HandiResponse: Software tools for designing optimal One Health surveillance portfolio for emerging zoonotic diseases

JS MCKENZIE[1]*, S WANG[2], RS MORRIS[3], EN NEUMANN[4], BD O'LEARY[5], M. SUJAU[5], RM CANNON[6]
[1]International Development Group, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Palmerston North, New Zealand; [2]World Bank, Washington DC, United States of America; [3]MorVet Ltd., Masterton, New Zealand; [4]Epi-Insight Ltd. Palmerston North, New Zealand; [5]EpiSoft Ltd., Palmerston North, New Zealand; [6]Warrnambool, Vic., Australia

*j.s.mckenzie@massey.ac.nz

Abstract

Human and Animal Disease Response (HandiResponse) is a practical software tool for designing an economically optimal multi-component surveillance portfolio for promptly detecting infectious disease incursions. The software is particularly useful for early detection of zoonotic emerging and re-emerging infectious diseases (ERID) by optimising risk-based surveillance approaches across humans and animals considering both technical and economic efficiency of the various sources of surveillance data. The software includes five modules for: generating a disease risk landscape, mapping disease risk, modelling disease spread and applying various surveillance methods in animals and humans to these outbreaks, evaluating the economic benefits and costs of each surveillance method, and then using a global optimisation algorithm to identify an optimal portfolio of surveillance methods that detects incursions promptly and optimises the use of available resources. The components of HandiResponse optimise the use of existing information and can be readily updated as further information becomes available, making this a useful tool in data-sparse environments. It is a valuable tool for building surveillance capability and capacity within resource-limited countries. It is currently being used in Liberia for training epidemiologists to design integrated surveillance strategies for Ebola and other zoonotic diseases, and building understanding of surveillance optimisation amongst decision-makers and Ministers.

Application of HandiResponse to design surveillance systems for Crimean Congo Haemorrhagic Fever (CCHF) in Mongolia and an invented disease of pigs and humans in Australia demonstrates the utility of components of the suite of software tools to develop economically optimal surveillance systems for early detection of the diseases. Preparation of a risk landscape for CCHF using climatic and environmental variables associated with *Hyalomma* tick distribution facilitated targeted serological testing of humans and sheep. This demonstrated the presence in both of CCHF infection, which had previously been unrecognised in Mongolia. A combination of modelling, economic evaluation and an optimisation tool identified optimal surveillance portfolios for detection of the invented disease of pigs and humans.

Keywords: *One Health, risk-based surveillance, surveillance portfolio, optimisation, disease modelling*

Introduction

The emergence and spread of a series of major infectious diseases of zoonotic origin over recent years has caused considerable interest in developing improved methods of responding to such problems, because they have major ramifications not just for the health of people and animals, but also for economic growth, national development, social stability, and international movement of people and products (1). To mitigate the negative impacts of an identified ERID in countries at risk of becoming infected with the disease it is imperative to have a sensitive surveillance system for early disease detection. Furthermore, from the economic perspective, resources are always scarce and have opportunity cost, so investment in surveillance programs has to demonstrate that it can maximise the utility of available resources. Having a suite of tools to facilitate the design of optimal disease surveillance systems is particularly helpful to both optimise the use of limited resources and to facilitate training of personnel to enhance disease surveillance in countries where such expertise and skills are limited.

Human and Animal Disease Response (HandiResponse) includes the following five software modules:

1. HandiMap- for storing global satellite imagery (70+ layers), administrative boundaries, population data sets, etc and visualising individual spatial data layers and risk landscapes derived from multiple layers;
2. HandiSurv – for combining several layers of spatial data to prepare a disease risk landscape that represents spatial variation in the expected occurrence of a disease, based on epidemiological literature and evidence;
3. HandiSpread - for modelling disease spread in animals and humans using the risk landscape to adjust transmission coefficients, and modelling the time to disease detection, cost and benefit of a range of surveillance methods (2);
4. HandEcon – for evaluating the economic benefit and costs of each of a range of surveillance activities to detect a disease incursion rapidly and cost-effectively, allowing for variation in detection sensitivity and investigation intensity;

5. OptiSurv – a global optimisation procedure for identifying a portfolio of surveillance methods that optimises the use of available resources to meet specified disease control objectives.

The software operates as an integrated web-enabled tool set, which is available globally or can be installed in a country.

The objective of this study was to demonstrate the utility of applying the components of the HandiResponse software tools to develop optimal surveillance systems for early detection of two diseases: Crimean Congo Haemorrhagic Fever (CCHF) in Mongolia and an invented "emerging disease" of pigs and humans in Australia, named Austeria.

