ORIGINAL ARTICLE

Economic Assessment of Zoonoses Surveillance in a 'One Health' Context: A Conceptual Framework

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Impacts

- There is increasing pressure on public and private resources allocated to surveillance and intervention activities aimed at reducing the impact of zoonoses in society.
- While enhanced collaboration and sharing of surveillance information between the animal and the public health sectors are of strategic importance for public health, evidence on the added value of an integrated approach to surveillance is lacking.
- A framework to identify the cross-sectoral links between zoonoses surveillance and mitigation activities and the associated benefits and costs is presented as a basis for the assessment of the economic value of integration of zoonoses surveillance.

Keywords:
Zoonoses; surveillance; 'One Health'; economic assessment; economic framework; cross-sectoral surveillance; surveillance integration

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Summary

Collaboration between animal and public health sectors has been highlighted as a means to improve the management of zoonotic threats. This includes surveillance systems for zoonoses, where enhanced cross-sectoral integration and sharing of information are seen as key to improved public health outcomes. Yet, there is a lack of evidence on the economic returns of such collaboration, particularly in the development and implementation of surveillance programmes. The economic assessment of surveillance in this context needs to be underpinned by the understanding of the links between zoonotic disease surveillance in animal populations and the wider public health disease mitigation process and how these relations impact on the costs and benefits of the surveillance activities. This study presents a conceptual framework of these links as a basis for the economic assessment of cross-sectoral zoonoses surveillance with the aim of supporting the prioritization of resource allocation to surveillance. In the proposed framework, monetary, non-monetary and intermediate or intangible cost components and benefit streams of three conceptually distinct stages of zoonotic disease mitigation are identified. In each stage, as the final disease mitigation objective varies so does the use of surveillance information generated in the animal populations for public health decision-making. Consequently, the associated cost components and benefit streams also change. Building on the proposed framework and taking into account these links, practical steps for its application are presented and future challenges are discussed.

Introduction

Background

A growing recognition of the impacts of zoonotic disease in society has prompted the scientific community and decision-makers to look for cross-cutting, holistic initiatives between the animal and the public health sectors in order to improve zoonotic disease management. Such 'One Health' frameworks are based on the principles that a multisectoral approach best captures the inter-relationships of health of different species and that intervention in the animal reservoir could result in a decrease in the global burden of zoonotic disease in humans (The World Bank, 2010; Zinsstag et al., 2011).

For surveillance of zoonotic events, cross-sectoral work and better integration and sharing of information on animal and human data are also increasingly seen as key to efficient health systems (Halliday et al., 2012; Morse et al., 2012). The potential to prevent human cases of zoonotic diseases through the identification of disease in the animal population is the main rational identified for the need to closely exchange information or integrate surveillance systems across species (Gubernot et al., 2008; Rabinowitz et al., 2009; Flanagan et al., 2012; Levinson et al., 2013). However, literature reviews have shown that thus far, the majority of the surveillance systems for zoonoses have examined human and animal data separately (Vrbova et al., 2010; DFID, 2011) with mainly descriptive links between the information (Scotch et al., 2009). A more recently published review summarizing twenty surveillance initiatives that integrate information from humans and animals on zoonotic diseases found that the degree of integration varied depending on surveillance purpose, structure and source of information used. The same study showed that integrated systems relied heavily on already existing data mainly collected for another purpose (Wendt et al., 2014).

One of the hurdles to the wider adoption of these 'One Health' holistic approaches for the surveillance and control of zoonotic diseases is the lack of evidence detailing the costs and benefits to both sectors of such collaborative efforts (The World Bank, 2010; Coker et al., 2011). Yet, such information is of particular importance considering that costs and benefits of all activities conducted by government administration, including surveillance of diseases, are under increasing budgetary constraint as well as scrutiny from the public.

Some have argued that 'One Health' approaches add value through improved effectiveness of interventions, sharing and saving on operational costs, and better disease detection (Rushton et al., 2012; Häsler et al., 2013, 2014a; Greter et al., 2014). It has also been shown that the control of disease in its animal reservoir can be economically beneficial to the public health sector and to society as a whole for some specific diseases (Hugh-Jones et al., 1975; Roth et al., 2003; Wegener et al., 2003; Zinsstag et al., 2007; Häsler et al., 2014b). This body of work focuses mainly on disease control, and comparable analysis has not been carried out addressing surveillance explicitly nor is there a systematic approach for such an assessment.

Objectives of the study

The background demonstrates that 'One Health' surveillance economics needs to focus on the question of whether overall resources are used more efficiently by integrated surveillance when compared to a surveillance system with separated, sector-specific components. Our objective therefore was to develop a conceptual framework to structure such an assessment. We aimed to investigate whether a generic approach to document the relationship between surveillance of zoonotic diseases in the animal population and economic benefits for the public health sector can be developed to provide a basis for an economic assessment of surveillance integration. Such an approach should be wide-ranging and applicable to the economic assessment in a variety of 'One Health' surveillance designs, degrees of integration and types of zoonoses. Building on this concept, this work identifies cost components and benefit streams and presents practical steps for its implementation in an assessment. By exploring questions surrounding integration of surveillance information across sectors and cross-sectorial collaboration, the overall aim of this work is to support priority setting and to inform resource allocation to surveillance.

