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Monitoring and surveillance for rare health-related events: a review from the veterinary perspective

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Disease monitoring and surveillance systems (MOSSs) have become one of the major components of veterinary activity. Such systems are used to assess the existing levels of prevalence, the effectiveness of control programmes and, after disease eradication, to document the continued absence of disease from a given region or zone. With decreasing disease or infection prevalence, traditional approaches become less reliable and increasingly costly. The objective of this work was to summarize and discuss methodological issues related to veterinary (animal health) MOSSs. There are considerable inconsistencies in the use of the terms 'monitoring' and 'surveillance'. Passive as well as active MOSS have their disadvantages when used for rare health-related events such as emerging and re-emerging diseases. There is a need for evaluation and improvement of these approaches. Integrated systems that call for the use of several parallel surveillance activities seem to be the favoured approach, and analytical methods to combine MOSS data from various sources into a population prevalence, or probability of disease freedom, are under development. The health and safety of the animal and human generations depends on our continuous ability to detect, monitor and control newly emerging or re-emerging livestock diseases and zoonoses rapidly. Uniform surveillance definitions, sound scientifically based approaches that use the resources and data available, and a pool of researchers and veterinary public health officials with sufficient training in epidemiology, are critically important to handle this challenging task.

Keywords: surveillance; monitoring; rare disease; health-related events; veterinary services; monitoring and surveillance systems

1. INTRODUCTION

Disease surveillance, here used in a broad sense, has become one of the major components of veterinary activity and is a prerequisite for effective disease control (Anonymous 2000). The Centers for Disease Control (CDC) in the USA identified good surveillance and quick response as the first of four major goals in modern strategies for preventing emerging infectious diseases (Anonymous 1998). Bovine spongiform encephalopathy (BSE), an emerging new cattle disease (Wells *et al.* 1987) and subsequent detection of related diseases in other species, such as variant Creutzfeldt–Jakob Disease (vCJD) in humans (Will *et al.* 1996) and feline spongiform encephalopathy (FSE) in domestic cats (Wyatt *et al.* 1991), highlight the specific danger of agents that are able to cross the species barrier. The ProMED-mail electronic mailing list (<http://www.promedmail.org>) has repeating threads about emerging diseases in previously free areas, including:

- (i) classical swine fever (CSF) in the Netherlands and the UK;

- (ii) foot-and-mouth disease (FMD) in pigs in South Africa, cattle in Brazil and Argentina, and pigs, cattle and sheep in the UK;
- (iii) Rift Valley fever in cattle, sheep and humans in Yemen and Saudi Arabia;
- (iv) bluetongue (virus) disease in sheep in Bulgaria and Sardinia (Italy);
- (v) bovine tuberculosis in Queensland (Australia);
- (vi) West Nile virus fever in New York State (USA) and the Camargue (France).

These outbreaks underline the importance for reliable surveillance systems that are able to identify such emerging and re-emerging diseases rapidly, and to aid in their control. The Food and Agricultural Organization (FAO)—and other agencies—warns that the movement of people as well as animals and animal products for trade is a potent force in the emergence of diseases (FAO 2000), which has led to an increased spread of animal diseases across national borders (Wilson 1995). 'In an increasingly globalised world', the FAO statement reads, 'veterinary surveillance systems and services are vital to detect these emerging and re-emerging diseases early enough and to prepare contingency plans to contain those outbreaks'. Further examples of emerging infectious

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diseases and zoonoses in humans, including tuberculosis, *Escherichia coli* O157, *Salmonella*-related food poisoning, cryptosporidiosis, Ebola haemorrhagic fever, hantavirus pulmonary syndrome, influenza and *Helicobacter pylori* (Morse 1995; Murphy 1998; Walford & Noah 1999)—to name a few—underline this statement.

The objective of this work was to summarize and discuss methodological issues related to veterinary animal health surveillance. It was felt impossible to capture all aspects of that topic or to even attempt to represent both the veterinary and the human perspective. A decision was therefore made to focus on the main goals of veterinary disease surveillance, the most important sources for veterinary surveillance data, and the two most often used data collection approaches: 'passive' and 'active' surveillance. In addition, some insight is provided into newer approaches in surveillance system design and data analysis when applied to rare disease. The proceedings of the 9th Meeting of the International Society for Veterinary Epidemiology and Economics (ISVEE) that took place in August 2000 in Breckenridge, Colorado (USA), and recently published governmental and other institutional reports related to surveillance issues, were used as important sources of information to capture the most recent developments in the field. In some instances, examples from human or zoonotic disease studies were included.

