A portfolio framework for allocating resources to risk-based national disease surveillance activities, with an application to Bovine Spongiform Encephalopathy

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Summary

Protection analysis is described as a new approach to the allocation of resources to different components of a national animal health surveillance system, in order to build an optimum national animal health surveillance strategy. The example of BSE is used to illustrate how this framework can be applied to a disease which represents major challenges in achieving cost-effective surveillance. Using a combination of simulation modelling and iterative solution by the method of moments, biased surveillance sources can be combined to produce a best estimate of the BSE status of the standing cattle population for a country, applying a Bayesian approach to take account of prior information about the history of BSE exposure for the country.

Introduction

While the concept of relating surveillance to the nature and scale of particular risks has been talked about, there is little evidence that much progress has been made in achieving this objective of "risk-based surveillance". Traditional thinking about surveillance has divided techniques into active and passive surveillance, but this differentiation has become outdated as the range of techniques and their sophistication has grown, with many techniques having features of both. Moreover, these terms focus on the data gathering method, whereas it would be more appropriate to consider the objectives of the surveillance system.

We prefer the following classification:
Scanning surveillance provides an overview of the patterns of overall disease occurrence, and detection of marked changes in disease patterns within particular animal populations.
Targeted surveillance answers specific questions of importance on the occurrence and epidemiological features of diseases of particular national interest or concern.
Food safety surveillance focuses specifically on the safety of the food supply for human consumption, including matters such as drug residues and zoonotic pathogens.

These elements are combined in various ways to form an integrated surveillance strategy. In order to make the strategy "risk-based", it is proposed that "protection analysis" be developed as a new approach to assess the optimum mix of different components of particular surveillance activities. An initial example is under development using bovine spongiform encephalopathy (BSE) to test the approach in a case study of an important global disease surveillance issue.

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Objective: To develop a method which can be used to interpret BSE surveillance data for infected countries, and to optimally allocate surveillance resources for BSE in both infected and free countries.

Materials and methods

Surveillance for BSE presents some exceptionally challenging problems. We cannot directly measure the level of infection in the national cattle herd (termed the standing cattle population) as we can do for many other diseases, but have to estimate it indirectly from animals examined at the time of death. Because BSE can only be definitively diagnosed on brain samples, surveillance can only be conducted on animals which are leaving the population as a result of slaughter or death. These animals can be examined through four different mechanisms, which we call for this purpose ‘surveillance streams’, since animals are flowing through each stream continuously as individuals die or are slaughtered, and material becomes available for testing from:

1. Clinical suspects: animals examined on farms showing neurological signs which may be consistent with BSE.
2. Fallen stock: animals which die or become moribund on farms, and from which samples are taken for diagnosis.
3. Casualty culls or slaughters: animals which are abnormal in some respect, but are eligible for slaughter under special restrictions.
4. Healthy slaughters: adult animals in the eligible age group, for which brains are examined after slaughter.

Items 1 to 3 are targeted surveillance activities, while item 4 is a scanning surveillance procedure, and in infected countries may also be used for food safety surveillance.

Each of the four surveillance streams is drawn from a sub-population of the total standing cattle population which represents a biased sample of the standing population with respect to age distribution, industry sector, BSE prevalence, and ascertainment efficiency. Moreover, current tests can only detect infection a few months before the disease becomes clinically apparent.

Results and Discussion

For an infected country, the first objective is to estimate from these biased samples, the true prevalence of BSE in the standing cattle population of the country. This is done in two stages. First, a simple simulation model of the national cattle population is used to estimate (from data supplied by the country) the annual number of cattle from each birth cohort passing through each of the four surveillance streams, and hence the number of animals from each birth cohort remaining in the standing population. This requires only data on the age distribution, industry sector mix and number of cattle processed in each surveillance stream for the year, plus data on the age distribution, industry sector mix and total size of the standing population. The number tested in one or more streams may be zero.

Second, the number of animals which tested positive for BSE in each stream (by age and industry sector) is used in an iterative procedure based on the method of moments, to determine a value for the BSE prevalence in the standing population which equates the modelled number of BSE cases with the observed number of cases in the four surveillance streams. This method integrates the data from whichever of the surveillance methods are being used in the country, to produce a single estimate of the prevalence of BSE in the standing population, taking into account the percentage cover achieved in each surveillance stream. It also produces an estimate of the prevalence of BSE in each birth cohort (with confidence intervals), allowing assessment of the pattern of exposure over earlier years.

This information can be used in conjunction with information on test costs and sensitivity/specificity to estimate the payoff from investing additional resources in each of the four component surveillance activities, and hence to optimise the allocation of surveillance resources to different activities in order to estimate BSE prevalence in the country with the desired width of confidence interval.

For countries which are conducting surveillance but have not ever detected an infected animal, a similar procedure can be applied to calculate an upper confidence limit on prevalence of BSE which could be present in the country but as yet undetected, consistent with the types and levels of surveillance activities which have been conducted. However this does not consider prior knowledge on the extent to which the country has been exposed to the risk of BSE occurring, as a consequence of its past record of importing risky items such as meat and bone meal and live cattle from infected countries. This prior information on exposure risk and amplification risk is therefore used in a Bayesian analysis to adjust the risk level for each country, and hence to revise the estimated payoff from resources applied to each of the four surveillance streams.

Again, information on test costs and sensitivity/specificity can be used to optimise the allocation of resources to each of the four surveillance streams, in order to give the desired level of confidence that the country is highly unlikely to have any BSE present. For a country with a risk profile of past practices which indicates low to very low risk, resources are best spent entirely on targeted surveillance, whereas a country with higher risk may choose to undertake some surveillance of healthy slaughter stock.

Hence this approach offers a structured analytical and evaluation method for establishing an optimal portfolio of BSE surveillance activities from the four options available, according to the country's particular history, and allows evidence to be progressively accumulated over a period of years to increase the level of confidence surrounding statements of its BSE status.

This same protection analysis approach can equally well be applied to any other disease or risk, and the information from evaluations for different components of the national risk profile can be examined jointly so that resources can be progressively reallocated from low payoff to higher payoff components of the total surveillance system.