

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Risk-based surveillance in animal health

A thesis presented in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
at Massey University, Palmerston North,
New Zealand

by

Deborah Jayne Prattley

January 2009

Supervisors:

Associate Professor M.A. Stevenson

Professor R.S. Morris

Institute of Veterinary, Animal and Biomedical Sciences

Massey University

Palmerston North, New Zealand

Abstract

Animal health surveillance is an important part of animal health care, particularly in countries dependent on livestock for food production and international trade. There are two major issues related to the provision of effective surveillance activities. Firstly, for good information to become available, the design and conduct of data collection activities should be carried out following sound statistical principles. In reality, constraints such as imperfect tests and unavoidably-biased sampling strategies hinder straightforward analysis and interpretation of survey results. Risk-based surveillance is used to target high-risk sub-populations to increase efficiency of disease detection; however, biased datasets are generated.

This thesis develops methodologies to design risk-based surveillance systems and allow statistically valid analysis of the inherently biased data they generate. The first example describes the development of a method to analyse surveillance data gathered for bovine spongiform encephalopathy (BSE). The data are collected from four different surveillance streams of animals tested for BSE, with each stream containing unavoidable biases and limitations. In the BSurVE model, these data are combined with demographic information for each birth cohort to estimate the proportion of each birth cohort infected with BSE. The prevalence of BSE in a national herd can then be estimated using the method of moments, whereby the observed number of infected animals is equated with the expected number. The upper 95% confidence limit for the prevalence is estimated both for infected countries and for those where no BSE has previously been detected.

A similar approach to that used in BSurVE is then applied to surveillance data for trichinellosis, for which risk-based post-mortem testing is also performed. Negative results from multiple species using different, imperfect tests are combined to give an estimate of the upper 95% confidence limit of the national prevalence of trichinellosis in a reference population. This method is used to provide support for freedom from trichinellosis in Great Britain.

A different approach to risk-based surveillance is explored as the surveillance strategy for detection of exotic causes of abortion in sheep and goats in New Zealand is examined. Using a geographic information system (GIS) maps of disease risk factors were overlain to produce a risk landscape for the lower North Island. This was used to demonstrate

how areas of high- and low-risk of disease occurrence can be identified and used to guide the design of a risk-based surveillance programme.

Secondly, within one surveillance objective there may be many ways in which the available funds or human resources could be distributed. This thesis develops a method to assess BSE surveillance programmes, and provides tools to facilitate BSE detection on the basis of infection risk and to increase the efficiency of surveillance strategies.

A novel approach to allocation of resources is developed, where portfolio theory concepts from finance are applied to animal health surveillance. The example of surveillance for exotic causes of sheep and goat abortion is expanded upon. Risk of disease occurrence is assessed for a population over different time periods and geographical areas within a country, and portfolio theory used to allocate the number of tests to be carried out within each of these boundaries. This method is shown to be more likely to detect disease in a population when compared to proportional allocation of the available resources.

The studies presented here show new approaches that allow better utilisation of imperfect data and more efficient use of available resources. They allow development of surveillance programmes containing an appropriate balance of scanning and targeted surveillance activities. Application of these methods will enhance the implementation and value of surveillance in animal health.

Publications

Peer-reviewed papers

Prattley, D.J., Cannon, R.M., Wilesmith, J.W., Morris, R.S. and Stevenson, M.A. 2007. A model (BSurvE) for estimating the prevalence of bovine spongiform encephalopathy in a national herd. *Preventive Veterinary Medicine* 80 330-343.

Prattley, D.J., Morris, R.S., Cannon, R.M., Wilesmith, J.W. and Stevenson, M.A. 2007. A model (BSurvE) for evaluating national surveillance programs for bovine spongiform encephalopathy. *Preventive Veterinary Medicine* 81 225-235.

Prattley, D., Morris, R.S., Stevenson, M.A. and Thornton, R. 2007. Application of portfolio theory to risk-based allocation of surveillance resources in animal populations. *Preventive Veterinary Medicine* 81 56-59.

Reports

Prattley, D., Morris, R.S., Sujau, M., Sauter-Louis, C., Cogger, N. and Cannon, R.M.C. 2007. Interpretation of *Trichinella* surveillance data from Great Britain. A report for the United Kingdom's Food Standards Agency.

Cogger, N., Morris, R.S. and Prattley, D. 2007. Farm-specific risk analysis system to determine risk status for *Trichinella*. A report for the United Kingdom's Food Standards Agency.

Prattley, D. and Stevenson, M.A. 2006. Saleyard risk analysis. A report for the Ministry of Agriculture and Fisheries.

Prattley, D. 2006. Scenario tree analysis of surveillance for vector-borne causes of ovine abortion in New Zealand. A study conducted for the Ministry of Agriculture and Forestry, New Zealand.

Prattley, D. 2005. Review on the use of serological surveillance for FMD in sheep. A report for the National Centre for Disease Investigation, Biosecurity New Zealand.

Prattley, D. 2005. Risk-based surveillance for causes of ovine and caprine abortion exotic to New Zealand. A case study conducted for the Ministry of Agriculture and Forestry, New Zealand.