2. DEFINITIONS OF DISEASE MONITORING AND SURVEILLANCE

The concept of—and term—'surveillance' can be traced back to the French revolution, which at that time meant 'to keep watch over a group of persons thought to be subversive' (Eylenbosch & Noah 1988), very likely with the objective to take action if deemed necessary. There are considerable inconsistencies in the use of the terms monitoring and surveillance. 'Surveillance' (or 'epidemiological surveillance') has been defined by some as the systematic collection of data on the occurrence of specific diseases, the analysis and interpretation of these data, and the dissemination of consolidated and processed information to contributors to the programme and other interested persons (Langmuir 1971; Raska 1966; Kelsey *et al.* 1986; Dufour & Audigé 1997). Other authors and institutions more clearly separate the terms 'monitoring' and 'surveillance'. For them, 'monitoring' is a continuous, dynamic process of collecting data about health and disease and their determinants in a given population over a defined period of time, but without any immediate control activities. 'Surveillance' is a specific extension of monitoring where obtained information is used and measures are taken if certain threshold levels related to disease status have been passed. It is therefore part of disease control programmes (Noordhuisen *et al.* 1997; OIE 1998, 2000a; European Commission 2000a). In a recently published review of the situation in England and Wales, 'veterinary surveillance' was more broadly defined as 'the on-going systematic collection, collation and interpretation of accurate information about a defined animal population with respect to disease and/or infection, closely integrated with timely dissemination of that information to those responsible for control and prevention measures' (Meah & Lewis 1999).

In most instances the activities related to collection, collation, interpretation and potential dissemination of disease information are the same for monitoring systems and for disease surveillance. The main objectives of the monitoring systems are to describe disease trends over time, thus providing veterinary authorities with the necessary data on the current disease status of the animal population. If, as the result of disease detection, a set of activities (usually predefined) related to disease control is undertaken, then the objective changes from sole description to control (and, *in extremis*, eradication) of the disease. Classification of monitoring and surveillance programmes should therefore be based on the objectives of the respective programmes and the resulting activities, and the terminology should be used appropriately. Additionally, the use of 'disease' often implies clinical disease, while most monitoring or surveillance activities can be directed towards (clinical) disease, infection, the causative agent(s), or even risk factors for a specific outcome. Since all these entities can be summarized under the term 'health-related events', we from now on use (animal health) Monitoring and Surveillance System, abbreviated MOSS (or MOS system) (Stärk 1996; Noordhuisen *et al.* 1997), as an umbrella term for all activities related to the detection and control of diseases, infections, agents and other health-related events. The use of monitoring in this paper will be restricted to a MOSS without control measures and surveillance to a MOS system that includes such control efforts.

All MOS systems can be classified as follows:

- (i) with regard to their objectives, i.e. the specific reasons for data collection;
- (ii) by the type of information collected and the data sources themselves; and
- (iii) by the mode of data collection, i.e. whether the data collection is considered to be passive or active.

Some authors like Dufour & Audigé (1997) propose further classification criteria including:

- (i) the number of diseases included in the activity (focused on one disease or broad-based);
- (ii) the area under surveillance (regional, national or international);
- (iii) the population monitored (suspect cases or susceptible animals);
- (iv) the sampling strategy (sample-based or exhaustive); and
- (v) the type of management (autonomous or integrated).

The main focus of the following sections will be on (i) the objectives, (ii) the data sources, and (iii) the modes of data collection as these three are considered to be the most important categories for classification.

3. OBJECTIVES OF MOS SYSTEMS

The ultimate goal of veterinary MOS systems is to minimize, as far as is practicable, the negative effects of health-related events in the animal population that affect public health (consumer protection), trade in animals and animal products, and animal health and welfare (Meah & Lewis 1999). The availability of animal health information can therefore be seen as an essential requirement in

