The value of information: Current challenges in surveillance implementation

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Abstract

Animal health surveillance is a complex activity that involves multiple stakeholders and provides decision support across sectors. Despite progress in the design of surveillance systems, some technical challenges remain, specifically for emerging hazards. Surveillance can also be impacted by political interests and costly consequences of case reporting, particularly in relation to international trade. Constraints on surveillance can therefore be of technical, economic and political nature. From an economic perspective, both surveillance and intervention are resource-using activities that are part of a mitigation strategy. Surveillance provides information for intervention decisions and thereby helps to offset negative effects of animal disease and to reduce the decision uncertainty associated with choices on disease control. It thus creates monetary and non-monetary benefits, both of which may be challenging to quantify. The technical relationships between surveillance, intervention and loss avoidance have not been established for most hazards despite being important consideration for investment decisions. Therefore, surveillance cannot just be maximised to minimise intervention costs. Economic appraisals of surveillance need to be done on a case by case basis for any hazard considering both surveillance and intervention performance, the losses avoided and the values attached to them. This can be achieved by using an evaluation approach which provides a systematic investigation of the worth or merit of surveillance activities. Evaluation is driven by a specific evaluation question which for surveillance systems commonly considers effectiveness, efficiency, implementation and/or compliance issues. More work is needed to provide guidance on the appropriate selection of evaluation attributes and general good practice in surveillance evaluation. Due to technical challenges, economic constraints and variable levels of capacity, the implementation of surveillance systems remains variable. Political and legal issues are also influential. A particular challenge exists during outbreaks when surveillance needs to be conducted under emergency conditions. Decision support systems can help make epidemiologically and economically sound choices among surveillance options. However, contingency planning is advisable so that pre-defined options allow for rapid decision making.

1. Introduction: State-of-the art in surveillance

Surveillance has been defined as "the ongoing collection, validation, analysis and interpretation of health and disease data that are needed to inform key stakeholders in order to permit them to take action by planning and implementing more effective, evidence-based public health policies and strategies relevant to the prevention and control of disease or disease outbreaks" (ECDC, 2007). Although this definition was established for surveillance in the context of public health, it is largely transferable to veterinary contexts. The information of stakeholders – often referred to as dissemination – is an essential component of surveillance as it assures that the purpose of collecting surveillance data is to inform decisions. If the last step is missing, the value of surveillance information is likely to remain limited.

In animal health, surveillance is applied to a large number of applications. As part of a European-wide research project, reviews of surveillance activities with different objectives are being conducted. These include surveillance for emerging diseases (Rodriguez-Prieto et al., 2014), surveillance for endemic diseases and surveillance for disease freedom. Surveillance provides decision support across sectors, including government, private industry and individual veterinary practices and their clients. Surveillance standards for selected hazards are set at both international and national level, most importantly by the World Organisation for Animal Health (OIE) and published in the Terrestrial Animal Health Code. Such standards are also relevant for international trade decisions and thus have economic impact.

Some technical challenges in the design of surveillance systems remain. Over the last years, risk-based surveillance has become popular and progress in its development has been made (Stärk et al., 2006; Cameron 2012). For some hazards, however, considerable design issues remain. Most notably, the surveillance for antimicrobial resistance continues to challenge surveillance system design at multiple levels. First, it is not clear what the unit of analysis should be. We could focus on certain phenotypes of pathogens which exhibit defined resistance patterns against specific antimicrobials. However, some genetic elements are mobile and can be exchanged between bacteria of different species. Thus, EFSA suggests that the focus should rather be at the gene level (EFSA, 2011). Due to the almost unlimited number of combinations between host species, bacteria species and antimicrobial substances, priority setting is a paramount need. Some attempts have been made, but are quickly outdated also due to the rapid progress in diagnostic possibilities. Next generation sequencing is now much more widely available and may well become the tool of choice in the near future. However, statistical tools, sampling frameworks and surveillance designs have yet to adapt to this new situation. And until international standards will integrate these new methods, even more time – possibly years – will be needed.

The emergence of Schmallenberg virus in the European Union in 2011 (Afonso et al., 2014) is a good example to illustrate both strengths and limitations of surveillance systems at present (Roberts et al., 2014). The first signal of the outbreak came from performance recordings on dairy farms. This could be seen as a successful application of syndromic surveillance, a relatively recent approach to surveillance where unspecific signals such as performance, body temperature, abortion rates or mortality are used to trigger investigations at an early stage of an outbreak (Vial & Berezowski, 2014). In the case of this incident, a previously unknown virus was isolated as part of the investigations and disease control measures were taken based on a tentative case definition. Using a metagenomics approach, a novel viral agent was identified (Beer et al., 2013). Emergency risk assessments were conducted with emphasis on both animal and public health. The development of diagnostic procedures was very rapid with only 3 months until validation and commercialisation; mass-screening kits were available within five months. The development of a legal status for Schmallenberg, however, took longer and remained variable across Europe. While some countries made it notifiable, others did not. It was highlighted that disease control policy should be such that early reporting of unusual cases is not penalised (*Anonymous*, 2012; Beer et al., 2013).