Conceptual Links Between Animal Health Surveillance and Public Health Intervention

The identification, quantification and valuation of resources and of health consequences are key steps in the economic evaluation of health programmes (Guiness and Wiseman, 2011). For interventions that reduce the impact of disease, the identification of health consequences can be performed directly. Surveillance, on the other hand, entails a sequence of collection, analysis and dissemination of health-related data and a final step of the application of generated data to intervention decisions (Thacker and Berkelman, 1988; Declich and Carter, 1994). This important final link in the surveillance chain means that for the economic evaluation of surveillance, the identification of the associated health consequences and thus of the economic benefits requires the thorough understanding of the surveillance objectives, its links to interventions and to the broader mitigation process (Häsler et al., 2011). The identification of the benefits of surveillance and their attribution to intervention are consistent tasks in the field of surveillance economics (Elbasha et al., 2000; Tambi et al., 2004; Somda et al., 2010; Häsler et al., 2012a; Guo et al., 2014). To assess surveillance in a 'One Health' context and explore the added value of integration, the link between data generation and application to interventions further entails the understanding of how surveillance information is used and how it generates health consequences and benefit streams across different sectors.

This section develops and specifies the links between zoonotic disease surveillance in the animal population and the wider public health disease mitigation process, as a basis for the economic assessment and for the identification of monetary and non-monetary costs and benefits of integrated zoonoses surveillance. It draws on concepts from reviewed literature and inductive reasoning to explore how the public health sector can use information generated by surveillance of zoonoses in the animal populations.

The conceptual links between surveillance and intervention in the animal health sector alone have been described by Häsler et al. (2011). In their framework, the authors defined three distinct stages where disease mitigation and surveillance objectives shift as disease progresses in the animal population, with implications for the economic assessment.

Three conceptual stages where the use of information generated in the animal populations in public health decision-making are also distinguishable according to the dynamics of the disease in the human and animal populations and the risk profile for public health. The dynamics of the disease component relates to the phase in the zoonoses transmission process. The identification of the disease in animals could take place ahead of initial spillover events to humans, once the spillover takes place and localized human infections occur, or at a stage of sustained human-to-human transmission of the zoonotic hazard that is established (Daszak et al., 2000; Morse et al., 2012). In each of these phases, the public health and animal health disease mitigation objectives will vary accordingly, as well as the interventions and surveillance activities implemented in each of the affected populations. The latter element is connected to the fact that the establishment of a risk profile to public health of each situation will direct the need for public health interventions. Such risk profile is established assessing the nature of the pathogen and possible exposure pathways amongst other factors (FAO, 2006). The importance of information generated by surveillance in the animal population to support these actions will subsequently vary according to the specific risk profile developed. The conceptual links between zoonotic disease surveillance in the animal population and the wider public health disease mitigation process in each of the phases are described in more detail in the subsections below.

Early warning for impending public health threats

Zoonotic diseases originate in the animal population and spread to humans by a range of transmission pathways at the human–animal interface. If cases in the animal population precede the identification of human cases, and the risk profile for public health has been identified as warranting public health mitigation activities, the public health zoonotic disease mitigation objective will be to avoid or reduce the initial spillover events and thus prevent human cases. It has been commonly recognized that at this stage, surveillance data generated in the animal population can offer an early warning signal of the presence or of changes of status of a certain pathogen in this population, and enable a quick and more efficient public health response (Gubernot et al., 2008; Rabinowitz et al., 2009; Flanagan et al., 2012; Levinson et al., 2013). Activities that can be triggered in the public health sector could include the initiation or targeting of surveillance activities in humans, and interventions, such as vaccination if available, activation of preparedness plans and public health messaging activities to increase awareness and prevention, in addition to specific patient-level preventive interventions. In parallel, animal health surveillance can inform interventions in the animal population that reduce the impact of disease in animals and thus indirectly will also benefit public health.

West Nile virus (WNV) infection provides a good example to illustrate this stage. Surveillance of the disease and reporting of bird dye-offs can provide early warning and more effectively prevent human disease caused by the virus (Mostashari et al., 2003; Rabinowitz et al., 2009). Currently, animal health data from wildlife and domestic animals are used to identify high risk areas for WNV transmission to humans and enable public health intervention, such as public education campaigns, preparedness, surveillance and mosquito control in the USA and other countries (Carney et al., 2011; Alba et al., 2013; Chaintoutis et al., 2014). As another example, in Brazil, surveillance of yellow fever in non-human primates was shown to be useful in targeting the efforts for vaccine distribution to populations in affected areas, prior to the emergence of human cases (Almeida et al., 2014).

Information for public health policy and implementation of control strategies

Once a zoonotic hazard is present in the human population, and the risk profile established identifies the need for public health interventions, the public health disease mitigation objective shifts to intervention in order to reduce or eradicate a pathogen from the population. Here, it is likely that animal health surveillance data will be used in addition to public health surveillance data to directly inform actions, namely public health messaging, implementation of control measures along the food chain and implementation and/or targeting of public health surveillance.