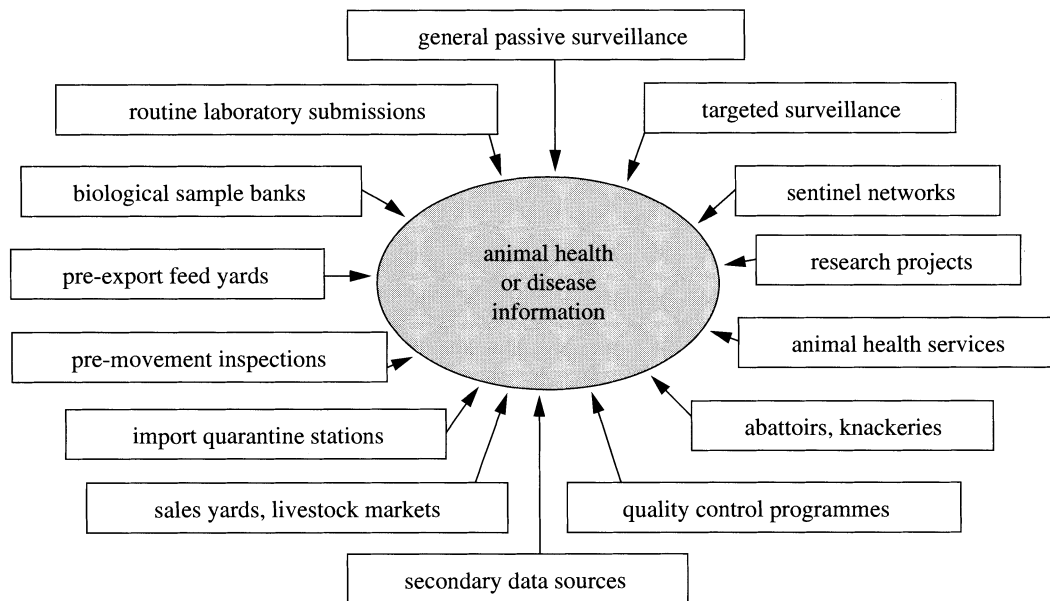


Figure 1. Potential data sources for monitoring or surveillance of animal health-related events.

meeting a strategic goal of most veterinary regulatory agencies.

When designing national MOS strategies, the ultimate goals of the activities need to be clearly defined first (Bush 2000). Teutsch & Thacker (1995) identified eight steps as essential in the planning phase of MOS systems, with the first step being the establishment of the objectives of the system under design. The authors emphasize that the data collection instruments need to be carefully selected and tested in the field. Already implemented MOS systems should be evaluated based on this scheme and, if necessary, adjusted. One component that is not listed is the economic assessment of such systems, which is of considerable importance if the health-related event under surveillance neither has a public health nor a large economic impact. In such situations, the expenses required for animal health surveillance (and control) might be higher than the economic benefits as a result of the programme. Another argument for assessing the cost-effectiveness associated with different MOS systems is the increasing need to justify expenses to the respective authorities in times of decreasing budgets (Meah & Lewis 1999).

The objectives of specific MOS systems will depend on the health-related events and their potential (veterinary) public health impact within a given region, country or zone. Proposals to group these specific objectives into principal objective categories were presented by Morris (1991), Dufour & Audigé (1997), and Bush (2000). The first group of objectives is related to so-called 'foreign animal diseases' (FADs), which can also be referred to as novel, 'exotic' or 'emerging and re-emerging' diseases or infections. Novel health-related events might be a result of a truly new disease (or agent) in a host species or a new clinical expression of a pathological problem caused by a known agent. Typical recent veterinary examples for emerging or re-emerging diseases are FMD, CSF and BSE. These conditions were either historically absent or absent as the result of successful eradication programmes from many geographical regions or zones, and the main

objective of all MOS activities was, and still is, to detect their (re-)occurrence. Reliable detection of and thorough follow-up on clinically suspicious cases, the traditional 'passive surveillance', is a critical element of the initial—early—recognition, reporting and investigation of emerging and re-emerging diseases or infections.

The second group of objectives is related to endemic diseases or infections, i.e. conditions that are prevalent in at least some regions within a country or zone. These health problems are often subject to control or eradication efforts, and the main objective of the MOS system is to assess changes in their prevalence over time and space. This is necessary in order to monitor the success of control activities, and to collect sufficient information to rank various health-related events in terms of (economic) importance.

In addition we propose a third group of objectives, in which the focus is not on monitoring or surveillance for outcomes itself but on the monitoring of risk factors and other information derived from or related to MOSS activities. Activities with these objectives should heighten the awareness for certain diseases and identify potential high-risk populations that could be targeted with such systems. Martin *et al.* (2000) provide an example for Western Australia where data from animal trade and the (reported) disease situation in other countries or regions (trading partners) is screened and used in risk assessments to derive probabilities of disease freedom (or introduction) for the home country.

4. DATA SOURCES FOR MOS SYSTEMS

There is a wide range of potential primary sources for MOS data, including: the animal owners; veterinary professionals (primarily the private practitioners); animal health laboratories; the livestock industry (sale yards, abattoirs, etc.); research institutions; pre-export feedlots; and import quarantine stations (figure 1). Secondary data sources include printed or electronically distributed accounts (via the Internet) of disease outbreaks and

summary MOSS reports that can be used to assess the risk of disease introduction from other geographical regions (trading partners).

Information from primary data sources varies considerably in its source population, in its representativeness, i.e. whether it is statistically acceptable to make extrapolations from the (sample) data to the source population, and in its validity, i.e. how well the measured information truly reflects the status of what is being measured. Some data sources, like random population surveys, provide both the numerators (number of cases) as well as the denominators (animal population at risk in the population under surveillance) required for disease prevalence estimation. In contrast, reporting of clinical suspects does not provide information on the source population at risk that gave rise to these suspects, and prevalence can only be estimated when other denominator information, such as animal census data, are available. Evaluation and interpretation of the data should depend on the data source. When health-related events become rare, accurate estimates on their true prevalence in a population (rare or absent?) are increasingly difficult to obtain. Factors like data validity and precision as well as economic considerations become very important, and pooling of data from different sources to derive an overall estimate on the prevalence, or sufficient evidence for the absence of disease, seems logical. This is addressed to some extent later in this paper.