The Schmallenberg example also illustrates the close links between surveillance and disease control as described by Häsler et al. (2011). The purpose of surveillance is to provide information for evidence-based disease control decisions. The value of surveillance information remains therefore limited if it is not considered in a disease management context. Interventions can of course have very different features and range from extremes such as eliminating animals on affected farms to very minor measures such as information of farmers to heighten awareness or improve biosecurity. The decision can of course also be not to initiate any measures, or not yet. As animal health decisions are taken by different stakeholders, in different contexts and for different reasons, the decision making process is generally complex and influenced by many factors. Ideally, most relevance would be attributed to factual information on disease occurrence as produced by surveillance activities and the quality, feasibility, economics and acceptance of disease management options.

With regards to international trade, if surveillance data demonstrated a favourable health situation, and if the surveillance was conducted according to international standards or even more demanding requirements, animals and animal-derived products should be accepted by all markets. Unfortunately, this is not always how it works out. Other factors such as consumer concerns or protection of the domestic industry are a political reality. In principle, all countries being member of the World Trade Organisation (WTO) are subscribing to the principle of free trade. To protect the health of animals, plants and people, the Sanitary and Phyotsanitary (SPS) Agreement (WTO, 1995) allows for trade restriction measures to be taken albeit only for a limited period or if based on a formal risk assessment. A dispute settlement process is in place to address disagreements on trade restrictions. This system is now well established, and although it appears to be generally working, economic and political factors do remain active and influential in trade decisions. However, not all countries are member of the WTO, but the wast majority of major trade partners are.

Constraints on surveillance can therefore be of technical, economic and political nature. Consider two countries, one with a very effective surveillance in place which duly reports outbreaks at an early stage, and another, with limited surveillance and therefore less ability to detect outbreaks. In the latter, some diseases may go undetected for a long time while trade still continues. This can have wide reaching consequences in the long run, if losses are higher than if control started earlier. However, short-term economic interests, fear of loss of reputation and other factors may still provide incentives for non-reporting. This is also true at the farm level where reporting decisions may be influenced by compensation as well as the fear of discrimination and stigmatisation.

The aim of this article is to consider technical, economic and political contraints and their impact on surveillance. We also aim to provide an overview of recent methodological and conceptual developments indicating progress in the

2. Economics of surveillance

In economic terms, animal production systems exist to provide goods or services to people in society, such animal source foods, wool, and leather, animals kept as companions, used for sport, work, or research. However, animal disease reduces the economic benefit people gain from animals, poses a threat to human health because of foodborne and zoonotic diseases and uses resources that in the absence of disease could be allocated to alternative purposes and therefore have an opportunity cost. The economic cost of animal disease is of growing concern given increasing international trade, changes in production practices fuelled by changes in lifestyle across the world, and changing environmental conditions.

Both surveillance and intervention are resource-using activities that are part of a mitigation strategy. Surveillance provides information for response or intervention decisions and thereby helps to offset negative effects of animal disease. Without relevant data from surveillance programmes, policy makers would not know if a threat was emerging, if a certain disease was present or if an intervention was effective. Expected surveillance benefits most often relate to improved disease mitigation, commonly expressed as avoidance of disease impact including a large variety of monetary and non-monetary direct and indirect consequences. Examples include the avoidance of human *E. coli O157:H7* cases through identification and removal of the pathogen from the beef chain (Elbasha et al., 2000); the reduction of herds infected with classical swine fever at the time of detection and the related epidemic costs (Klinkenberg et al., 2005); the increase of value people assign to recreational fishing when controlling notifiable fish diseases (Moran and Fofana, 2007); or averting production losses in animals when controlling bovine virus diarrhoea effectively and efficiently (Häsler et al., 2012). Surveillance information reduces the decision uncertainty associated with choices on disease mitigation, and - if effective – adds value by helping to select adequate mitigation measures as required by the true epidemiological status of a population (Grosbois et al., 2015).