The control of foodborne diseases, such as Salmonellosis and Campylobacter in Europe, can be considered as an example of the use of animal health surveillance at such a stage. For these diseases, preventive measures can be targeted within the food chain through data collected on the disease status of the animal population. Post-harvest interventions, such as pasteurization of eggs in response to positive testing for Salmonella (Wegener et al., 2003), provides an example of these links. Information regarding changes in anti-microbial susceptibility of zoonotic pathogens generated by surveillance of anti-microbial resistance in animals, in the food chain and in humans can also provide triggers to redirect anti-microbial drug use in humans (Tollefson et al., 1999).

Generation of knowledge, including the clarification of the epidemiology of health hazards

The risk profile of a certain zoonotic pathogen might be uncertain so that no direct control measures in the human population are warranted, or not yet warranted. The disease mitigation objective is therefore to monitor and gain a better understanding of the situation. Animal health surveillance can be used by the public health sector to inform risk assessments, to identify gaps and improve surveillance systems, or to shape research, all of which contribute with knowledge and understanding that can be used in future interventions.

An example of the animal health and public health links at this stage is given by the integration of surveillance information along the food chain, including food, animal and human data. For anti-microbial resistance, for example, this allowed an integrated analysis of the relationships between the consumption of anti-microbial agents and the occurrence of anti-microbial resistance in humans and food-producing animals at the European level (ECDC et al., 2015).

From Conceptual Links to Operational Economic Assessment

From an economic viewpoint, the presence of zoonotic disease is a source of economic costs related to losses due to morbidity and mortality in humans, animals and impact on the environment. Added to these are expenditures caused by our reaction to the presence of or the risk of presence of a disease. Such reactions include market impacts, such as trade and travel regulations and restrictions, and those derived from consumer reaction and changes in consumer confidence in the food chain. They also include expenditure on our reaction to counterbalance the presence of or the risk of presence of a disease, through the implementation of mitigation activities such as surveillance and intervention (McInerney, 1996; Rushton, 2009, 2013). To maximize economic efficiency, the costs accrued by these surveillance and intervention should be offset by the value resulting from reductions in the set of direct and indirect costs mentioned above. In addition to the assessment of the economic efficiency achieved with resource allocation to surveillance and interventions in itself, central to the economic assessment of zoonoses surveillance in a 'One Health' context is the question of whether integration represents a more effective use of resources and the comparative dimension between integrated and non-integrated surveillance designs.

In the previous section, the conceptualization of the relations between animal health surveillance and public health intervention was provided to form an understanding of possible health consequences and resources associated with zoonoses surveillance and interventions across sectors. In the following subsections, this conceptualization is deepened by adding the identification of the costs and benefit streams for an economic assessment of surveillance in a 'One Health' context. Practical issues for the quantification and valuation of cost and benefits are also considered to support the implementation of an analysis.

The initial framing for the analysis entails the conceptualization of the relations between animal health surveillance and public health as described above and is key to the subsequent steps of identifying costs and benefits of integrated surveillance within the wider disease mitigation context. The identification of a comparative scenario is then needed if a marginal analysis is to be carried out. Once cost items and benefit streams have been identified, their quantification and valuation can be conducted. These steps are systematized in Fig. 1.

Identifying cost components

In a cross-sectoral disease mitigation system, cost components are associated with surveillance and triggered intervention activities, both in the human and in animal populations, as well as information linking components. These include labour, operations and expenses associated with surveillance activities in the animal population, costs associated to share this information with the public health sector, that is an informatics platform to share data or the existence of regular meetings, and costs associated with the existence of public health surveillance systems. If surveillance triggers any actions, then also labour, operations and expenses associated with those interventions in the animal or in the human population need to be considered.

Identifying benefit streams

As mentioned earlier, the benefits streams associated with zoonoses surveillance in the animal population will vary according to the use of surveillance and links to triggered activities. If surveillance of zoonoses in the animal population provides an early warning for public health, and actions are triggered to avert a possible zoonotic threat, the benefit streams from surveillance in the animal population to public health are directly linked to the avoided or reduced cost of illness or burden of disease in the human population and indirect impacts. When surveillance of

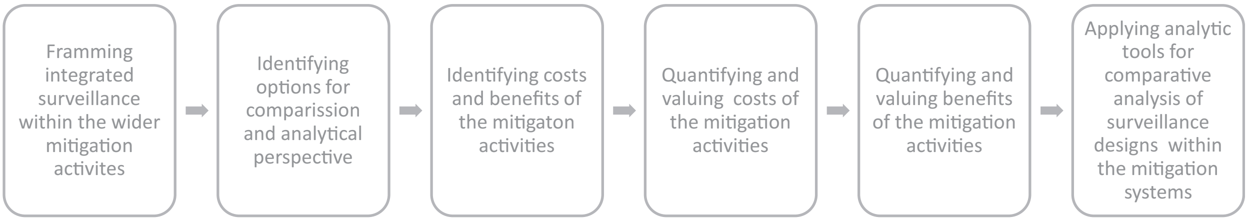

Fig. 1. Proposed steps to carry out on an economic assessment of surveillance of zoonoses in a One Health context (adapted from Guiness and Wiseman, 2011).

zoonoses in the animal population is used by public health to shape health policy and support the implementation of control strategies once disease is present in the human population, benefits to public health of surveillance are related to targeting control and prevention interventions that will ultimately limit the burden of disease in the human population and in the process reduce the expenditure on costs of treatment. Lastly, if surveillance of zoonoses in the animal population is mainly generating knowledge and an increased epidemiological understanding, the benefits associated with surveillance provide a set of intangible benefits associated with knowledge creation, social and intellectual capital, peace of mind, political and technical reassurance and capacity building. Figure 2 illustrates how conceptual links can be used to identify benefit streams associated with surveillance.