5. MODES OF DATA COLLECTION

A frequently used activity-related classification of systems is the separation into 'passive surveillance' and 'active surveillance'—both of which are addressed in more detail below—and other activities like sentinel (surveillance) networks that might have both passive and active components.

(a) *Passive monitoring and surveillance systems*

(i) *Definitions, approach and objectives*

A passive MOS system is commonly defined as the reporting of (clinical) suspect cases (to the health authorities) by health-care professionals at their discretion (Lilienfeld & Stolley 1994). Suspect reporting quite frequently is made mandatory within disease control legislation. This mandatory reporting has its origin in regional or national infectious disease control programmes that evolved during the 19th century in Europe, first for rinderpest and later for other infectious diseases such as anthrax, rabies, FMD, glanders, contagious bovine pleuropneumonia, sheep pox, dourine, and scabies of sheep and horses (Bisping 1999).

These systems rely on a pyramid of scrutiny, in which the animal owners (livestock producers) form the first level (Meah & Lewis 1999). Animals must be under sufficient vigilance (or disease awareness) to permit detecting changes from the (clinical) norm, and the animal owners' (livestock producers) vigilance as well as their decision to seek assistance when such deviations are observed, contribute to this level of scrutiny.

Alert private practitioners typically provide the second level of scrutiny. They may, or may not, decide that it is necessary to submit samples for further diagnosis to the

veterinary laboratories. These two levels together act like the screening test in a serial testing scheme: only animals that are considered disease suspects (i.e. screening-test positive) are passed on to the veterinary diagnostic laboratories—the third level of scrutiny in this pyramid—for confirmatory diagnosis. On a continuous basis, the resulting laboratory volume (of submissions for diagnosis) reflects to a large extent the industry's and veterinary practitioners' assessment of the cost-to-benefit ratio associated with species submission (Meah & Lewis 1999). Actual disease detection depends on the appropriateness and quality of the biological samples submitted, on the use of the right tests, and on the experience of the diagnostic laboratory personnel. The series of subsequent events that have to occur before a case is actually diagnosed is displayed in an event tree (figure 2).

There is an evolving discussion on the definition, and use, of the term 'passive' for this mode of data collection. The approach is perceived as passive since the decision on inclusion, or exclusion, of individuals is done by the animal owners or practitioners, and not by the investigators or veterinary authorities that require the information. The term places an unfavourable image onto a MOSS component that has a long and successful history in animal disease control, and which is still widely and effectively used for a range of emerging and re-emerging diseases. In the United Kingdom, passive MOSS accounts for 65% of the Veterinary Laboratory Agency (VLA) expenditures for all MOSS activities (Meah & Lewis 1999).

There might be additional information besides mandatory reporting of clinical suspects, such as routine reports of laboratory diagnoses of disease, reports of clinical conditions observed during animal markets, and data collected within sentinel networks that can be considered as passively collected. The VLA therefore proposed to widen the definition of a passive MOSS to 'the continuous monitoring of the existing disease status of the population surveyed, using routinely collected data to produce outputs which can be fed into policy decisions'. Another suggestion was the use of 'general surveillance' for all these activities, and 'targeted surveillance' for activities in which the sample collection is initiated by the investigators (P. Martin, personal communication).

(ii) *Advantages*

Passive MOS systems in theory continuously cover (screen) the whole susceptible animal population that is under owner (farmer) or veterinary observation and that, if infected, is expected to express clinical signs of disease. It therefore represents a very important source of information for a variety of diseases (Kelsey *et al.* 1986). The approach has worked with satisfaction, and when targeting acute emerging and re-emerging health-related events such as CSF or FMD in well-established, intensive animal industries, passive MOSS seems to be the approach of choice (Martin *et al.* 1987). It is often inexpensive for the individual health-related event since the veterinary infrastructure—including a practitioners' network—is already in place. As passive MOSS is a continuous process, one can express the outcome, if denominator estimates are available, as a cumulative incidence of the outcome of interest, such as clinical disease.