Further, surveillance information contributes to the general body of knowledge of diseases and their management and can therefore be seen as a long-term investment that will enhance the efficiency of mitigation in the future. Another major group of benefits stems from the ability of a country to demonstrate freedom from disease or infection, which facilitates trade in line with the SPS agreement (WTO, 1995), as the likelihood of importation of the disease is zero. Finally, effective surveillance produces non-monetary benefits that do not have a market price, but nevertheless have a value, such as peace of mind, feelings of safety when a hazard is absent, freedom from fear, collaborations and partnerships resulting in social capital, good reputation nationally and internationally, and consumer confidence. These non-monetary benefits are directly linked to the surveillance activity; their valuation can be conducted using economic valuation methods (e.g. contingent valuation).

Surveillance benefits related to improved disease mitigation result from a combination of surveillance and intervention measures. While surveillance provides information for management decisions, intervention constitutes the process of implementing measures directed at mitigation. Together surveillance and intervention achieve disease control and therefore loss avoidance, which constitutes the final outcome of interest (Howe et al., 2013). In this three variable relationship, surveillance and intervention can be economic complements or substitutes. Surveillance and intervention resources as complements are always used in a given ratio and can be considered to be one input, as for example seen in a strategy that combines testing (surveillance) and culling (intervention). Surveillance and intervention as substitutes means that using more of one input requires the use of less resources for the other; the most prominent example here is early warning surveillance, where timely detection enables a response at a time when the cumulative incidence and spread (and associated losses) may not yet be too far advanced and fewer intervention resources are therefore needed to contain the outbreak (relative to a scenario where disease is detected later).

However, this does not automatically mean that surveillance should always be maximised to minimise intervention costs. The key consideration is whether the value of outputs consequently recovered is at least sufficient to cover the additional resource costs and, ideally, the net benefits to society should be maximised (McInerney et al., 1992). Surveillance and intervention resources for labour, materials and services are required to design, plan and implement effective mitigation measures; they include the provision of personnel (e.g. for planning, field and laboratory work, data analysis, communication), sampling and testing equipment, drugs, vaccines, cleaning and disinfection equipment, and laboratory services. While many costs vary with the design and intensity of surveillance and intervention, there are also fixed costs such as available infrastructure (e.g. laboratory and intellectual capacity, trained personnel).

When surveillance and intervention are economic substitutes, the economic optimum can be identified by quantifying the technical relationships between loss avoidance and use of surveillance and intervention resources, translating loss avoidance and resource use into (monetary) values, determining least cost combinations for surveillance and intervention, and identifying the least cost combination(s) consistent with the avoidance loss that maximises people's economic welfare (Howe et al., 2013). Hence, the value of surveillance information is dependent on the technical efficiency of surveillance and intervention, the value of losses caused by disease, and the price ratio of mitigation resources. The latter means that if we are able to use surveillance in the place of intervention to some degree (and vice versa), it makes intuitive sense to prefer the cheaper resource.

Because at present, limited empirical data on these relationships are available, economic appraisals of surveillance systems need to be done on a case by case basis for any disease looking at surveillance and intervention performance in conjunction, the losses avoided and the values attached to them. In some instances, these relationships can be simplified, for example in situations where the economic consequences of an outbreak and the associated response are known to be very large, because it creates fears in consumers and changes in consumption behaviour or causes high mortality, pain and discomfort in animals and/or people, or trade bans. Then the analysis may focus on maximising the technical and economic performance of surveillance keeping the intervention fixed. Such an approach has for example been applied by Guo et al. (2014) who used technical surveillance performance parameters in simulations models in combination with a multi-criteria decision-making model to identify technically and economically efficient surveillance set ups.

Economic efficiency criteria allow weighing and comparing of alternative strategies to come up with measures that enable the allocation of limited funds to projects in a way that guarantee the best outcome for society as a whole (Rushton, 2009) and to help understand complex interactions and the possible effects of a decision. The leading criterion is optimisation, which defines how the net benefit accruing to society from allocating scarce resources to disease mitigation is maximised. Another criterion refers to acceptability; it allows to judge whether the benefits stemming from a mitigation policy at least cover its costs, thus making a strategy justifiable (e.g. seen in cost-benefit analysis or cost-effectiveness analysis). Finally, the least-cost criterion applies when achieving a technical target for mitigation without quantification of the benefit is the policy objective. Without systematic economic analysis, resource allocation and budgeting decisions for animal health rely on other considerations, such as technical, political or logistical factors.

