

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.

Epidemiological investigations of the New Zealand horse population and the control of equine influenza

A thesis submitted in the partial fulfilment of
the requirements for the degree of

Doctor of Philosophy

in Veterinary Epidemiology
Massey University, Palmerston North,
New Zealand

Sarah Margaret Rosanowski

February 2012

Supervisors:

Dr Naomi Cogger

Dr Chris W. Rogers

Dr Jackie Benschop

Associate Professor Mark A. Stevenson

Institute of Veterinary, Animal and Biomedical Sciences

Massey University

Palmerston North, New Zealand

2012

Abstract

The aim of this thesis was to develop a disease model to evaluate the effectiveness of movement restriction and vaccination for the control of equine influenza in the New Zealand horse population. In order to achieve this aim, a series of epidemiological investigations into the characteristics, movement behaviour and biosecurity practices of the New Zealand horse population were conducted.

The New Zealand equine population has never experienced an outbreak of the highly infectious, respiratory virus, equine influenza (EI). As such, New Zealand horses are naïve to the virus and completely susceptible to infection. Disease models are one tool that can be used to examine the effectiveness of control strategies and can be used to initiate informed discussion regarding potential control options.

In order to develop an EI InterSpread plus model, data were required regarding the New Zealand equine population. Data were collected via cross-sectional survey regarding the non-commercial horse population, through face-to-face interviews with stud managers and through the analysis of data regarding race meetings. Properties keeping horses for competition, recreation or racing were more likely to report a movement event than properties that did not. Movement events and the frequency of movement increased with increasing numbers of mares and stallions on a stud farm and with the presence of a shuttle stallion. There were significant differences between Standardbreds and Thoroughbreds travelling to race meetings and horses travelled further to attend premier race meetings. The level of biosecurity practiced was low and unlikely to be effective at preventing EI transmission during an outbreak.

The disease model investigated three vaccination strategies in conjunction with movement restriction, compared to movement restriction alone. Additionally, the

timeliness of vaccination strategies and enhanced surveillance were investigated. The results of the InterSpread plus model showed that the predicted length of an EI epidemic and the number of properties infected were fewer, if vaccination was implemented. The vaccination strategy that predicted the fewest number of infected properties, and the shortest epidemic duration, was implemented on day seven after official detection at a three kilometre radius around an infected property. This thesis highlights the complexity inherent in developing disease models to support decision making.

Acknowledgements

Primarily, I wish to thank those involved in the New Zealand equine industry whose participation and interest has made this work possible. To the people who have taken the time to complete surveys and participate in interviews: the trainers, stud managers, and horse owners. Particular thanks to Stuart Duggan of New Zealand Thoroughbred Racing and Wayne Reid of Harness Racing New Zealand for their assistance with accessing racing industry records and taking the time to answer my (sometimes numerous) questions.

I would like to thank my supervisory team, Naomi Cogger, Chris Rogers, Jackie Benschop and Mark Stevenson; I always knew it would take a village to raise a child, I did not realise the same was true for creating a PhD. I am indebted for taking to time to read my papers, for your advice, insights and suggestions for improvement. Most of all, I appreciate the patience and enthusiasm you have shown me.

Funding for the work contained within this thesis has been provided by the Ministry of Agriculture and Forestry (Biosecurity), the Norman Cunningham Fellowship, the Allan Graham Chalmers scholarship, and bursaries from Massey University, the Institute of Veterinary, Animal and Biomedical Sciences and the EpiCentre.

This thesis would not have been possible without the support of a great group of colleagues, in the EpiCentre and at IVABS. To the Angels: Charlotte Bolwell, Jaz Tanner, Niki Stowers, and Sophie Bogers, I never thought I would meet such a like minded group of people who would be so happy to talk horse with me for hours. Thanks for the input, advice, proof reading and excitement about my project. Thanks for keeping me motivated. Always aim for another “Paper by Friday”. A special thanks to Lesley Stringer, Simon Verschaffelt, Juan Sanchez, Sarah Moore and Bryan O’Leary at the EpiCentre for your

support. Thanks also to Robyn Hirst for letting me hitch a ride to stud farms during your pasture research. I have never looked at grass the same way since.

A sincere thanks to my family; Mum and Dad, Lala and Craig, Matt and Kendra, Stuart, Chloe and Vikki. Your support and understanding during this thesis has been so important to me. If anyone had suggested I would complete a PhD 10 years ago, we would have laughed ourselves silly. Go figure. Thank-you for bearing with me. To Stuart, it has been a challenging few years, but things will only get better from here (and we survived!).

A PhD journey is solitary and intensely personal, but there are others who we encounter along the way who share the same quest and have the same desire for knowledge. To those I have connected with along the way, I have enjoyed your insights and sharing your story; the triumphs and the trials. I also hope that I have made your journey easier and at times more exciting.

List of Publications

Rosanowski, S.M., Rogers, C.W., Cogger, N., Benschop, J., Stevenson, M.A., 2011. A description of the demographic characteristics of the New Zealand non-commercial horse population with data collected using a generalised random-tessellation stratified sampling design Prev. Vet. Med. Accepted.