Wilesmith, J.W., Morris, R.S., Stevenson, M.A., Cannon, R.M., Prattley, D.J. and Bernard, H. 2004. Development of a method for evaluation of national surveillance data and optimization of national surveillance strategies for bovine spongiform encephalopathy. A project conducted by the European Union TSE Community Reference Laboratory, Veterinary Laboratories Agency Weybridge, United Kingdom.

Selected conference papers and presentations

Cogger, N., Morris, R. and Prattley, D. 2007. Solutions to a “Tricky” surveillance problem. Australian and New Zealand Chapter of the Society for Risk Analysis.

Prattley, D., Morris, R.S., Stevenson, M.A. and Thornton, R. 2006. Matching risk and resources in design of surveillance strategies. Presented as a lead paper at the conference of the International Society of Veterinary Epidemiology and Economics.

Prattley, D., McIntyre, L., Morris, R.S., Stevenson, M.A. and Howe, M. 2006. Clinical practice as a source of veterinary surveillance data - what is it worth? Presented at the Annual Conference of the New Zealand Veterinary Association.

Prattley, D., Cannon, R.M., Wilesmith, J.W., Stevenson, M.A. and Morris, R.S. 2006. Scoring points - an objective method to evaluate BSE testing data and optimise surveillance activity. Presented at the Annual Conference of the New Zealand Veterinary Association.

Prattley, D., Morris, R.S., Stevenson, M.A. and Thornton, R. 2006. Matching risk and resources in design of surveillance strategies. Presented at the Annual Conference of the New Zealand Veterinary Association.

When
you are
describing
A
shape
or
sound
or tint
Don't
state
the
matter
plainly
But
put
it in
a
hint
And
learn
to
look
at
all
things
With
a
sort
of
mental
squint

Lewis Carroll

Contents

Abstract	ii
Publications	iv
Contents	xi
List of Tables	xiii
List of Figures	xvi
1 Introduction	1
2 Literature review	3
2.1 Introduction to animal health surveillance	3
2.2 Classification of surveillance activities	5
2.3 Data analysis in risk-based surveillance	10
2.4 Combining data sources	11
2.5 Evaluation of alternative surveillance strategies	16
2.6 Allocation of resources	21
2.7 References	24
3 BSE prevalence estimation	33
3.1 Abstract	33
3.2 Introduction	33
3.3 Methods	35

3.3.1	Input data	35
3.3.2	BSE status assessment	36
3.4	Results	40
3.4.1	Input data	40
3.4.2	BSE status assessment	43
3.5	Discussion	43
3.6	Conclusions	46
3.7	References	46
4	Evaluating national surveillance programmes for BSE	49
4.1	Abstract	49
4.2	Introduction	49
4.3	Methods	51
4.3.1	BSE surveillance assessment	51
4.3.2	Surveillance resource allocation	52
4.4	Results	54
4.4.1	BSE surveillance assessment	54
4.4.2	Surveillance resource allocation	54
4.5	Discussion	57
4.6	Conclusions	59
4.7	References	59
5	Integration of diverse surveillance data	61
5.1	Abstract	61
5.2	Introduction	62
5.3	Methods	63
5.3.1	Fox data	63
5.3.2	Horse data	63
5.3.3	Pig data	64

5.3.4	Species and sub-population weighting	66
5.3.5	Theory for estimating prevalence	67
5.3.6	Analysis	68
5.4	Results	68
5.4.1	Sampling effort	69
5.4.2	Upper confidence limit (95%) for the estimate of prevalence . . .	71
5.5	Discussion	72
5.6	Conclusions	77
5.7	References	77
5.8	Appendix 1: Additional figures	79
5.9	Appendix 2: Sample weightings	96
5.9.1	References	105
6	Risk-based surveillance for exotic ovine abortion	109
6.1	Abstract	109
6.2	Introduction	109
6.3	Methods	110
6.3.1	Surveillance zones	110
6.3.2	Incursion zones	110
6.3.3	Sheep and goat population data	111
6.3.4	Abortion data	111
6.3.5	Estimation of abortion and case submission rates	111
6.3.6	Number of cases to test to detect disease	113
6.3.7	Surveillance system design	113
6.4	Results	114
6.4.1	Surveillance zones and population data	114
6.4.2	Incursion zones	115
6.4.3	Abortion data	117

6.4.4	Estimation of abortion and case submission rates	124
6.4.5	Number of cases to test to detect disease	127
6.4.6	Surveillance system design	128
6.4.7	Incursion zone surveillance	130
6.5	Discussion	133
6.6	Conclusions	137
6.7	References	138
7	Application of portfolio theory to risk-based surveillance	140
7.1	Abstract	140
7.2	Introduction	141
7.3	Methods	142
7.3.1	Characteristics of a portfolio	142
7.3.2	Portfolio allocation	143
7.3.3	The surveillance portfolio	144
7.3.4	Evaluation of resource allocation methods	147
7.4	Results	147
7.4.1	Safety first: multiple exotic diseases	147
7.4.2	Safety first: regional and temporal allocation	147
7.4.3	SIM: allocation of laboratory tests	150
7.4.4	Evaluation of resource allocation methods	151
7.5	Discussion	151
7.6	Conclusions	154
7.7	References	155
8	General discussion	157
8.1	A review of the studies in this thesis	157
8.2	Future research	163
8.3	Conclusions	165

