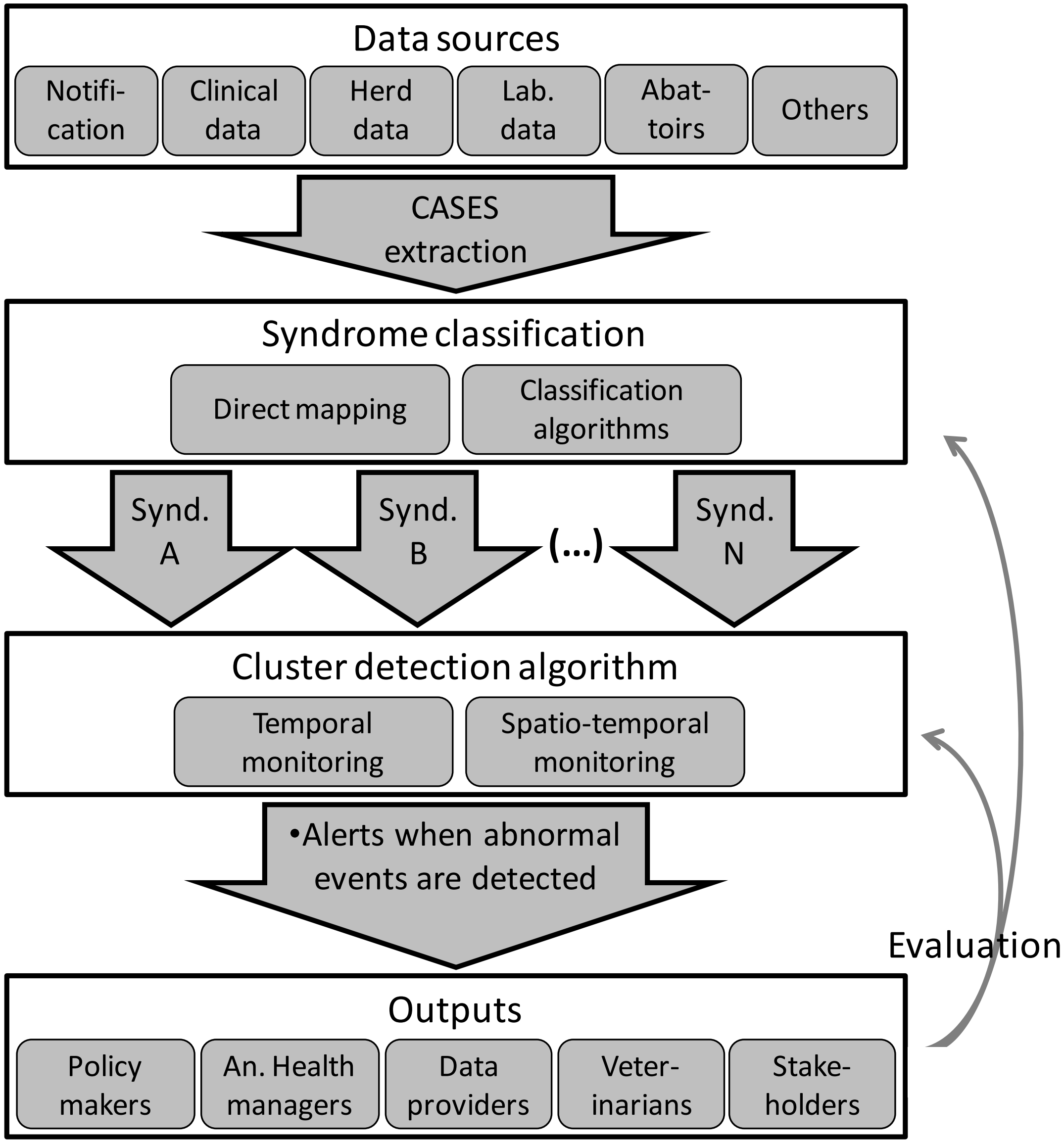

Syndromic surveillance
Traditional surveillance
Population
Health provider
Laboratory submission
Laboratory confirmation
Notification (passive)
days
EXPOSED
Human population
Companion animals
Livestock (animals *vs.* herds/flocks)
Seen by a doctor/veterinarian
Specimen collected
Laboratory confirmation
Reported
Electronic records
Paper records
H Hospital
V Vet. practitioner
L Laboratory

Figure 2


Data sources
Notifi-cation
Clinical data
Herd data
Lab. data
Abat-toirs
Others
CASES extraction
Syndrome classification
Direct mapping
Classification algorithms
Synd. A
Synd. B
(...)
Synd. N
Cluster detection algorithm
Temporal monitoring
Spatio-temporal monitoring
•Alerts when abnormal events are detected
Evaluation
Outputs
Policy makers
An. Health managers
Data providers
Veter-inarians
Stake-holders