The development of a syndromic surveillance system for the extensive beef cattle producing regions of Australia

by

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Declaration

Apart from the assistance stated in the acknowledgements and where reference is made in the text, this thesis represents original work of the author. I certify that the work presented in this thesis has not been submitted for any other degree or qualification at any other university.

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List of Publications

Dato, VM, Shephard, RW & Wagner, MM 2006, 'Outbreaks and investigations' in *Handbook of Biosurveillance*, eds MM Wagner, AW Moore and RM Aryel, Elsevier Academic Press, Oxford, 13–26.

Shephard, RW, Aryel, RM & Shaffer, L 2006, 'Animal health' in *Handbook of Biosurveillance,* eds MM Wagner, AW Moore and RM Aryel, Elsevier Academic Press, Oxford, 111–127.

Shephard, RW, Cameron, AR, Toribio, JA & Thomson, P 2006a, Can syndromic surveillance play a role within a modern national veterinary surveillance system? Paper presented to New Zealand Veterinary Association Conference, Auckland, New Zealand, pp. 35–40.

Shephard, RW, Cameron, AR, Toribio, JA & Thomson, P 2006b, Development of the Bovine Syndromic Surveillance System (BOSSS), paper presented to The 11th International Symposium on Veterinary Epidemiology and Economics, Cairns, Australia, ed. J McKenzie, ISVEE.

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Abstract

All surveillance systems are based on an effective general surveillance system because this is the system that detects emerging diseases and the re-introduction of disease to a previously disease free area. General surveillance requires comprehensive coverage of the population through an extensive network of relationships between animal producers and observers and surveillance system officers. This system is under increasing threat in Australia (and many other countries) due to the increased biomass, animal movements, rate of disease emergence, and the decline in resource allocation for surveillance activities.

The Australian surveillance system is state-based and has a complex management structure that includes State and Commonwealth government representatives, industry stakeholders (such as producer bodies) and private organisations. A developing problem is the decline in the effectiveness of the general surveillance system in the extensive (remote) cattle producing regions of northern Australia. The complex organisational structure of surveillance in Australia contributes to this, and is complicated by the incomplete capture of data (as demonstrated by slow uptake of electronic individual animal identification systems), poorly developed and integrated national animal health information systems, and declining funding streams for field and laboratory personnel and infrastructure. Of major concern is the reduction in contact between animal observers and surveillance personnel arising from the decline in resource allocation for surveillance. Fewer veterinarians are working in remote areas, fewer producers use veterinarians, and, as a result, fewer sick animals are being investigated by the general surveillance system.

A syndrome is a collection of signs that occur in a sick individual. Syndromic surveillance is an emerging approach to monitoring populations for change in disease levels and is based on statistical monitoring of the distribution of signs, syndromes and associations between health variables in a population. Often, diseases will have syndromes that are characteristic and the monitoring of these syndromes may provide for early detection of outbreaks. Because the process uses general signs, this method may support the existing (struggling) general surveillance system for the extensive cattle producing regions of northern Australia.

Syndromic surveillance systems offer many potential advantages. First, the signs that are monitored can be general and include any health-related variable. This generality provides potential as a detector of emerging diseases. Second, many of the data types used occur early in a disease process and therefore efficient syndromic surveillance systems can detect disease events in a timely manner. There are many hurdles to the successful deployment of a syndromic surveillance system and most relate to data. An effective system will ideally obtain data from multiple sources, all data will conform to a standard (therefore each data source can be validly combined), data coverage will be extensive (across the population) and data capture will be in real time (allowing early detection). This picture is one of a functional electronic data world and unfortunately this is not the norm for either human or animal heath. Less than optimal data, lack of data standards, incomplete coverage of the population and delayed data transmission result in a loss of sensitivity, specificity and timeliness of detection.

In human syndromic surveillance, most focus has been placed on earlier detection of mass bioterrorism events and this has concentrated research on the problems of electronic data. Given the current state of animal health data, the development of efficient detection algorithms represents the least of the hurdles. However, the world is moving towards increased automation and therefore the problems with current data can be expected to be resolved in the next decade. Despite the lack of large scale deployment of these systems, the question is becoming when, not whether these system will contribute.

The observations of a stock worker are always the start of the surveillance pathway in animal health. Traditionally this required the worker to contact a veterinarian who would investigate unusual cases with the pathway ending in laboratory samples and specific diagnostic tests. The process is inefficient as only a fraction of cases observed by stock workers end in diagnostic samples. These observations themselves are most likely to be amenable to capture and monitoring using syndromic surveillance techniques.

A pilot study of stock workers in the extensive cattle producing Lower Gulf region of Queensland demonstrated that experienced non-veterinary observers of cattle can describe the signs that they see in sick cattle in an effective manner. Lay observers do not posses a veterinary vocabulary, but the provision of a system to facilitate effective description of signs resulted in effective and standardised description of disease. However, most producers did not see personal benefit from providing this information and worried that they might be exposing themselves to regulatory impost if they described suspicious signs. Therefore the pilot study encouraged the development of a syndromic surveillance system that provides a vocabulary (a template) for lay observers to describe disease and a reason for them to contribute their data.