From a wider societal perspective, animal health surveillance can also inform interventions in the animal population that reduce the direct and indirect impact of disease in animals. These indirectly benefit public health through better allocation of resources to prevent the transmission of pathogens to human population – a cost saved – and through the avoidance of disease in human population leading to reduced losses in terms of human productivity change, human mortality and the costs of treatments. In summary, a set of monetary, non-monetary and intermediate and other intangible benefits can be associated with surveillance and its links to intervention across sectors.

Valuing costs and benefits and applying analytical approaches

Guidance on the elements to be considered when assessing costs of surveillance and control programmes have been proposed (The World Health Organization, 2005; Centers for Disease Control and Prevention, 2012; Drewe et al., 2014; Calba et al., 2015) and have been described in detail by authors in disease specific scenarios (Somda et al., 2009; Häsler et al., 2012b).

The valuation of monetary and non-monetary benefits will depend on the perspective of the analysis and the outcome chosen. Reductions in cost of illness or in health burden (using metrics such as DALYs or QALYs) are possible ways to express changes on the impact of disease in the human population following implementation of surveillance activities and intervention. Details on the methodology to calculate burden of disease and cost of illness are reviewed in detail elsewhere (Devleesschauwer et al., 2014). Benefit streams in the animal population generally are measured by considering the averted economic loss from the disease through the implementation and expenditure in control and expressed in monetary units. The most common economic analysis tools used in the economics of animal health and production sector are reviewed by Rushton (2009). Intermediate and intangibles benefit streams generated should be considered although its quantification is not straightforward and not always possible. Methods to evaluate these non-market resources include stated preference methods such as contingency valuation, revealed preference methods and qualitative approaches (Guiness and Wiseman, 2011).

These data can then be used in the context of analytical approaches such as cost-benefit analysis, where outcomes of the assessment are expressed in monetary terms, or cost-effectiveness analysis and cost-utility analysis, in which the outcomes monetary costs are expressed per unit of effect of interest (Drummond et al., 2005; Guiness and Wiseman, 2011). The results of these analyses will allow the comparison of additional costs with both monetary and non-monetary outcomes of surveillance conducted in cross-sectoral way.

Discussion

In the aftermath of recent events with pandemic potential, such as severe acute respiratory syndrome, highly pathogenic avian influenza or the 2009 H1N1 influenza pandemic, the recognition of the need for a global effort to implement surveillance systems for zoonotic events has increased. A cross-species approach, including humans, is grounded on the fact that humans share an ecological space with animals with great potential for sharing pathogens. While the integration of surveillance data and better communication along the human–animal-ecosystems