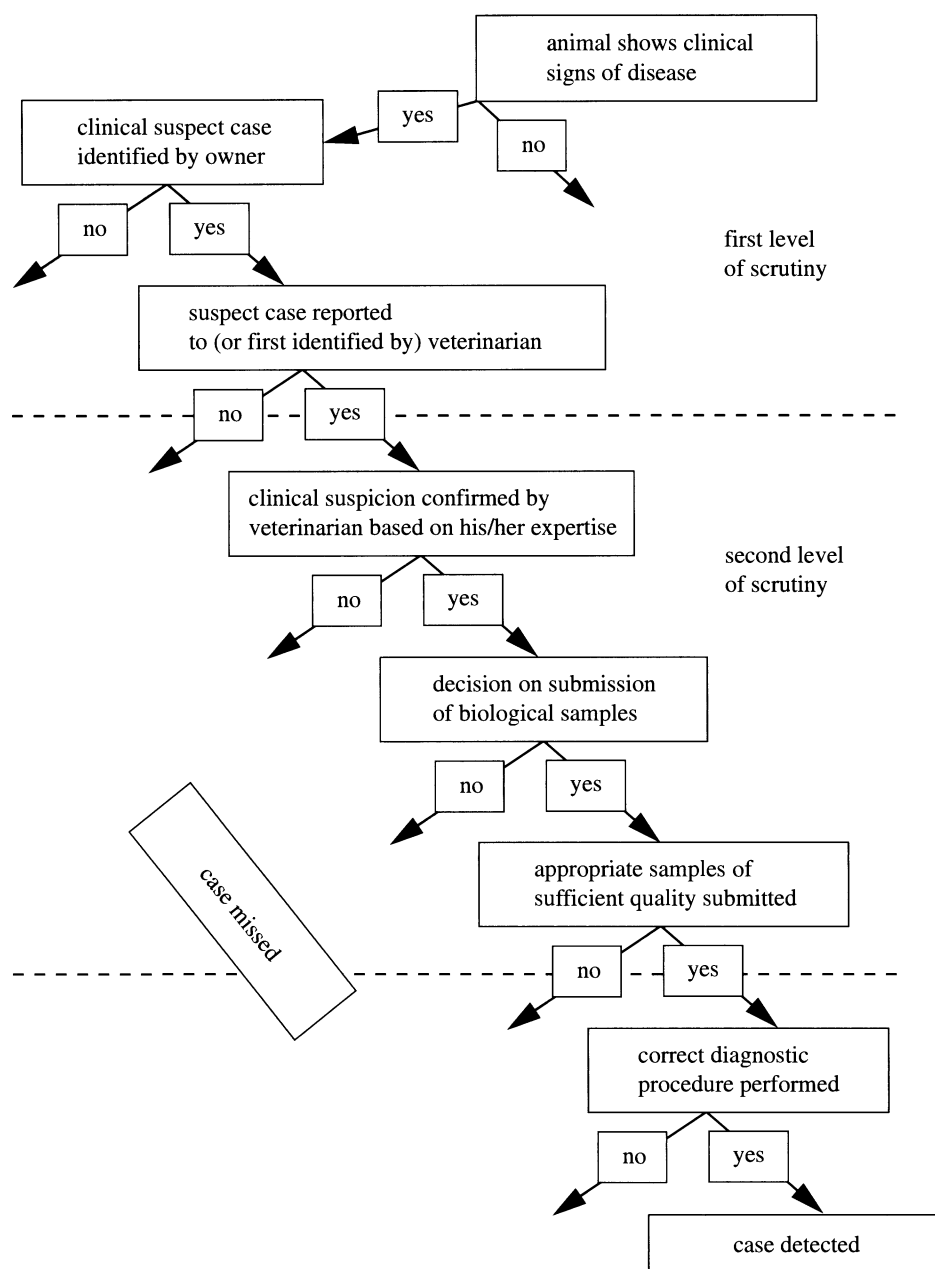


Figure 2. Flow diagram on case detection in passive monitoring or surveillance for clinical diseases.

(iii) Disadvantages

A major limitation of passive MOSS is that it requires the particular disease to produce clinical signs. Subclinical infections or preclinical stages of disease will not be recognized. This, for example, has resulted in problems with CSF surveillance that traditionally relies on the reporting of typical clinical suspects. Outbreak investigations during the last decade in Germany have revealed that the range and severity of clinical signs expressed especially in older pigs has changed over time, with more animals expressing little or non-typical CSF symptoms (M. Kramer, personal communication). This prolonged the time until a first CSF suspicion was reported, thus allowing for a spread of the disease to other herds. It indicates the need for careful monitoring of the range of clinical symptoms expressed by infected animals and the adaptation of suspect case definitions if necessary.