Decision-makers must not only comply with national and international requirements and guidelines, but also consider what is technically possible in the existing setting (structure and organisation of the veterinary services and industry), follow political visions and address widespread public scares that may impact on consumer confidence (e.g. bovine spongiform encephalopathy or avian influenza). Further, they are expected to consider concerns of livestock holders and base their decisions on scientific evidence. Thus, the resources invested reflect the value policy makers implicitly attribute to the mitigation measures willingly paid to protect society from potential negative disease effects. However, if one accepts that the utility of economic analysis consists in informing decisions, it is necessary to understand and measure the relationships outlined above. An *ex ante* economic appraisal provides important information for resource allocation decisions before the start of a programme, an interim assessment shows whether the programme is on track and allows implementing corrective measures, and an *ex post* analysis allows demonstrating the value realised. Of course these phases of disease mitigation may not be so clear-cut in reality, but we believe they help understand the different approaches from an economic perspective. Generally, economic efficiency in diseases mitigation depends on the effectiveness of disease management. Therefore, both economic and technical considerations should be included when evaluating surveillance.

3. Evaluation

Evaluation includes a systematic investigation of the worth or merit of a project or programme to appraise its value or quality (Joint Committee on Standards for Educational Evaluation, 1994). It allows assessing the effectiveness, efficiency and impact of a programme, creating an evidence base, determining factors that lead to programme success or failure, identifying areas for programme improvement, and providing justification for funding. As evaluation is a generic approach, each discipline commonly has its own set of standardised evaluation metrics, approaches and methods that may be of relevance. For example, evaluation of health information technology looks at clinical outcomes measures, clinical processes, staff adoption, patient knowledge and attitudes measures, workflow and financial impact measures (Cusack and Poon, 2007), while evaluation of nutrition programmes may consider anthropometric measurements, body mass index, dietary diversity scores or blood composition (Habicht et al., 2009). Metrics, both qualitative and quantitative, constitute a reportable and systematic means for examining how a programme is performing and to which extent desired goals are achieved.

The evaluation of surveillance systems commonly assesses its effectiveness, efficiency, implementation and/or compliance issues. The specific approach depends on the reasons for evaluation, the client, the system under consideration, and how activities link to desired outcomes. Once the evaluation questions are defined, relevant data are collected, analysed, interpreted and recommendations made and communicated in a way appropriate to the target audience (HSCC, 2004). Such evaluation can help to identify the strengths and weaknesses of a surveillance system and provide feedback for continuation of activities with the view of achieving the stated surveillance objectives. Numerous guidelines are available for the evaluation of surveillance (e.g. HSCC, 2004; Meynard et al., 2008; Hendrikx et al., 2011; Drewe et al., 2015) including international standards for human and animal health surveillance systems, respectively, provided by the WHO (2008) and OIE (2014).

An important aspect of evaluation is that it should be inclusive in terms of the contributing stakeholders. Ideally, evaluation methods – typically interviews – should include the views and opinions of all relevant organisations, sectors and individuals that are affected by or benefiting from surveillance activities. Typically, these will be the providers of information such as farmers, veterinarians or laboratories, as well as the decision makers, i.e. the “users” of information such as policy makers, industry or consumers.

Such guidelines offer some consensus in the broad steps to follow (i.e. description of the context and evaluation process, implementation, and recommendations), but there currently remain gaps including the lack of detailed implementation guidance, the absence of a comprehensive list of attributes to be assessed, and a lack of advice for the selection of attributes and their assessment (Calba et al., 2015). Given the large variability of surveillance contexts, objectives, approaches and designs, as well as differing interests of policy makers with regards evaluation outcomes, some degree of flexibility in evaluation (guidelines) is needed to account for variations in evaluation question, complexity, evaluation capacity, data and resource availability.

One aspect that is currently neglected or only treated superficially in such guidelines is the economic evaluation of surveillance. Economics implies the recognition of scarcity and the best possible use of the disposable resources. It is concerned with choices about the allocation of scarce resources to satisfy peoples' needs with the aim to achieve a desired end by minimal use of resources or to maximise a desired end under the given amount of resources. Consequently, there is always a choice element attached to economic evaluation. It therefore requires a comparison of alternatives and assessment of economic efficiency criteria which rely on the consideration of technical and economic data. This is in stark contrast to performance or operational attributes that describe a surveillance quality and can be assessed individually.

To make progress in the use of surveillance evaluation, the RISKSUR project (http://www.fp7-risksur.eu/) has developed an integrated theoretical framework and evaluation tool for the technical and economic evaluation of surveillance. It guides the user through a series of steps and pathways to help select the right evaluation question, attributes, criteria and methods to evaluate surveillance systems or components.

4. Challenges in surveillance implementation

It is not only essential to decide for which hazards surveillance should be conducted, but also how to design and implement surveillance programmes. The design includes all considerations from the legal basis to the diagnostic test. Implementation may become a challenge when capacity and/or funding is limited. Providing the legal basis for surveillance may be a political challenge if there is disagreement about where priorities for investments should be set and if responsibilities are unclear. Implementation of surveillance is particularly challenging if there is an emergency situation around an outbreak. The following paragraphs discuss such challenges in surveillance.