8.4	References	165
	Bibliography	167

List of Tables

3.1	The BSurvE age data entry table for country A	41
3.2	Observed number of animals tested and testing positive	44
4.1	The observed number of animals tested and testing positive	52
4.2	Calculated number of points required	56
4.3	Summary of the number of points gained	57
4.4	Calculated time to achieve point target	57
5.1	Categorisation of high- and low-risk accommodation for pigs	65
5.2	Weighting values assigned to surveillance tests	69
5.3	Estimated number of pigs present by sub-population	70
5.4	Estimated number of pigs slaughtered per year	71
5.5	Estimated number of pigs tested in 2005	71
5.6	95% upper confidence limit for the prevalence estimate	74
5.7	Results of studies investigating prevalence in the red fox	97
5.8	Results of testing of horsemeat in various countries	99
5.9	Results of studies investigating infection in domestic pigs	102
6.1	Composition of surveillance zones	110
6.2	Characteristics of surveillance zones	115
6.3	Stock numbers by surveillance zone	115
6.4	Seaports: stock numbers by incursion zone	116
6.5	International airports: stock numbers by incursion zone	117

6.6	Seaports 2003: vessel arrivals and international cargo weights	117
6.7	Airports 2003: international aircraft arrivals	118
6.8	Descriptive statistics for actual and simulated flock sizes	125
6.9	Within-flock incidence risk of abortion	126
6.10	Number of flocks with high estimated abortion incidence risk	127
6.11	Number of flocks to be tested to detect disease	127
6.12	Maximum number of infected flocks	128
6.13	Number of flocks required to be tested to detect disease	136
6.14	Seaports: total number of animals to test to detect disease	139
6.15	Airports: total number of stock to test to detect disease	139
7.1	The number of surveillance tests required to detect one positive flock . .	148
7.2	The simulated mean risk score for each surveillance area	149

List of Figures

3.1	The distribution of exiting uninfected animals	41
3.2	The distribution of exiting BSE-infected animals	42
3.3	Infection status of BSE-infected cattle	42
3.4	Predicted true BSE prevalences for each birth cohort	43
4.1	Proportion of each age group tested in the casualty slaughter stream . .	54
4.2	Points associated with the value of testing an animal	55
4.3	Calculated number of points required	55
5.1	95% UCL for the prevalence of <i>Trichinella</i> in low-risk grower pigs	73
5.2	Sampling effort for foxes tested	79
5.3	Sampling effort for horses	80
5.4	Sampling effort for low-risk grower pigs	81
5.5	Sampling effort for high-risk grower pigs	82
5.6	Sampling effort for low-risk breeder pigs	83
5.7	Sampling effort for high-risk breeder pigs	84
5.8	Upper 95% confidence limit for foxes (unweighted)	85
5.9	Upper 95% confidence limit for horses (unweighted)	86
5.10	Upper 95% confidence limit for low-risk grower pigs (unweighted)	87
5.11	Upper 95% confidence limit for high-risk grower pigs (unweighted) . . .	88
5.12	Upper 95% confidence limit for low-risk breeder pigs (unweighted) . . .	89
5.13	Upper 95% confidence limit for high-risk breeder pigs (unweighted) . . .	90

5.14	Upper 95% confidence limit for foxes	91
5.15	Upper 95% confidence limit for horses	92
5.16	Upper 95% confidence limit for high-risk grower pigs	93
5.17	Upper 95% confidence limit for low-risk breeder pigs	94
5.18	Upper 95% confidence limit for high-risk breeder pigs	95
6.1	Simulation of abortion incidence risk	112
6.2	Surveillance zones in New Zealand and breeding ewe density	114
6.3	The main incursion zones within New Zealand	116
6.4	Ewe population size compared to abortion submissions	118
6.5	Total number of abortion submissions to each laboratory	119
6.6	Number of surveillance cases	120
6.7	Total number of abortion case submissions	120
6.8	Diagnosis of laboratory submissions	121
6.9	Diagnoses by surveillance zone in 2003	122
6.10	Submissions suitable for use as surveillance cases	122
6.11	Diagnosis of surveillance cases	123
6.12	Proportion of cases undiagnosed at each laboratory	123
6.13	Simulated within-flock abortion incidence risk	124
6.14	Histogram of simulated flock sizes for Southland	125
6.15	Simulated incidence risk of abortions in Southland flocks	126
6.16	Areas where disease conditions were met in January	129
6.17	Areas where disease conditions were met in April	130
6.18	Areas where disease conditions were met in July	131
6.19	Areas where disease conditions were met in October	132
6.20	Number of cases submitted from each surveillance zone in 2003	136
7.1	Median risk score and interquartile range of risk scores for each disease .	148
7.2	Number of surveillance tests to be carried out in each SA by month . .	150

7.3	The number of tests allocated to each SA	151
7.4	The maximum prevalence of diseased ewe flocks to be missed	152