Diseases that have high case fatality rates, that are rapidly fatal, and that are relatively easily diagnosed, are most likely to be recorded accurately. The longer the period between onset and death, the greater the likelihood of occurrence of another fatal disease or, in the production animal context, a decision to replace (cull or slaughter) the animal preventing the diagnosis of the underlying cause. A passive MOSS approach is likely to be a problem if the disease is stigmatized, not considered serious because of the lack of information (disease awareness), if there is nomadism (in developing countries), or if there is distrust of governmental authorities, lack of appreciation of common responsibility and/or shortage of compensation funds (Kelsey *et al.* 1986; Martin *et al.* 1987; Lilienfeld & Stolley 1994; Toma *et al.* 1999). Stigmatized diseases with variable (non-specific) clinical symptoms, long incubation periods, low within-herd and between-herd spread, and

Table 1. Target population, sample selection, repetition frequency and resulting frequency measure for active monitoring and surveillance approaches.

target population for examination/testing	selection (sampling scheme)	repetition	resulting frequency measure
national population	exhaustive (all)	single cross-section	point prevalence
	sample-based	annually repeated cross-sections	point prevalence
more frequently repeated cross-sections		point prevalence or cumulative incidence	
identified subpopulation of higher disease risk	exhaustive or sample based	continuous sampling and testing as above	cumulative incidence as above
		as above but for target (or sample thereof); assumption that national source population has lower event frequency than target	point prevalence or cumulative incidence in target population

an unfavourable cost–benefit ratio—such as occurs (but not only) in BSE and scrapie—have often combined case-ascertainment and case-reporting levels of below 50% of the detectable cases in the population (Marier 1977; Alter *et al.* 1987; Martin *et al.* 1987; Schreuder *et al.* 1993; Doherr *et al.* 1999, 2001; Hoinville *et al.* 1999; Baumgarten *et al.* 2000). This incomplete case-ascertainment and case-reporting creates a bias in the numerator required to derive a population incidence estimate (of clinical cases of disease).

It therefore becomes obvious that it is very difficult to compare passive surveillance results for the same clinical condition from different regions, countries or zones. One needs to assess carefully if events have occurred that would either result in an increase or decrease in case-ascertainment or case-reporting before trying to interpret an observed (reported) change in the disease prevalence over time.

(iv) *Areas for improvement*

With the increasing evidence that passive surveillance approaches might underestimate the true incidence of clinical disease in the population, suggestions have been made to increase case-ascertainment and case-reporting levels. Most of these recommendations address the issues of disease awareness and reporting incentives, and event trees such as the one presented in figure 2 can be used to visualize the order of events necessary for a clinical suspect case to be diagnosed. When including probability estimates for each step, one can assess the resulting probability of case detection, and identify areas where the (assumed) probabilities are low and improvement is necessary.

One approach to enhance reporting is to provide financial incentives (premiums) for all reported suspect cases. There is documented evidence where such activities, for a period in time, changed the disease reporting levels (Wineland *et al.* 1998). MOSS performance levels should be assessed formally over time. Examples for evaluation of case-ascertainment and case-reporting levels using age–period and age–cohort models have been published for vCJD and for BSE (Cohen 2000; Cohen *et al.* 2000). Assessments of underestimation of disease through passive surveillance by initiating parallel active surveillance

components have been described for dengue reporting in Florida, USA (Gill *et al.* 2000), for scrapie in the UK (Hoinville *et al.* 1999) and for BSE in Switzerland (Doherr *et al.* 1999, 2001). Screening of clinical records was used to assess the extent of misclassification of death from vCJD in the UK (Majeed *et al.* 2000). Supplementing (human) passive tuberculosis surveillance data with an active screening of health professional records showed that pharmacy dispensing information (the subscription of two or more tuberculosis drugs) provided a useful pointer towards additional human tuberculosis cases that had been missed by traditional public health surveillance methods (Yokoe *et al.* 1999).

(b) *Active monitoring and surveillance systems*

(i) *Definitions, approach and objectives*

Active surveillance, in human epidemiology, has been defined as the regular periodic collection of case reports from health-care providers or facilities (Lilienfeld & Stolley 1994). Emphasis here is on the active role of the (veterinary) health authorities. In contrast to passive surveillance, individuals to be included in an active surveillance programme are selected through a formal sampling process initiated by the investigator that in theory should provide each individual within the target population with an equal chance of being selected. Alternatively, terms like ‘targeted surveillance’ or ‘targeted screening’ could be used, since appropriate target populations to address the surveillance objectives have to be defined first. The identification of such an appropriate target population depends on the condition of interest to be detected in the target, its expected prevalence, the risk factors influencing the distribution of the condition within the population, the diagnostic tests available for this condition, and the availability of a sampling frame. The approach can be population or high-risk (sub)population based (table 1). Randomized samples are often drawn from the identified target population in a cost-effective way to either estimate the population prevalence with a desired precision or to detect disease if disease prevalence is above a predefined threshold level. Cannon & Roe (1982) published guidelines for statistically based sample size calculations for simple random sampling that still are widely used. Several other randomized sampling schemes,

including stratified random sampling, systematic sampling with random seed, cluster sampling and multistage stratified or cluster sampling schemes, can in addition be used to address one or both questions (Scheaffer *et al.* 1990; Toma *et al.* 1999).