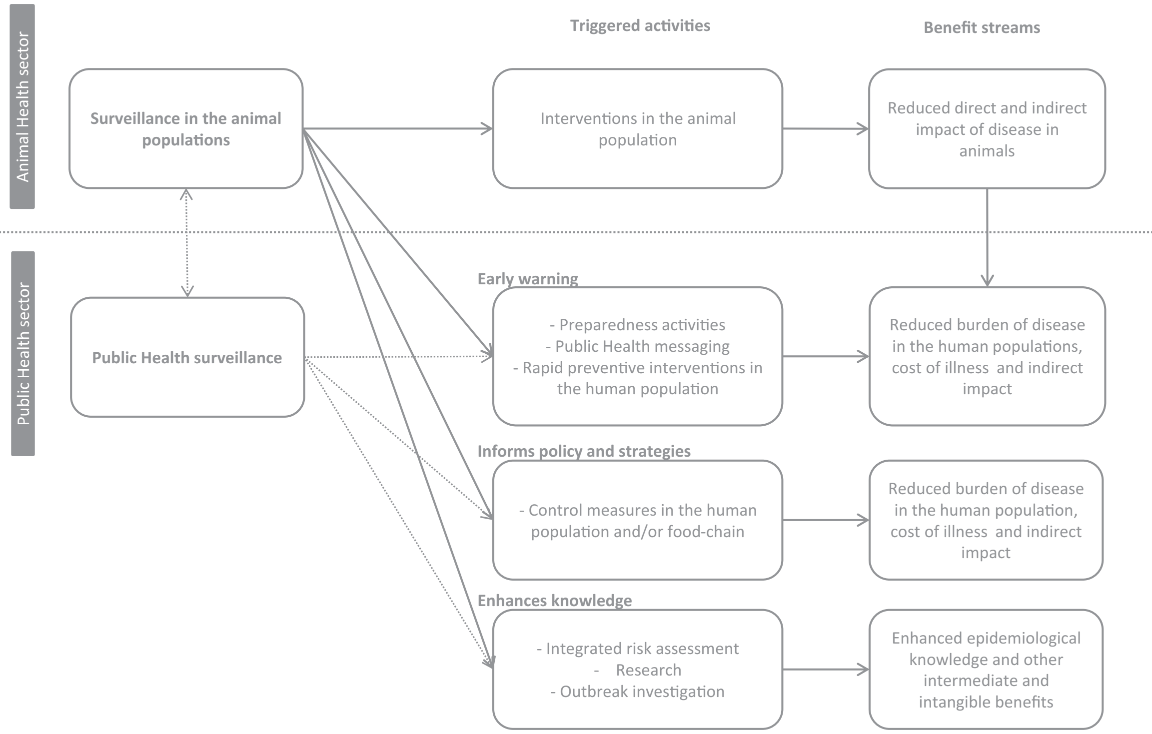

Fig. 2. Conceptual framework of the links between surveillance of zoonoses in the animal population, the wider public health disease mitigation system, and benefit components associated. The diagram depicts possible links between information generated by surveillance in the animal population and examples of triggered public health activities for each conceptual stage. Lastly, economic benefits associated with surveillance and triggered activities are identified. Dotted arrows identify possible links with public health surveillance.

continuum has been identified as key to public health, discussions on the relevance of 'One Health' surveillance have identified that challenges and opportunities remain in the implementation of these approaches (Stärk et al., 2015).

It can be challenging to generate information that allows decision-makers to make informed decisions regarding the allocation of resources to surveillance. The benefit streams of surveillance are not always clear, particularly when seen in a cross-sectoral context. To our knowledge, there is currently no accepted framework providing a recommended approach to document the association between surveillance of zoonotic diseases in animals and/or cross-sectoral approaches and the economic benefits for the public health sector. We propose a generic framework that allows understanding the links between disease mitigation elements across the two sectors and the cost components and benefits streams generated, to be used as a basis for economic assessment. This should help to identify costs and benefits of zoonotic disease surveillance programmes, pillars of the economic assessment of ongoing surveillance programmes for zoonoses and of the planning of effective and efficient future programmes.

In our framework, in addition to the disease dynamics in each population (human and animal species), the risk profile to human health established plays a key role in the utility of information generation by surveillance in the animal population and on the generated benefits. Because the risk profile is not necessarily linked to prevalence or incidence, and takes into consideration other aspects such as pathogen, exposure pathways to the human population and risk perception by the public, the disease mitigation stages and objectives here do not necessarily follow a continuum. An example is when the detection of human cases triggers surveillance and intervention in the animal population (Alves et al., 2012). Humans serving as sentinels for animals can occur in situations where public health disease surveillance and capacity exceed animal health capacity (Rabinowitz et al., 2009). In such a situation, surveillance of animal populations will not provide an early warning signal to the public health sector, but can contribute to knowledge enhancement or to the implementation of control strategies.

The presented framework identifies links between animal health and public health disease mitigation, and the possible health consequences and benefits generated. Yet, factors such as professional segregation, the lack of communication between human health and animal health care professionals, data separation, that is surveillance streams operating independently, and evidence gaps continue to prevent better integration of human and animal disease information (Rabinowitz et al., 2009; Stärk et al., 2015). To overcome these obstacles, suggested solutions include enhanced communication between human and animal health, the use of new technologies to better link animal and human data and addressing gaps in evidence (Rabinowitz et al., 2009). The presented conceptualization will ultimately add to the latter point, by contributing to the enhanced knowledge on economic aspects of surveillance in a cross-sectoral perspective.

For the public health sector, guidelines for the economic evaluation of surveillance and response for epidemic-prone infectious diseases have been proposed following the increasing international call for enhanced surveillance and response capacities and the recognition of the need for further evaluation of costs and benefits of these systems (The World Health Organization, 2005). On the animal health sector, work conducted on the economic aspects of surveillance has showed that the economic value of surveillance cannot be assessed if not seen as part of the wider disease mitigation process. The authors developed a framework which conceptualizes the technical relationships between animal disease mitigation, surveillance and intervention as a tool to guide economic analysis in terms of allocation of scarce resources to animal disease mitigation (Häsler et al., 2011). More recently, Guo et al. (2014) propose a framework for single-hazard surveillance system economic evaluation, in a three-step approach including the obtainment of the most efficient set of set-ups of surveillance, determination of the impacts of each surveillance set-up on the hazard and the subjective evaluation of the impacts by stakeholders.

The practical applications of these economic assessments to public health and animal health surveillance systems have emphasized their usefulness, but have also highlighted the existing constraints surrounding data availability to populate the economic models developed (Elbasha et al., 2000; Somda et al., 2010). The economic assessment of surveillance and interventions in specific cases is data-demanding, which eventually can limit the feasibility of such assessments. Information on valuation of both monetary and non-monetary costs and benefits in the human and animal populations is needed to populate the economic models. Hence, improvements on data collection and availability are pre-requisites for an enhanced capacity to conduct economic assessments and estimate the outcomes of zoonoses surveillance. Possibly due to the intensity of data requirements, the availability of economic assessments of surveillance systems, more specifically those that address zoonoses, is still scarce (DFID, 2011).