Risk-based surveillance for Crimean Congo Haemorrhagic Fever (CCHF) in Mongolia

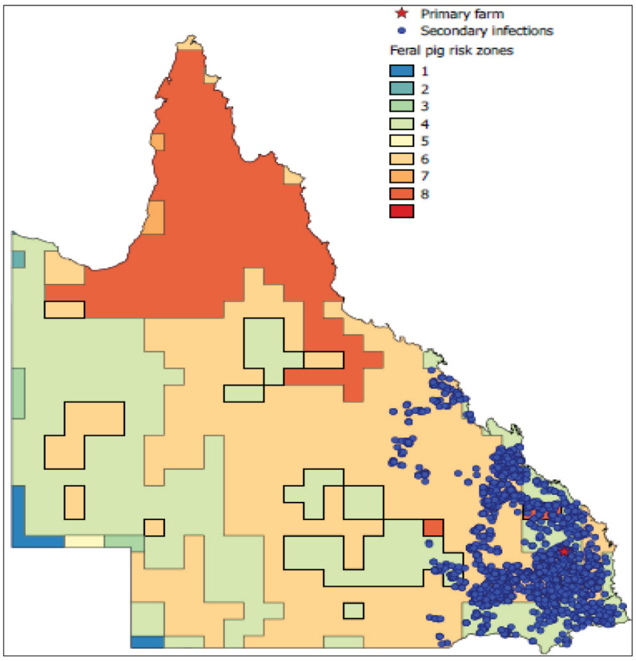
There was no evidence of human or animal exposure to CCHF virus in Mongolia prior to 2013, despite the country having some areas with similar ecological conditions and fauna to areas in surrounding countries where CCHF is endemic (3,4), and the severe nature of the disease. Areas of Mongolia with high and low risk for the presence of CCHF were identified by building risk landscapes based on habitat suitability for the vector *Hyalomma spp.* (5) and the ecological requirements for disease maintenance in HandiSurv and visualising the resulting risk landscapes in HandiMap. The risk landscapes derived by the two methods were similar. A cross-sectional serological investigation for the presence of antibodies to CCHF virus among transhumant herders and their sheep was implemented in districts predicted to be high and low risk for the occurrence of CCHF virus. Antibodies to CCHFV were detected in either sheep or human blood in all 21 districts sampled in the sparsely populated high risk Gobi Desert area in the south of Mongolia, and in both species in 15 of 21 districts. One district in the province of Selenge in the low risk area was completely negative for anti-CCHFV IgG in both sheep and human blood samples.

This study generated the first serological evidence that CCHF infection has occurred in both people and domestic animals in Mongolia, and that the evidence of infection is present in areas of high ecological risk for both host ticks and the disease, but not in a low risk area. While this pattern of CCHF sero-positivity among both human and sheep in multiple locations suggests that the disease is likely to be endemic in at least some parts of the country, isolation and characterisation of the virus would be required to provide definitive proof. Further investigation needs to be conducted to understand why no human cases of CCHF have not yet been reported in Mongolia.

Optimised surveillance portfolios for Austeria - an invented "emerging disease" of pigs and humans in Australia

We used a hypothesised zoonotic disease, Austeria, as an example to model the effects of different surveillance options for detection of a novel disease and to demonstrate the process for identifying an optimised disease surveillance portfolio. A temporal and spatial dynamic model of Austeria in pigs and humans in Queensland, Australia was developed in HandiSpread, using the distribution of feral pigs in the State as the basis for the risk landscape (figure 1). Eight surveillance components were designed to detect the disease by using various traditional and risk-based surveillance procedures to detect infected pig or human populations. Each component had nine variant sub-components that differed in surveillance intensity and sensitivity of detection. The efficiency of each surveillance method in detecting a disease incursion was evaluated using the Austeria model in HandiSpread, as measured by: (i) number of days from primary case to outbreak detection (efficiency), (ii) proportion of simulated outbreaks detected (effectiveness), (iii) cost of the surveillance activity, and (iv) number of farms infected by the date of detection (which strongly influences economic consequences of the outbreak).

Figure 1. Spatial distribution of Austeria infected pig herds in a median outbreak overlaid on top of the feral pig zones in Queensland, Australia



The evaluation was conducted by simulating 99 epidemiologically distinct outbreaks, then separately evaluating the performance of each surveillance component and its subcomponents on these 99 outbreaks.