Surveillance is a key requirement for accessing markets and facilitating trade with animals and animal-derived food. Even if a disease is absent from a country or region, evidence will be required to document this status. To facilitate the process of determining appropriate intensity and design of surveillance, the most relevant hazards are covered in the International Animal Health Code published by the OIE. Partner countries are committed to accepting this standard and to implementing the policies defined there. If their own requirements go beyond the standard and if operating under WTO rules, more stringent policies have to be justified. Thus, the rules in relation to international trade are quite clear. If countries still have a dispute, there is a defined process how this should be addressed. Countries may also have entered regional trade agreements which may define surveillance and disease control activities at even more detailed level. In general, standards that focus on the output of surveillance leave more flexibility for implementation and are therefore preferable.

For hazards that are not relevant to international trade or subject to international requirements, policy setting is a domestic or industry (i.e. private) affair. This process will involve key stakeholders and – depending on the country's current practice – may have more or less government involvement. The role of government will also depend on the economic relevance of the disease and the importance of the affected livestock sector. Political processes such as lobbying by interest groups will also influence whether a disease surveillance or control issue will be put on the agenda. Similarly, ongoing outbreaks, risk of loss of international reputation, and imminent elections may all impact on whether a hazard will or will not be of political interest.

Government involvement is typically increased for zoonoses. In this situation, policy development tends to become more complicated because more than one ministry may be involved (Stärk et al., in press). Disease mitigation including surveillance and interventions are resource-demanding activities and it may not be clear which ministry should pay for what. Data sharing may also be difficult and slow. Nevertheless, cross-sectoral surveillance may be essential to protect public health. To facilitate the appraisal of technical processes and their economic relevance for both animal health and public health, a new framework has been developed for surveillance conducted in a “One health” context (Babo Martins et al., 2013). This framework allows the economic assessment of surveillance and intervention across sectors with an explicit allocation of costs and benefits.

Even if policies are agreed and budgets are available, practical implementation of surveillance may not be straightforward. Capacity may be limited in terms of either personnel or equipment or both, thus requiring investment into the training of people and into the establishment of facilities and methods that are required for ongoing surveillance and disease control activities. In some countries, substantial limitations of such capacities have been identified (e.g. Namatovu et al., 2013). Developing capacity is often a mid- to long-term goal. But as an added benefit, investments into routine surveillance activities are likely to also improve preparedness for emerging diseases. Rapid detection and effective management of emerging diseases require an established level of technical capacity and general awareness among professionals. This is more likely to be present if surveillance activities are already implemented for other hazards. This was recently discussed in the context of the Ebola outbreak in several countries in Africa. The importance of general preparedness and capacity building has been identified as a key requirement for rapid control.

During an outbreak situation, there may be a serious shortage of capacity at all levels, including qualified personnel, impacting on both surveillance as well as intervention activities. This was experienced in an extreme form during the FMD outbreak in the UK in 2003 (Davies, 2002) when veterinarians had to be sourced from around Europe. Roche et al. (2014) showed that the expected capacity was influential on effectiveness of a control strategy for FMD and therefore also influential on the choice of strategy.

Some benefits are possible during an outbreak if time-consuming tasks can be automated. This requires investments during peace time into infrastructure (e.g. databases and information systems), such that location, size and other relevant characteristics of holdings are known. Using such data, it is possible to provide decision support to staff by using, for example, expert systems for setting priorities. Models can also be used to investigate possible outbreak scenarios and to estimate the impact of specific surveillance and interventions (Stärk et al., 1998; Jalvingh et al., 1999; Nielen et al., 1999; Sanson et al., 1999; Harvey et al., 2007; Boklund et al., 2009; Roche et al., 2014a).

While simple decision algorithms for surveillance and outbreak management are relatively easy to implement, the development of underlying disease models for scenario predictions and assessment of the impact of surveillance and intervention strategies is much more complex. Comparisons of different simulation models have shown that they provide technically comparable results, for example for foot-and-mouth disease (FMD) (Dubé et al., 2007, Roche et al., 2014b). But only few such models have been applied under emergency conditions because they are technically difficult to run and thus require specialists which may not be available during an outbreak. It may also be too expensive to maintain such a high level of expertise over years when no outbreaks occur. Finally, modelling results remain uncertain and may be difficult to communicate. At the moment, such models are therefore mainly used during peace time to assess the suitability of specific control scenarios.