The most important disease related drivers for producers relate to what impact the disease may have in their herd. For this reason, the Bovine Syndromic Surveillance System (BOSSS) was developed incorporating the Bayesian cattle disease diagnostic program BOVID. This allowed the observer to receive immediate information from interpretation of their observation providing a differential list of diseases, a list of questions that may help further differentiate cause, access to information and other expertise, and opportunity to benchmark disease performance. BOSSS was developed as a web-based reporting system and used a novel graphical user interface that interlinked with an interrogation module to enable lay observers to accurately and fully describe disease. BOSSS used a hierarchical reporting system that linked individual users with other users along natural reporting pathways and this encouraged the seamless and rapid transmission of information between users while respecting confidentiality. The system was made available for testing at the state level in early 2006, and recruitment of producers is proceeding.

There is a dearth of performance data from operational syndromic surveillance systems. This is due, in part, to the short period that these systems have been operational and the lack of major human health outbreaks in areas with operational systems. The likely performance of a syndromic surveillance system is difficult to theorise. Outbreaks vary in size and distribution, and quality of outbreak data capture is not constant. The combined effect of a lack of track record and the many permutations of outbreak and data characteristics make computer simulation the most suitable method to evaluate likely performance.

A stochastic simulation model of disease spread and disease reporting by lay observers throughout a grid of farms was modelled. The reporting characteristics of lay observers were extrapolated from the pilot study and theoretical disease was modelled (as a representation of newly emergent disease). All diseases were described by their baseline prevalence and by conditional sign probabilities (obtained from BOVID and from a survey of veterinarians in Queensland). The theoretical disease conditional sign probabilities were defined by the user. Their spread through the grid of farms followed Susceptible-Infected-Removed (SIR) principles (in herd) and by mass action between herds. Reporting of disease events and signs in events was modelled as a probabilistic event using sampling from distributions. A non-descript disease characterised by gastrointestinal signs and a visually spectacular disease characterised by neurological signs were modelled, each over three outbreak scenarios (least, moderately and most contagious).

Reports were examined using two algorithms. These were the cumulative sum (CuSum) technique of adding excess of cases (above a maximum limit) for individual signs and the generic detector What's Strange About Recent Events (WSARE) that identifies change to variable counts or variable combination counts between time periods. Both algorithms detected disease for all disease and outbreak characteristics combinations. WSARE was the most efficient algorithm, detecting disease on average earlier than CuSum. Both algorithms had high sensitivity and excellent specificity. The timeliness of detection was satisfactory for the insidious gastrointestinal disease (approximately 24 months after introduction), but not sufficient for the visually spectacular neurological disease (approximately 20 months) as the traditional surveillance system can be expected to detect visually spectacular diseases in reasonable time.

Detection efficiency was not influenced greatly by the proportion of producers that report or by the proportion of cases or the number of signs per case that are reported. The modelling process demonstrated that a syndromic surveillance system in this remote region is likely to be a useful addition to the existing system. Improvements that are planned include development of a hand-held computer version and enhanced disease and syndrome mapping capability. The increased use of electronic recording systems, including livestock identification, will facilitate the deployment of BOSSS.

Long term sustainability will require that producers receive sufficient reward from BOSSS to continue to provide reports over time. This question can only be answered by field deployment and this work is currently proceeding.

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AHA	Animal Health Australia
AHC	Animal Health Committee
ARIMA	Autoregressive Integrated Moving Average
ARL	Average Run Length
BOSSS	Bovine Syndromic Surveillance System
BSE	Bovine spongiform encephalopathy
CDC	Centers for Disease Control and Prevention
CoCo	Complaint Coder
CSV	Comma-separated Values
CVO	Chief Veterinary Officer
DAFF	Department of Agriculture, Fisheries and Forestry Australia
DEFRA	Department of Environment, Food and Rural Affairs
DOS	Disk Operating System
DVO	Divisional Veterinary Officer
EARS	Early Aberration Reporting System
ED	Emergency Department
EMF	Enhanced Metafile Format
ESSENCE	Electronic Surveillance System for the Early Notification of Community-Based Epidemics
EWMA	Exponentially Weighted Moving Average
FDR	False Discovery Rate
FMD	Foot-and-mouth disease
FTP	File Transfer Protocol

FWER	Family Wise Error Rate
GIS	Geographical Information System
GLMM	Generalised Linear Mixed Model
GPS	Global Positioning System
GTIN	Global Trade Item Number
GUI	Graphical User Interface
HL7	Health Level 7
HMM	Hidden Markov Model
HTTP	Hypertext Transfer Protocol
I	Infected
ICD	International Classification of Diseases
LOINC	Logical Observation Identifiers Names and Codes
MLA	Meat & Livestock Australia
NAHIS	National Animal Health Information System
NAMP	National Arbovirus Monitoring Program
NAQS	Northern Australian Quarantine Strategy
NLIS	National Livestock Identification Scheme
NPG	Northern Pastoral Group
NRDM	National Retail Data Monitor
OIE	Office International des Épizooties (World Organization for Animal Health)
OTC	Over the Counter
PANDA	Population-wide Anomaly Detection and Assessment
QDPIF	Queensland Department of Primary Industry and Fisheries
R	Removed
RADAR	Rapid Analysis and Detection of Animal Risks

RODS	Real-time Outbreak Detection System
RSVP	Rapid Syndrome Validation Project
RSVP-A	Rapid Syndrome Validation Project - Animal
RVO	Regional Veterinary Officer
S	Susceptible
Se	Sensitivity
SI	Stock Inspector
SIR	Susceptible-Infected-Removed model of infectious disease
SMTP	Simple Mail Transfer Protocol
SNOMED	Systematized Nomenclature of Medicine
Sp	Specificity
SPC	Statistical process control
SQL	Structured Query Language
WNV	West Nile virus
WSARE	What's Strange About Recent Events
WTO	World Trade Organization