Foot-and-Mouth Disease 2007: Statistical Surveillance in Real-Time

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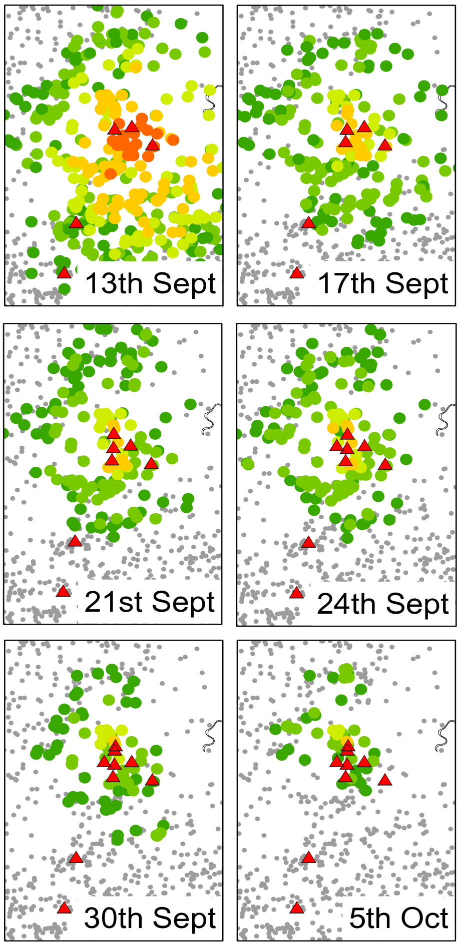
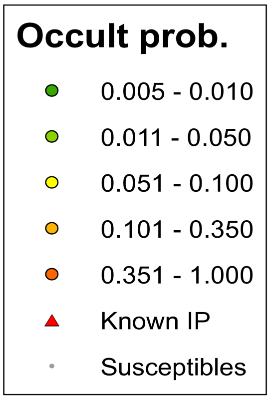
Undetected Infection Probabilities





Real-time analysis of FMD2007, starting immediately after IP4. Coloured dots represent the probability that a farm at that location is infected-but-undetected.

This gives information to inform surveillance strategy and shows a probabilistic representation of the current epidemic extent.

Modelling details

Basic model:

Susceptible → **E**xposed → **I**nfected → **N**otified → **R**emoved

Farm-farm transmission, β_{ij}, between **I**nfected (or **N**otified) *i*, and **S**usceptible *j* :

$$\beta_{ij}=(\beta_1 \cdot c_i^{\phi}+s_i^{\phi})(\beta_2 \cdot c_j^{\phi}+s_j^{\phi}) \cdot \frac{\beta_3}{\rho[i,j]+\beta_3}, \quad i \in \boldsymbol{I}, j \in \boldsymbol{S}$$

$$\beta_{ij}=(\beta_1 \cdot c_i^{\phi}+s_i^{\phi})(\beta_2 \cdot c_j^{\phi}+s_j^{\phi}) \cdot \frac{\beta_4}{\rho[i,j]+\beta_4}, \quad i \in \boldsymbol{N}, j \in \boldsymbol{S}$$

c_k and s_k the number of cattle and sheep on farm *k*; $\rho[i,j]$ the Euclidean distance between *i* and *j*; β_1 infectivity of cattle wrt. sheep; β_2 susceptibility of cattle wrt. sheep; β_3, β_4 *spatial kernel parameter* (Keeling et al. 2001)[4]

Exposed to Notified time, *d*, imputed with prior:

$$F(d)=\exp(-a\exp(-b \cdot d)-1)$$

modified Gumbell distribution with mean 7.5 days (Kypraios 2007)

Exposed to Infected time: Fixed at 4 days (Keeling et al 2001)[4]

Introduction

During epidemics, contact tracing is used to identify individuals who are at high risk of being infected due to their relationship with a known infective individual. Contact tracing requires high efficiency in terms of detecting *all* possible contacts with a known infective and, for large epidemics, this can be shown to be unfeasibly high[1]. Historically, for large epidemics, contact tracing is assumed on a spatial basis and has lead to the concepts of ring-culling and contiguous-premises culling.

The aim of this study was to predict the existence of infected-but-undetected farms at any stage during the epidemic, providing information for targetted surveillance and on the current extent of the epidemic.

Analysis

This analysis uses recent **Bayesian methodology** which was primarily developed for making inference on infection transmission rates[2,3]. However, the incorporation of unobserved infection times and infected-but-undetected infections makes this **suitable for statistical contact-tracing**.

Transmission model: based on Keeling et al (2001)[4]. Each farm treated as an individual.

Data: Location, number of cattle, number of sheep. Obtained from 2003 census data. Detection and end of cull times obtained as days after the first detection:

IP	IP1	IP2	IP3a	IP3b	IP4	IP5	IP6	IP7
Detected	0	4	40	40	41	45	49	52
Cull ended	2	5	42	42	41.5	45.5	50	52.5

Prior information: Bayesian prior information based on the posteriors in Kypraios (2007)[5] Bayesian analysis of the UK 2001 FMD outbreak.

References

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2. O'Neill PD, Roberts GO (1999) Bayesian inference for partially observed stochastic epidemics. *J Roy. Statist. Soc. Ser. A*, **162**:121
3. Neal PJ, Roberts GO (2004) Statistical inference and model selection for the 1861 Hagelloch measles epidemic. *Biostatistics*, **5**:249
4. Keeling MJ *et al* (2001) Dynamics of the 2001 UK Foot-and-Mouth epidemic: Stochastic dispersal in a heterogeneous landscape. *Science*, **249**:831
5. Kypraios T (2007) *Efficient Bayesian Inference for Patially Observed Stochastic Epidemics, and a New class of Semi-Parametric Time Series Models.* PhD thesis, Department of Mathematics and Statistics, Lancaster University, Lancaster.