Not all diseases are as contagious as FMD and require such rigorous surveillance and disease control activities. Therefore, time is not always the most limiting factor in the implementation of surveillance activities. Of course any delay in decision making may eventually come at a cost.

A further complication in the management of an outbreak can be the fact that it is a zoonosis and therefore affects public health. Consumers are sensitive about food risks and can react drastically to animal-related hazards causing substantial market disruptions and losses to the farming and food sectors (McDonald et al., 1998; Knowles et al., 2007; Miller & Parent, 2012). Communication therefore becomes a critical element. Risk perception is a complex process affected by many factors and communication requires expertise and needs to be planned carefully (Cope et al., 2010).

5. Conclusions

Surveillance for animal health and food safety hazards is not conducted in isolation but an integrated component of complex decision making. The economic perspective of surveillance confirms the intrinsic link between surveillance and intervention. Choices on disease control options are, however, subject to constraints, not only an economic, but also a political matter. As the analysis of such drivers is often not easily conducted in an outbreak situation, it is important to assess and learn from outbreaks with sufficient breadth and depth after they are over (e.g. Taylor, 2003; Hueston, 2013). Lessons learnt are valuable for general preparedness and also in order to evaluate costs and benefits of alternative control options. Economic assessments are not yet commonly conducted which is surprising at a time where resources are limited in any industry. Increased awareness for economic consequences of decisions and the extent and nature of the achieved benefits (and beneficiaries) are a pre-requisite for informed decisions. A policy cycle that includes evaluation provides opportunities for improvements, savings and progress in disease control. Such evaluation should be an inherent part of any policy and planned systematically, so that the necessary data and information can be collected to allow for a sound assessment.

References

Anonymous, 2012. New Orthobunyavirus isolated from infected cattle and small livestock – potential implications for human health. ECDC, RIVM, RKI, 4 pp. [available online http://ecdc.europa.eu/en/publications/_layouts/forms/Publication_DispForm.aspx?ID=607&List=4f55ad51-4aed-4d32-b960-af70113dbb90 accesses 09/04/2015]

Afonso, A., Cortinas Abrahantes, J., Conraths, F., Veldhuis, A., Elbers, A., Roberts, H., van der Stede, Y., Meroc, E., Gache, C., Richardson J., 2014. The Schmallenberg epidemic in Europe – 2011-2013. Prev. Vet. Med. 116, 391-403. doi: 10.1016/j.prevetmed.2014.02.012

Babo Martins, S., Rushton, J., Stärk K.D.C., 2013. Economic assessment of surveillance in a One Health context: a research project on the impact of zoonotic disease surveillance. Proc. MedVetNet Conference, Copenhagen, Denmark, ES04:37

Beer, M., Conraths, F.J., van der Poel, W.H.M., 2013. "Schmallenberg virus"--a novel orthobunyavirus emerging in Europe. Epidemiol. Infect. 141, 1–8. doi:10.1017/S0950268812002245

Boklund, A., Toft, N., Alban, L., Uttenthal, A., 2009. Comparing the epidemiological and economic effects of control strategies against classical swine fever in Denmark. Prev. Vet. Med. 90, 180–93. doi:10.1016/j.prevetmed.2009.04.008

Calba, C., Goutard, F., Hoinville, L., Hendrikx, P., Lindberg, A., Saegerman, C., Peyre, M. (2015). Surveillance systems evaluation: a review of the existing guides. BMC Public Health.

Cameron, A.R., 2012. The consequences of risk-based surveillance: Developing output-based standards for surveillance to demonstrate freedom from disease. Prev. Vet. Med. 105, 280–6. doi:10.1016/j.prevetmed.2012.01.009

Cope, S., Frewer, L.J., Houghton, J., Rowe, G., Fischer, A.R.H., de Jonge, J., 2010. Consumer perceptions of best practice in food risk communication and management: Implications for risk analysis policy. Food Policy 35, 349–357. doi:10.1016/j.foodpol.2010.04.002

Cusack, C.M., Poon, E.G., 2007. Health Information Technology Evaluation Toolkit. AHRQ Publication No. 08-0005-EF. Prepared for the AHRQ National Resource Center for Health Information Technology under contract No. 290-04-0016, Rockville, MD: Agency for Healthcare Research and Quality

Davies, G., 2002. The foot and mouth disease (FMD) epidemic in the United Kingdom 2001. Comp. Immunol. Microbiol. Infect. Dis. 25, 331–343. doi:10.1016/S0147-9571(02)00030-9

Drewe, J.A., Hoinville, L.J., Cook, A.J., Floyd, T., Gunn, G., Stark, K.D., 2015. SERVAL: A New Framework for the Evaluation of Animal Health Surveillance. Transboundary and emerging diseases 62, 33-45.

