The Spatio-temporal Epidemiology of Bovine Spongiform Encephalopathy and Foot-and-Mouth Disease in Great Britain

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Mark Anthony Stevenson

Institute of Veterinary, Animal and Biomedical Sciences
Massey University
Palmerston North, New Zealand

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Institute of Veterinary, Animal and Biomedical Sciences
Massey University
Palmerston North, New Zealand
2003

Massey University
COLLEGE OF SCIENCES

EpiCentre
Institute of Veterinary, Animal and Biomedical Sciences
Private Bag 11 222,
Palmerston North,
New Zealand
Telephone: 64 6 350 5270
Facsimile: 64 6 350 5716

CERTIFICATE OF REGULATORY COMPLIANCE

This is to certify that the research carried out in the Doctoral Thesis entitled

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(a) is the original work of the candidate, except as indicated by appropriate attribution in the text and/or in the acknowledgements;

(b) that the text, excluding appendices/annexes, does not exceed 100 000 words;

(c) all the ethical requirements applicable to this study have been complied with as required by Massey University.

Candidate's Name: Mark Stevenson

Signature: M. Stevenson

Date: 2 April 2004

Supervisor's Name: Roger Morris

Signature: R S Morris

Date: 2 April 2004

Abstract

Great Britain suffered two of the most globally notable animal disease epidemics of recent decades — the bovine spongiform encephalopathy (BSE) epidemic which began in November 1986, and the foot-and-mouth disease (FMD) epidemic which lasted from February to September 2001. This thesis applies various analytical techniques to these two quite different epidemics: a rapidly spreading highly contagious disease for which urgent decisions are essential (FMD), and a feed-borne non-contagious disease with an exceptionally long incubation period (BSE). The BSE epidemic, in particular, presented major investigational challenges because its recent emergence meant that its epidemiological features were not yet fully clear.

The studies of BSE reported here showed that the control measures recommended as a consequence of the first epidemiological study of the new disease were remarkably effective. The July 1988 meat and bone meal ban resulted in a 60% reduction in BSE risk for cattle born in the first 12 months after its introduction. Descriptive spatial analyses, using kernel density and regression techniques showed a marked concentration of BSE risk in the south of Great Britain. Following the July 1988 meat and bone meal ban BSE risk shifted to the east of the country, an effect partly explained by cross contamination of cattle feed with high-protein concentrates destined for the pig and poultry industry.

Detailed investigation of the earliest BSE-exposed farm holdings identified the south of England as an area of excess exposure density. While interpretation of these findings is complicated by the fact that the disease must have been present for some years before it was first diagnosed, the evidence suggests initial amplification in the south provided risk material which progressively distributed the disease to the rest of the country.

In contrast to BSE, FMD presents different challenges, in that affected farms can be diagnosed rapidly, but it is difficult to accurately evaluate the relative importance of the different mechanisms of transmission, and hence determine how best to apply control efforts. Foci of FMD infection of matched size in the English counties of Cumbria and

Devon were compared to dissect out factors contributing to the two quite different epidemic patterns in these areas. This analysis showed evidence of strong spatio-temporal interaction of infection risk in Cumbria, due initially to cattle herds as the dominant influence, with a later growth in the role of sheep as a source of infection.

During the FMD epidemic a stochastic spatial simulation model was used extensively as an aid for decision making. After the epidemic was over the predictive accuracy of earlier real-time modelling was assessed for the whole of Britain and the most concentrated focus of disease in Cumbria. The model predicted the temporal epidemic curve closely at both levels, and predicted the national spatial pattern of infection with high specificities (over 99%) and useful sensitivities (37% to 71%). It was concluded that the model predicted FMD-infected locations within 0 to 14 days after simulation start date with sufficient accuracy to guide surveillance activities and to provide estimates of resources required for contingency planning. The spatial accuracy of predictions might be further improved through the use of a series of sub-regional models, better-capturing the characteristics of individual outbreak foci that typically emerge during extended large scale, multicentred epidemics.

The studies presented in this thesis demonstrate that the application of temporal, spatial and spatio-temporal analytical methods can enhance the understanding of the epidemiological features of diseases in animal populations. The value in applying these methods of analysis comes from the ability to identify high and low disease-risk time frames and locations, allowing more focussed allocation of investigative resources.

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Nomenclature

AR	Autoregressive (model)
BSE	Bovine spongiform encephalopathy
CAR	Conditional autoregressive (model)
CI	Confidence interval
CIGAR	Conditional intrinsic Gaussian autoregressive (model)
CPH	County-parish-holding (identifier)
FMD	Foot-and-mouth disease
ESDA	Exploratory spatial data analysis
GAM	Generalised additive model
GIS	Geographic Information System
HEPP	Heterogeneous Poisson process (model)
LISA	Local indicators of spatial association
MAFF	Ministry of Agriculture, Fisheries and Food
MPL	Maximum pseudolikelihood
DEFRA	Department for Environment, Food and Rural Affairs
SAR	Simultaneous autoregressive (model)
SERAD	Scottish Executive Rural Affairs Department
SMD	Standardised mortality difference
SMR	Standardised mortality ratio
SOAEFD	Scottish Office, Agriculture, Environment and Fisheries
TIN	Triangular irregular network

List of Publications

Wilesmith, J., Ryan, J., Stevenson, M., Morris, R., Pfeiffer, D., Lin, D., Jackson, R., & Sanson, R. (2000). Temporal aspects of the bovine spongiform encephalopathy epidemic in Great Britain: holding-associated risk factors for disease. *Veterinary Record*, 147, 319 – 325.

Stevenson, M., Wilesmith, J., Ryan, J., Morris, R., Lockhart, J., Lin, D., & Jackson, R. (2000). Temporal aspects of the bovine spongiform encephalopathy epidemic in Great Britain: individual animal-associated risk factors for the disease. *Veterinary Record*, 147, 349 – 354.

Stevenson, M., Wilesmith, J., Ryan, J., Morris, R., Lawson, A., Pfeiffer, D., & Lin, D. (2000). Descriptive spatial analysis of the bovine spongiform encephalopathy epidemic in Great Britain to June 1997. *Veterinary Record*, 147, 379 – 384.

Stevenson, M., Morris, R., Lawson A., Wilesmith, J., Ryan, J., & Jackson R. (2003). Area-level risks for BSE in British cattle before and after the July 1988 meat and bone meal feed ban. Submitted.

Morris R., Wilesmith J., Stern M., Sanson R., & Stevenson M. (2001). Predictive spatial modelling of alternative control strategies for the foot-and-mouth disease epidemic in Great Britain. *Veterinary Record*, 149, 137 – 144.

Morris R., Sanson R., Stern M., Stevenson, M., & Wilesmith, J. (2002). Decision-support tools for foot and mouth disease control. *Revue Scientifique Et Technique De L'Office International Des Epizooties*, 21, 557 – 567.

Stevenson, M., Wilesmith, J., King, C., & Morris, R. (2002). Spatial, temporal and spatio-temporal epidemiology of foot-and-mouth disease in Cumbria, February to September 2001. In J. Rigby, C. Skelly, & P. Wigham (Eds.), *GeoHealth 2002 Proceedings of the Spatial Information Research Centre's 14th Colloquium* (p. 71 – 74). Wellington, New Zealand: Victoria University.

Wilesmith J., Stevenson M., King C., & Morris R. (2003). Spatio-temporal epidemi-

ology of foot-and-mouth disease in two areas of Great Britain in 2001. *Preventive Veterinary Medicine*, 61, 157 – 170.

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