Previous work made reference to conceptual aspects of 'One Health' surveillance. Narrod et al. (2012) proposed an integrated epidemiological and economic framework for assessing zoonoses using a 'One Health' concept. The authors propose a 4-step approach using a modified risk analysis framework to inform decision-making on intervention programmes. The sequential stages within the framework involve the estimation of the extent of the disease and potential spread, the estimation of the cost of disease, the assessment of the cost-effectiveness of various interventions and the identification of factors affecting adoption of risk reduction strategies. The conceptual approach proposed by Guo et al. (2014) for the economic analysis of single-hazard surveillance systems also allows incorporating human health aspects. More recently, Häsler et al. (2014b) proposed a framework to assess the value of rabies interventions holistically where the economic assessment is seen within a wider cadre of epidemiological, animal health and social assessment. Our work is hence contributing to and integrating an increasing body of work and consideration on the conceptual aspects of animal disease mitigation and public health benefits within the current 'One Health' *momentum*. As our understanding of the added value of cross-sectoral efforts to tackle zoonoses builds, other important dimensions to 'One Health', such as the ecosystem component, can be conceptualized and added in future work to this conceptual framework. It is possible that this could help in the identification of environmental interventions capable of benefiting both human and animal health.

Importantly, surveillance in animal populations and established linkages to human health that allow sharing and co-analysis of such information can convey significant intangible benefits. These intangibles pertain to, amongst others, knowledge generation, intellectual and social capital, peace of mind and have been identified in reviewed literature (Häsler et al., 2014a). The acknowledgment and possible valuation of the generation of these assets are central to accurately understand the added value of 'One Health' approaches to surveillance.

Information on the added economic value of surveillance of zoonoses conducted in a 'One Health' needs to be assessed to understand how much integration of information should be pursued. Whilst the proposed framework should be applicable to a range of surveillance types, for example passive and active surveillance, disease categories and integration levels, it is likely that different surveillance designs, the biology of the hazard under consideration, the category of disease and country settings will impact on the results. These characteristics will ultimately define the resources needed for the surveillance system (e.g. active surveillance tends to be more costly than passive designs) and the health outcomes and benefits accrued by the surveillance and intervention activities. Hence, the use of the presented framework in specific contexts and disease examples is encouraged. A case-by-case assessment will provide detailed information on whether a 'One Health' design is the most efficient way to allocate surveillance resources. The application of the framework to the assessment of specific programmes will also provide information on issues related to sharing costs and benefits of mitigation across the animal and the public health sector. Based on experiences from its use, debate should continue on how the framework can be improved.

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References

Alba, A., A. Allepuz, S. Napp, M. Soler, I. Selga, C. Aranda, J. Casal, N. Pages, E. B. Hayes, and N. Busquets, 2013: Ecological surveillance for west Nile in Catalonia (Spain), learning from a five-year period of follow-up. *Zoonoses Public Health* 61, 181–191.

Almeida, M. A. B., J. da. C. Cardoso, E. Dos Santos, D. F. da Fonseca, L. L. Cruz, F. J. C. Faraco, M. A. Bercini, K. C. Vettorello, M. A. Porto, R. Mohrdieck, T. M. S. Ranieri, M. T. Schermann, A. F. Sperb, F. Z. Paz, Z. M. A. Nunes, A. P. M. Romano, Z. G. Costa, S. L. Gomes, and B. Flannery, 2014: Surveillance for yellow Fever virus in non-human primates in southern Brazil, 2001–2011: a tool for prioritizing human populations for vaccination. *PLoS Negl. Trop Dis.* 8, e2741.

Alves, M. J., J. M. D. Poças, T. Luz, L. Zé-Zé, F. Amaro, and H. Osório, 2012: Infecção por vírus West Nile (Flavivírus) em Portugal caso clínico de síndrome febril/ West Nile virus (Flavivirus) infection in Portugal Considerations about a clinical case with febrile. *RPDI* 8, 46–51.

Calba, C., F. L. Goutard, L. Hoinville, P. Hendrikx, A. Lindberg, C. Saegerman, and M. Peyre, 2015: Surveillance systems evaluation: a systematic review of the existing approaches. *BMC Public Health* 15, 448.

Carney, R. M., S. C. Ahearn, A. McConchie, C. Glaser, C. Jean, C. Barker, B. Park, K. Padgett, E. Parker, E. Aquino, and V. Kramer, 2011: Early warning system for west Nile virus risk areas, California, USA. *Emerg. Infect. Dis.* 17, 1445–1454.

Centers for Disease Control and Prevention, 2012. SurvCost. Available at: http://www.cdc.gov/globalhealth/healthprotection/ghsb/idsr/tools/survcost.html (accessed on 8 May 2014)

Chaintoutis, S. C., C. I. Dovas, M. Papanastassopoulou, S. Gewehr, K. Danis, C. Beck, S. Lecollinet, V. Antalis, S. Kalaitzopoulou, T. Panagiotopoulos, S. Mourelatos, S. Zientara, and O. Papadopoulos, 2014: Evaluation of a West Nile virus surveillance and early warning system in Greece, based on domestic pigeons. *Comp. Immunol. Microbiol. Infect. Dis.* 37, 131–141.

Coker, R., J. Rushton, S. Mounier-Jack, E. Karimuribo, P. Lutumba, D. Kambarage, D. U. Pfeiffer, K. Stärk, and M. Rweyemamu, 2011: Towards a conceptual framework to support one-health research for policy on emerging zoonoses. *Lancet Infect. Dis.* 11, 326–331.