Dubé, C., Stevenson, M.A., Garner, M.G., Sanson, R.L., Corso, B.A., Harvey, N., Griffin, J., Wilesmith, J.W., Estrada, C., 2007. A comparison of predictions made by three simulation models of foot-and-mouth disease. N. Z. Vet. J. 55, 280–8. doi:10.1080/00480169.2007.36782

ECDC, 2007. Surveillance of communicable diseases in the European union – a long-term strategy 2008- 2013. www.ecdc.europa.eu/en/aboutus/Key%20 Documents/08-13_KD_Surveillance_of_CD.pdf. Accessed November 30, 2014.

EFSA, 2011. Scientific Opinion on the public health risks of bacterial strains producing extended-spectrum β-lactamases and/or AmpC β-lactamases in food and food-producing animals. EFSA Journal 9(8), 2322, 95 pp. doi:10.2903/j.efsa.2011.2322. www.efsa.europa.eu/efsajournal. Accessed online November 30, 2014 www.efsa.europa.eu/efsajournal

Elbasha, E.H., Fitzsimmons, T.D., Meltzer, M.I., 2000. Costs and benefits of a subtype-specific surveillance system for identifying Escherichia coli O157:H7 outbreaks. Emerg Infect Dis 6, 293-297.

Grosbois, V., Häsler, B., Peyre, M., Thi Hiep, D., Vergne, T., 2015. A rationale to unify measurements of effectiveness for animal health surveillance. Preventive veterinary medicine.

Guo, X., Claassen, G.D., Oude Lansink, A.G., Saatkamp, H.W., 2014. A conceptual framework for economic optimization of single hazard surveillance in livestock production chains. Preventive veterinary medicine 114, 188-200.

Habicht, J.-P., Pelto, G.H., Lapp, J., 2009. Methodologies to evaluate the impact of large scale nutrition programmes. World Bank's Poverty Reduction and Economic Management. World Bank.

Häsler, B., Howe, K.S., Stärk, K.D.C., 2011. Conceptualising the technical relationship of animal disease surveillance to intervention and mitigation as a basis for economic analysis. BMC Health Serv. Res. 11, 225. doi:10.1186/1472-6963-11-225

Häsler, B., Howe, K.S., Presi, P., Stark, K.D., 2012. An economic model to evaluate the mitigation programme for bovine viral diarrhoea in Switzerland. Preventive veterinary medicine 106, 162-173.

Harvey, N., Reeves, A., Schoenbaum, M.A., Zagmutt-Vergara, F.J., Dubé, C., Hill, A.E., Corso, B.A., McNab, W.B., Cartwright, C.I., Salman, M.D., 2007. The North American Animal Disease Spread Model: a simulation model to assist decision making in evaluating animal disease incursions. Prev. Vet. Med. 82, 176–97. doi:10.1016/j.prevetmed.2007.05.019

Hendrikx, P., Gay, E., Chazel, M., Moutou, F., Danan, C., Richomme, C., Boue, F., Souillard, R., Gauchard, F., Dufour, B., 2011. OASIS: an assessment tool of epidemiological surveillance systems in animal health and food safety. Epidemiology and infection 139, 1486-1496.

Howe, K.S., Häsler, B., Stark, K.D., 2013. Economic principles for resource allocation decisions at national level to mitigate the effects of disease in farm animal populations. Epidemiology and infection 141, 91-101.

HSCC, 2004. Framework and Tools for Evaluating Health Surveillance Systems. Health Surveillance Coordinating Committee (HSCC) Ottawa: Health Canada.

Hueston, W.D., 2013. BSE and variant CJD: Emerging science, public pressure and the vagaries of policy-making. Prev. Vet. Med. 109, 179–84. doi:10.1016/j.prevetmed.2012.11.023

Jalvingh, A.W., Nielen, M., Maurice, H., Stegeman, A.J., Elbers, A.R.., Dijkhuizen, A.A., 1999. Spatial and stochastic simulation to evaluate the impact of events and control measures on the 1997–1998 classical swine fever epidemic in The Netherlands. Prev. Vet. Med. 42, 271–295. doi:10.1016/S0167-5877(99)00080-X

Joint Committee on Standards for Educational Evaluation, 1994. The program evaluation standards : how to assess evaluations of educational programs. Sage Publications Thousand Oaks, Calif.; London.

Knowles, T., Moody, R., McEachern, M.G., 2007. European food scares and their impact on EU food policy. Br. Food J. 109, 43–67. doi:10.1108/00070700710718507

Klinkenberg, D., Nielen, M., Mourits, M.C., de Jong, M.C., 2005. The effectiveness of classical swine fever surveillance programmes in The Netherlands. Preventive veterinary medicine 67, 19-37.