The most efficient surveillance approach was risk-based sampling of commercial herds in areas where there was substantial numbers of both commercial herds and feral pigs, detecting an outbreak at a median of 108 days after incursion, at which time a median of 23 farms were infected, and successfully detecting over 93 percent of the 99 simulated outbreaks. The least efficient method was using hunters to collect blood samples from feral pigs they captured. This

method detected only 3% of the 99 simulated outbreaks at a median number of 281 days after the incursion, by which time a median of 2,515 farms were already infected. The performance indicators of the remaining six surveillance components were clustered in the middle of the range between the two extreme results.
The costs and benefits of each surveillance component were assessed in HandEcon. Benefits were represented by the difference in the number of farms that had become infected at the time each component first detected the infection compared with no surveillance, multiplied by the impact of the disease on production at individual farm level. Impacts in the human population were estimated by calculating disability-adjusted life years (DALYs) lost plus costs of patient care.

The economic outcome of each surveillance component is utilised by OptiSurv to identify and rank the ten "best" surveillance portfolios using one of three different decision rules which could be applied by decision-makers, depending on the relative importance of human and animal disease caused by Austeria. For the eight individual surveillance components considered, each with nine different sub-components representing different combinations of intensity of investigation and detection sensitivity, 100 million different portfolios were possible. The optimisation procedure ranked the ten best portfolios of the 100 million in order, for a range of decision rules. The decision rules give different weightings to human health effects, animal health effects, and costs of surveillance. The ten best portfolios for each decision rule were all multi-component portfolios, ranking higher than any single component portfolio.

Discussion

Utilising the HandiSurv module of HandiResponse to identify areas of Mongolia that were high risk and low risk for CCHF based on habitat suitability for *Hyalomma spp.* or ecological factors favourable to the disease provided a useful tool to design an epidemiological study to determine whether there was evidence of CCHF infection in sheep and/or in humans. The risk assessment methods identified high risk areas with high specificity since either sheep or humans seropositive for CCHF were found in all 21 high risk areas that were tested. While testing was only conducted in one low risk area, the lack of any seropositive sheep or people indicated that this was accurately predicted to be low risk. Further testing would need to be conducted in other low risk areas to provide further confidence of the accuracy of the risk stratification. It was unclear why human cases of CCHF had never been diagnosed in Mongolia. Following this study, medical professionals working in the high risk areas were provided with training in the clinical symptoms of CCHF in people and the associated transmission risks, to increase the probability of cases being accurately diagnosed if present. The human population density in the high risk region is very low, and access to medical services very limited, which may help explain why no cases have been diagnosed. Further studies will need to investigate animal hosts for the presence of CCHF virus using PCR methods.

Analysis of outputs from HandiSpread modelling compared the performance of 72 different surveillance options for the hypothesised disease Austeria. In combination with subsequent economic analysis and processing with the global optimisation procedure OptiSurv, these tools provided a practical and efficient way for screening all 100 million possible combinations of the 72 surveillance components to identify the most suitable combination of components to make up a surveillance portfolio, using a range of decision rules which considered both epidemiological and economic factors. It demonstrated that multi-component surveillance programs could perform better than any single surveillance component, when evaluated for a range of 99 simulated variations of a single disease outbreak. The analytical approaches and the optimisation tool used in the study are generalisable for optimisation of surveillance programs for other infectious diseases, and can be applied in any country.

These studies illustrated a set of tools that could enable an epidemiologist in any country to use available evidence about an emerging disease which might enter the country to develop a risk landscape for the disease and use such knowledge to plan an optimal mix of surveillance activities to detect the disease promptly and cost-effectively should it be likely to enter the country.

The HandiResponse tool and associated methodologies are currently being used in a World Bank funded program to design optimal surveillance portfolios for early detection of a possible transfer of Ebola virus from animals to people in Liberia using global satellite data and national demographic information. The tools will also be made available for designing surveillance strategies for other zoonotic diseases in Liberia, and epidemiologists will be trained in use of the tools. A similar approach can also be applied in other countries, for any zoonotic disease

References

1. **UNDG.** *Socio-Economic Impact of Ebola Virus Disease in West African Countries - A call for national and regional containment, recovery and prevention*. New York, USA, United Nations Development Programme Regional Bureau for Africa, p93, 2015
2. **Stevenson M *et al.*** *Prev Vet Med* 109(1), 10-24, 2013
3. **Atkinson B *et al.*** *International Journal of Infectious Diseases* 17(11), e1031-e1037, 2013
4. **Yashina L *et al.*** *Journal of General_Virology* 84(5), 1199-1206, 2003
5. **Estrada-Peña A *et al.*** *Journal of Medical Entomology* 44(6), 1130-1138, 2007