Daszak, P., A. A. Cunningham, and A. D. Hyatt, 2000: Emerging infectious diseases of wildlife– threats to biodiversity and human health. *Science* 287, 443–449.

Declich, S., and A. O. Carter, 1994: Public health surveillance: historical origins, methods and evaluation. *Bull. World Health Organ.* 72, 285–304.

Devleesschauwer, B., A. H. Havelaar, C. Maertens de Noordhout, J. A. Haagsma, N. Praet, P. Dorny, L. Duchateau, P. R. Torgerson, H. Van Oyen, and N. Speybroeck, 2014: DALY calculation in practice: a stepwise approach. *Int. J. Public Health* 59, 571–574.

DFID, 2011. Surveillance and Monitoring of Zoonoses, Report for the Department for International Development. Available at http://r4d.dfid.gov.uk/PDF/Outputs/livestock/60877-Zoonoses_FinalReport_Oct2011_Submitted.pdf (accessed on 18 September 2013)

Drewe, J. A., B. Häsler, J. Rushton, and K. D. C. Stärk, 2014: Assessing the expenditure distribution of animal health surveillance: the case of Great Britain. *Vet. Rec.* 174, 16.

Drummond, M. F., M. J. Sculpher, G. W. Torrance, B. J. O'Brien, and G. L. Stoddart, 2005: Methods for the Economic Evaluation of Health Care Programmes. Oxford University Press, Oxford, Uk.

ECDC, EFSA, EMA, 2015: ECDC/EFSA/EMA first joint report on the integrated analysis of the consumption of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from humans and food-producing animals. *EFSA J.* 13, 114.

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

FAO, 2006: Food Safety Risk Analysis, A Guide for National Food Safety Authorities. FAO, Rome.

Flanagan, M. L., C. R. Parrish, S. Cobey, G. E. Glass, R. M. Bush, and T. J. Leighton, 2012: Anticipating the species jump: surveillance for emerging viral threats. *Zoonoses Public Health* 59, 155–163.

Greter, H., V. Jean-Richard, L. Crump, M. Béchir, I. O. Alfaroukh, E. Schelling, B. Bonfoh, and J. Zinsstag, 2014: The benefits of "One Health" for pastoralists in Africa. *Onderstepoort J. Vet. Res.* 81, E1–E3.

Gubernot, D. M., B. L. Boyer, and M. S. Moses, 2008: Animals as early detectors of bioevents: veterinary tools and a framework for animal-human integrated zoonotic disease surveillance. *Public Health Rep.* 123, 300–315.

Guiness, L., and V. Wiseman (Eds.), 2011. Introduction to Health Economics. Open University Press, Berkshire.

Guo, X., G. D. H. Claassen, A. G. J. M. Oude Lansink, and H. W. Saahtkamp, 2014: A conceptual framework for economic optimization of single hazard surveillance in livestock production chains. *Prev. Vet. Med.* 114, 188–200.

Halliday, J., C. Daborn, H. Auty, Z. Mtema, T. Lembo, B. M. D. Bronsvoort, I. Handel, D. Knobel, K. Hampson, and S. Cleaveland, 2012: Bringing together emerging and endemic zoonoses surveillance: shared challenges and a common solution. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 367, 2872–2880.

Häsler, B., K. S. Howe, and K. D. C. Stärk, 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.

Häsler, B., K. S. Howe, E. Di Labio, H. Schwermer, and K. D. C. Stärk, 2012a: Economic evaluation of the surveillance and intervention programme for bluetongue virus serotype 8 in Switzerland. *Prev. Vet. Med.* 103, 93–111.

Häsler, B., K. S. Howe, P. Presi, and K. D. C. Stärk, 2012b: An economic model to evaluate the mitigation programme for bovine viral diarrhoea in Switzerland. *Prev. Vet. Med.* 106, 162–173.

Häsler, B., W. Gilbert, B. A. Jones, D. U. Pfeiffer, J. Rushton, and M. J. Otte, 2013: The economic value of One Health in relation to the mitigation of zoonotic disease risks. *Curr. Top. Microbiol. Immunol.* 365, 127–151.

Häsler, B., L. Cornelsen, H. Bennani, and J. Rushton, 2014a: A review of the metrics for One Health benefits. *Rev. Sci. Tech. Off. Int. Epiz.* 33, 453–464.

Häsler, B., E. Hiby, W. Gilbert, N. Obeyesekere, H. Bennani, and J. Rushton, 2014b: A one health framework for the evaluation of rabies control programmes: a case study from Colombo city, Sri Lanka. *PLoS Negl. Trop. Dis.* 8, e3270.

Hugh-Jones, M. E., P. R. Ellis, and M. R. Felton, 1975: An Assessment of the Eradication of Bovine Brucellosis in England and Wales. Department of Agriculture and Horticulture, University of Reading, Reading, UK.

Levinson, J., T. L. Bogich, K. J. Olival, J. H. Epstein, C. K. Johnson, W. Karesh, and P. Daszak, 2013: Targeting surveillance for zoonotic virus discovery. *Emerg. Infect. Dis.* 19, 743–747.

McInerney, J., 1996: Old economics for new problems – livestock disease: presidential address. *J. Agric. Econ.* 47, 295–314.