McDonald, S., Roberts, D., 1998. The economy-wide effects of the BSE crisis: A CGE analysis. J. Agric. Econ. 49, 458–471.

McInerney, J.P., Howe, K.S., Schepers, J.A., 1992. A Framework for the Economic-Analysis of Disease in Farm Livestock. Preventive veterinary medicine 13, 137-154.

Meynard, J.B., Chaudet, H., Green, A.D., Jefferson, H.L., Texier, G., Webber, D., Dupuy, B., Boutin, J.P., 2008. Proposal of a framework for evaluating military surveillance systems for early detection of outbreaks on duty areas. BMC public health 8, 146.

Miller, G.Y., Parent, K., 2012. The economic impact of high consequence zoonotic pathogens: Why preparing for these is a wicked problem. J. Rev. Glob. Econ. 1, 47-61.

Moran, D., Fofana, A., 2007. An economic evaluation of the control of three notifiable fish diseases in the United Kingdom. Preventive veterinary medicine 80, 193-208.

Nielen, M., Jalvingh, A.W., Meuwissen, M.P.M., Horst, S.H., Dijkhuizen, A.A., 1999. Spatial and stochastic simulation to evaluate the impact of events and control measures on the 1997-1998 classical swine fever epidemic in The Netherlands. II. Comparison of control strategies. Prev. Vet. Med. 42, 297–317.

OIE, 2014. OIE Guide to Terrestrial Animal Health surveillance. Office International des Epizooties, Paris.

Roberts, H.C., Elbers, A.R.W., Conraths, F.J., Holsteg, M., Hoereth-Boentgen, D., Gethmann, J., van Schaik, G., 2014. Response to an emerging vector-borne disease: Surveillance and preparedness for Schmallenberg virus. Prev. Vet. Med. 116, 341–9. doi:10.1016/j.prevetmed.2014.08.020

Roche, S.E., Garner, M.G., Wicks, R.M., East, I.J., de Witte, K., 2014a. How do resources influence control measures during a simulated outbreak of foot and mouth disease in Australia? Prev. Vet. Med. 113, 436–46. doi:10.1016/j.prevetmed.2013.12.003

Roche, S.E., Garner, M.G., Sanson, R.L., Cook, C., Birch, C., Backer, J.A., Dube, C., Patyk, K.A., Stevenson, M.A., Yu, Z.D., Rawdon, T.G., Gauntlett, F., 2014b. Evaluating vaccination strategies to control foot-and-mouth disease: a model comparison study. Epidemiol. Infect. 1–20. doi:10.1017/S0950268814001927

Rodriguez-Prieto, V., Vicente-Rubiano, M., Sanchez-Matamoros, A., Rubio-Guerri, C., Melero, M., Martinez-Lopez, B., Martinez-Aviles, M., Hoinville, L., Vergne, T., Comin, A., Schauer, B., Dorea, F., Pfeiffer, D.U., Sanchez-Vizcaino, J.M., 2014. Systematic review of surveillance systems and methods for early detection of exotic, new and re-emerging diseases in animal populations. Epidemiol. Infect. 1–25. doi:10.1017/S095026881400212X

Rushton, J., 2009. The Economics of Animal Health and Production. CAB International Wallingford.

Stärk, K.D.C., 2012. Evaluating surveillance programmes: ensuring value for money. Vet. Rec. 171, 421-2 doi: 10.1136/vr.e7124

Stärk, K.D.C., Regula, G., Hernandez, J., Knopf, L., Fuchs, K., Morris, R.S., Davies, P., 2006. Concepts for risk-based surveillance in the field of veterinary medicine and veterinary public health: review of current approaches. BMC Health Serv. Res. 6, 20. doi:10.1186/1472-6963-6-20

Stärk, K.D.C., Arroyo Kuribreña, M., Dauphin, G., Vokaty, S., Ward, M.P., Wieland, B., Lindberg, A., in press. One Health Surveillance – more than a buzz word? Prev. Vet. Med.

Taylor, I., 2003. Policy on the hoof: the handling of the foot and mouth disease outbreak in the UK 2001. Policy Polit. 31, 535–546. doi:10.1332/030557303322439399

Vial, F., Berezowski, J., 2014. A practical approach to designing syndromic surveillance systems for livestock and poultry. Prev. Vet. Med. doi:10.1016/j.prevetmed.2014.11.015

WHO, 2008. International Health Regulations. WHO, Geneva.

WTO, 1995. The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). World Trade Organisation, Geneva.