(ii) *Advantages*

Active or targeted MOSSs, often done in the form of single or repeated cross-sectional surveys, measure the point prevalence of the condition of interest and therefore are well suited for outcomes (health-related events) with longer duration. The approach is not restricted to clinical cases of disease. They can be applied to every health-related event such as a disease, infection or condition of interest, like the presence of a long-lasting antibody titre, for which a diagnostic test or measurement system is available. The target population can be the national herd, or it can be a clearly defined high-risk (sub)population. Initiators of active surveillance activities, at least in theory, have good control over the sampling scheme, i.e. over the inclusion of subjects into the screening process. This provides (the impression of) a statistically based objectivity that passive MOS systems are lacking. It also allows for easier standardization of approaches between survey over time and countries, therefore increasing the comparability of results.

Information of the health-related event might be collected from owners by interview or mail, or biological samples are collected during farm visits, at abattoirs, knackeries or carcass rendering plants. In addition, the screening of animal medical records, either the files or electronic databases, for specific entries, or biological sample banks for specific pathogens or lesions, can be considered active and targeted surveillance. Examples of targeted MOS schemes for animal health-related events include the tuberculosis and brucellosis surveys routinely done each year in many European countries, infectious bovine rhinotracheitis (IBR) and enzootic bovine leucosis (EBL) serosurveys in Switzerland (Stärk 1996), BSE screening of fallen stock and emergency slaughtered cattle in Switzerland (Doherr *et al.* 1999, 2001), abattoir screening for contagious bovine pleuropneumonia (CBPP) in Switzerland (Stärk 1996) and for scrapie in the United Kingdom (Simmons *et al.* 2000), and mail surveys for scrapie in the UK, the Netherlands and in Switzerland (Morgan *et al.* 1990; Schreuder *et al.* 1993; Hoinville *et al.* 1999; Baumgarten *et al.* 2000). Some national targeted surveys include a mail or interview questionnaire as well as, in a second step, the collection of biological samples for laboratory testing (Traub-Dargatz *et al.* 2000a,b; Kane *et al.* 2000; Wagner *et al.* 2000).

(iii) *Disadvantages*

A major disadvantage is that population-based MOS systems are very costly when the target diseases become rare. It can easily be demonstrated that sample sizes, and therefore costs, increase exponentially with a decreasing prevalence to detect. To estimate the same prevalence with an accepted absolute error of estimation of 0.05% (relative error of estimation, 50%) would already require a sample size of over 14 000 individuals (Cannon & Roe 1982). If prevalence becomes very low (below 0.1%), however, it is often not feasible to further increase the

sample size simply because of limitations of the diagnostic test system and funding constraints. The aim of surveys then changes from estimating a low prevalence to the assumption of disease freedom, and therefore the identification of a health-related event if it occurs in the targeted population above a threshold prevalence (often 0.1% or 0.2%). Assuming that a sample drawn randomly from a large population includes at least one diseased individual—provided that the true population prevalence is 0.1%—would require a sample size of *ca.* 3000 individuals (Cannon & Roe 1982).

(iii) *Areas for improvement*

The main area for improvement in targeted MOS systems, besides clearly stating the objectives and identification of the appropriate target (high risk) populations, is the issue of survey design. Sampling strategies and sample sizes should be adjusted for the demography of the target population, the disease of interest and the diagnostic test characteristics. New manuals and software tools have been made available for this purpose (Cameron 1999). When good estimates of the population structure, individual animal diagnostic test characteristics, the sampling scheme and the epidemiology of the particular disease (condition) are available, simulation models can be constructed to assess the feasibility of a given targeted survey even before it is done, or assist in the interpretation of survey results (Audigé & Beckett 1999; Audigé *et al.* 1999a,b, 2000, 2001). One approach is to demonstrate, through stochastic modelling, the ability of a survey to discriminate between a (national) target population that is free of disease, and a population that has a given, albeit low, prevalence. The analysis of the approach taken for Johne's disease (*Mycobacterium paratuberculosis*) in the USA National Animal Health Monitoring system (NAHMS) 1997 bovine survey showed that the herd-level diagnostic test system would not effectively distinguish between infected and non-infected herds. The model outcome indicated that when the disease prevalence becomes very low, then the screening test should be highly sensitive and 100% specific to get interpretable survey results (Audigé *et al.* 1999b). Paisley *et al.* (2000a) took a very similar approach for the Norwegian paratuberculosis surveillance and came to the same conclusion. They also assessed the national IBR continuous surveillance. Their model estimated the likelihood of the current surveillance (sampling and testing) scheme (a) to include at least one infected herd in the sample if the country prevalence of infected herds is at 0.2%, and (b) to detect that herd as test-positive if the within herd prevalence and the diagnostic tests used have certain predefined properties (Paisley *et al.* 2000b). Their results indicated that in 99.7% of all model iterations an infected herd would have been included in the sampling, and in 98% of all iterations this herd would have been detected, i.e. tested positive.