Morse, S. S., J. A. Mazet, M. Woolhouse, C. R. Parrish, D. Carroll, W. B. Karesh, C. Zambrana-Torrelio, W. I. Lipkin, and P. Daszak, 2012: Prediction and prevention of the next pandemic zoonosis. *Lancet* 380, 1956–1965.

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

Narrod, C., J. Zinsstag, and M. Tiongco, 2012: A one health framework for estimating the economic costs of zoonotic diseases on society. *EcoHealth* 9, 150–162.

Rabinowitz, P., M. Scotch, and L. Conti, 2009: Human and animal sentinels for shared health risks. *Vet. Ital.* 45, 23–24.

Roth, F., J. Zinsstag, D. Orkhon, G. Chimed-Ochir, G. Hutton, O. Cosivi, G. Carrin, and J. Otte, 2003: Human health benefits from livestock vaccination for brucellosis: case study. *Bull. World Health Organ.* 81, 867–876.

Rushton, J., 2009. Economic Analysis Tools. In: Rushton, J. (ed.), The Economics of Animal Health and Production, pp. 65–107. CABI, Oxfordshire.

Rushton, J., 2013. An overview of analysis of costs and benefits of government control policy options In: Proceedings of the Workshop on Livestock Disease Policies: Building Bridges Between Science and Economics, 3-4 June 2013, Organisation for Economic Co-operation and Development, Paris, France. Available at http://www.oecd.org/tad/agricultural-policies/livestock-diseases-2013.htm.

Rushton, J., B. Häsler, N. De Haan, and R. Rushton, 2012: Economic benefits or drivers of a “One Health” approach: why should anyone invest? *Onderstepoort J. Vet. Res.* 79, 461–465.

Scotch, M., L. Odofin, and P. Rabinowitz, 2009: Linkages between animal and human health sentinel data. *BMC Vet. Res.* 5, 15.

Somda, Z. C., M. I. Meltzer, H. N. Perry, N. E. Messonnier, U. Abdulmumini, G. Mebrahtu, M. Sacko, K. Touré, S. O. Ki, T. Okorosobo, W. Alemu, and I. Sow, 2009: Cost analysis of an integrated disease surveillance and response system: case of Burkina Faso, Eritrea, and Mali. *Cost Eff. Resour. Alloc.* 7, 1.

Somda, Z. C., H. N. Perry, N. R. Messonnier, Z. C. Somda, H. N. Perry, N. R. Messonnier, M. H. Djingarey, S. O. Ki, and M. I. Meltzer, 2010: Modeling the cost-effectiveness of the integrated disease surveillance and response (IDSR) system: meningitis in Burkina Faso. *PLoS ONE* 5, 1–10.

Stärk, K. D. C., M. A. Kuribreña, G. Dauphin, S. Vokaty, M. P. Ward, B. Wieland, and A. Lindberg, 2015: One Health Surveillance – more than a buzz word? *Prev. Vet. Med.* 120, 124–130.

Tambi, E. N., O. W. Maina, and J. C. Mariner, 2004: Ex-ante economic analysis of animal disease surveillance. *Rev. Sci. Tech. Off. Int. Epiz.* 23, 737–752.

Thacker, S. B., and R. L. Berkelman, 1988: Public health surveillance in the United States. *Epidemiol. Rev.* 10, 164–190.

The World Bank, 2010. People, Pathogens and Our Planet Volume 1?: Towards a One Health Approach for Controlling Zoonotic Diseases, Report No. 50833-GLB. The World Bank, Washington, DC.

The World Health Organization, 2005. Evaluating the costs and benefits of national surveillance and response systems. Available at http://whqlibdoc.who.int/hq/2005/WHO_CDS_EPR_LYO_2005_25_eng.pdf (accessed on 18 September 2013).

Tollefson, L., P. J. Fedorka-Cray, and F. J. Angulo, 1999: Public health aspects of antibiotic resistance monitoring in the USA. *Acta Vet. Scand. Suppl.* 92, 67–75.

Vrbova, L., C. Stephen, N. Kasman, R. Boehnke, M. Doyle-Waters, A. Chablitt-Clark, B. Gibson, M. FitzGerald, and D. M. Patrick, 2010: Systematic review of surveillance systems for emerging zoonoses. *Transbound. Emerg. Dis.* 57, 154–161.

Wegener, H. C., T. Hald, D. Lo, F. Wong, M. Madsen, H. Korsgaard, F. Bager, P. Gerner-smidt, and K. Mølbak, 2003: Salmonella control programs in Denmark. *Emerg. Infect. Dis.* 9, 774–780.

Wendt, A., L. Kreienbrock, and A. Campe, 2014: Zoonotic disease surveillance – inventory of systems integrating human and animal disease information. *Zoonoses Public Health* 62, 61–74.

Zinsstag, J., E. Schelling, F. Roth, B. Bonfoh, D. de Savigny, and M. Tanner, 2007: Human benefits of animal interventions for zoonosis control. *Emerg. Infect. Dis.* 13, 527–531.

Zinsstag, J., E. Schelling, D. Waltner-Toews, and M. Tanner, 2011: From “one medicine” to “one health” and systemic approaches to health and well-being. *Prev. Vet. Med.* 101, 148–156.