6. NEW APPROACHES TO IMPROVE MOSSs FOR RARE DISEASES

The validity of passive as well as active MOS results is most often questioned when these are negative, i.e. when no cases were reported or detected within the activity. Nevertheless, based on this negative finding the investigators or

veterinary authorities often simply conclude that the target population is free of the event under scrutiny. Since surveillance for a rare health-related event and provision of 'freedom from infection' has become increasingly important for veterinary authorities, researchers have started to look into possibilities to assess especially the validity of the results from passive surveillance or targeted screening. Also, new approaches are taken to combine disease information from a range of (surveillance) sources into a probability estimate on disease freedom for a given country or region. Targeted surveys, as presented before, have been used for a range of diseases to compare the outcome with the data from the parallel operating passive surveillance systems in order to assess the respective levels of case-ascertainment and case-reporting. In addition to identifying additional cases of disease, introducing an active component can increase the disease awareness and provide an incentive for reporting clinically suspect cases.

Based on the targeted screening results, the validity of current (but also of historical) passive surveillance results can be determined, and models using passive surveillance data adjusted accordingly. The evaluation of targeted screening systems (and their results) has in part already been addressed at the end of the last section. It is believed that active MOSSs with surveys should be tailored to specific situations (Audigé *et al.* 2001), often to supplement results of a passive system. Recently published international recommendations, or requirements, for disease surveillance and control typically call for an integrated approach that includes (i) an assessment of the risk factors for disease presence, (ii) mandatory reporting of clinical suspects, and (iii) targeted screening activities to supplement/validate the results especially from the passive surveillance. Examples are the rinderpest surveillance and control guidelines (OIE 1998, 2000*a*; IAEA 1994) and CBPP (OIE 2000*b*), and the requirements or recommendations for BSE and scrapie surveillance (European Commission 1999; OIE 2000*c,d,e*). New analytical methods are currently under development to analyse data from complex MOS systems. In an attempt to combine data from a range of (parallel or serial) surveillance sources, Hueston & Yoe (2000) proposed the use of probabilistic scenario analysis and event trees to identify and assess the major pathways by which disease can be detected. They conclude that the approach is well suited to evaluate—and rank—the relative effectiveness of a set of surveillance systems (approaches). In a different approach, prior information on the disease status in a given target population was combined in a Bayesian approach with survey outcomes to derive an *a posteriori* probability of disease freedom (Audigé *et al.* 1999*a*, 2000, 2001). These and other approaches will be developed further.

For emerging and re-emerging diseases, in most instances a passive MOSS will be the core system in place. A good level of disease awareness needs to be maintained among all actors involved, from the farmers and veterinary practitioners all the way to the veterinary authorities, laboratory personnel and university researchers. This includes a good level of knowledge of the clinical conditions that such diseases might present themselves. In addition to the passive MOSS, repeated assessments of the introduction and dissemination risks for diseases present in

the animal population of neighbouring countries or trading partners need to be performed. Continued denial of the potential that a disease might be present in the domestic stock, as with BSE by the veterinary authorities of some European countries, has resulted in a delay in the implementation of appropriate (veterinary) public health measures, and very likely in an extended exposure of cattle—and humans—to the BSE agent. Not before the publication of a geographical BSE risk assessment by the European Commission (2000*b*) were these countries stimulated to improve their BSE surveillance systems—and subsequently detected their first domestic BSE cases (OIE 2001).

7. CONCLUSIONS

Veterinary health MOSSs for emerging and re-emerging health-related events currently seem to be in a transition phase. Increasing demands to detect these rare events or to provide evidence for freedom of disease or infection are a challenge since there is increasing evidence that purely passive MOSSs as well as isolated active screening approaches, for a variety of reasons, are no longer sufficient. Integrated systems that call for the use of several parallel surveillance activities seem to be the favoured approach, but analytical methods to combine MOSS data from various sources into a population prevalence estimate, or probability of disease freedom, are still under development. Once these analytical methods have been developed, however, the next challenge will be to communicate clearly the outcome, an estimated potentially high (but not 100%) probability of disease freedom to the decision-makers that might base potentially costly decisions on this probability.

Monitoring or surveillance for the 'unknown', or for rare events, appears to be a thankless undertaking (Childs *et al.* 1998). It is often difficult enough to justify even keeping up the existing standards and even more difficult to acquire the resources necessary actually to improve these systems. One has to realize, however, that the health and safety of the current and future animal and human generations depends on our continuous ability to detect rapidly, monitor and, if necessary, control newly emerging or re-emerging livestock diseases and zoonoses. Uniform surveillance definitions, sound scientifically based approaches that use the resources (and data) available, and a pool of researchers and veterinary public health officials with a sound training in epidemiology, are critically important to handle this challenging task.

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