Rosanowski, S.M., Rogers, C.W., Cogger, N., Benschop, J., Stevenson, M.A., 2011. The implementation of biosecurity practices and visitor protocols on non-commercial horse properties in New Zealand. Prev. Vet. Med. Accepted

Rosanowski, S.M., Cogger, N., Rogers, C.W., 2012. An investigation of the movement patterns and biosecurity practices on Thoroughbred and Standardbred stud farms in New Zealand. Prev. Vet. Med. Accepted.

Rosanowski, S.M., Cogger, N., Rogers, C.W., Bolwell, C.F., Benschop, J., Stevenson, M.A., 2012. Analysis of horse movements from non-commercial horse properties in New Zealand. N. Z. Vet. J.Submitted.

Table of Contents

Abstract	iii
Acknowledgements	v
List of Publications	vii
Table of Contents	viii
List of Abbreviations	xi
List of Tables	xii
List of Figures	xix
Chapter One	1
Introduction	1
1.1 <i>Government industry agreements</i>	<i>1</i>
1.2 <i>The equine influenza outbreak in Australia</i>	<i>2</i>
1.3 <i>Disease models for the control of equine influenza in New Zealand</i>	<i>3</i>
1.4 <i>The New Zealand equine industry</i>	<i>4</i>
1.5 <i>Thesis aim and structure</i>	<i>7</i>
Chapter Two	11
Literature Review	11
2.1 <i>Introduction</i>	<i>11</i>
2.2 <i>Equine influenza</i>	<i>11</i>
2.3 <i>Disease modelling</i>	<i>36</i>
2.4 <i>Conclusions</i>	<i>57</i>
Chapter Three	59
A description of the demographic characteristics of the New Zealand non-commercial horse population with data collected using a generalised random-tessellation stratified sampling design	59
3.1 <i>Abstract</i>	<i>60</i>
3.2 <i>Introduction</i>	<i>61</i>
3.3 <i>Materials and Methods</i>	<i>63</i>
3.4 <i>Results</i>	<i>70</i>
3.5 <i>Discussion</i>	<i>81</i>
3.6 <i>Conclusion</i>	<i>86</i>
Chapter Four	87
The analysis of horse movements from non-commercial horse properties in New Zealand	87
4.1 <i>Abstract</i>	<i>88</i>

4.2 Introduction.....	89
4.3 Materials and methods.....	91
4.4 Results.....	94
4.5 Discussion.....	104
4.6 Conclusion.....	108
Chapter Five.....	109
The implementation of biosecurity practices and visitor protocols on non-commercial horse properties in New Zealand.....	109
5.1 Abstract.....	110
5.2 Introduction.....	111
5.3 Materials and methods.....	113
5.4 Results.....	117
5.5 Discussion.....	128
5.6 Conclusion.....	133
Chapter Six.....	135
The movement pattern of horses around race meetings in New Zealand.....	135
6.1 Abstract.....	136
6.2 Introduction.....	137
6.3 Materials and methods.....	138
6.4 Results.....	141
6.5 Discussion.....	147
6.6 Conclusion.....	151
Chapter Seven.....	153
An investigation of the movement patterns and biosecurity practices on Thoroughbred and Standardbred stud farms in New Zealand.....	153
7.1 Abstract.....	154
7.2 Introduction.....	155
7.3 Methods.....	157
7.4 Results.....	161
7.5 Discussion.....	173
7.6 Conclusion.....	177
Chapter Eight.....	179
Evaluating the effectiveness of strategies for the control of equine influenza virus in the New Zealand equine population.....	179
8.1 Abstract.....	180
8.2 Introduction.....	181

8.3 Materials and methods.....	183
8.4 Results.....	193
8.5 Discussion.....	201
8.6 Conclusion.....	206
Chapter Nine.....	209
General Discussion.....	209
9.1 Key findings.....	209
9.2 Implications for the control of equine influenza.....	215
9.3 Future research.....	221
9.4 Conclusions.....	222
Bibliography.....	223
Appendix A.....	237
Non-commercial horse property questionnaire.....	237
Appendix B.....	247
Stud managers questionnaire.....	247
Appendix C.....	257
InterSpread Plus modelling parameters.....	257

List of Abbreviations

AI	Artificial Insemination
CTR	Competitive Trail Riding
CSF	Classical Swine Fever
EHV	Equine Herpes Virus
EI	Equine Influenza
ELISA	Enzyme linked immunosorbent assay
ESNZ	Equestrian Sports New Zealand
FEI	Fédération Équestre Internationale
FMD	Foot-and-mouth disease
GIA	Government Industry Agreement
GRTS	Generalised Random-Tessellated Stratified
Ha	Hectares
HA	Haemagglutinin
HRNZ	Harness Racing New Zealand
IFN	Interferon
IgA	Immunoglobulin A
IgG(T)	Immunoglobulin G(T)
IgGa	Immunoglobulin Ga
IgGb	Immunoglobulin Gb
IL	Interleukin
IQR	Interquartile Range
Km	Kilometres
MAF	Ministry of Agriculture and Forestry
NA	Neuraminidase
NAADSM	North American animal disease spread model
NAITS	National Animal Identification Scheme
NZRB	New Zealand Racing Board
NZTR	New Zealand Thoroughbred Racing
OR	Odds Ratio
QUADS	Quadrilateral countries (Australia, Canada, New Zealand, and United States of America)
ROC	Receiver Operating Characteristic
SE	Standard Error
TNF	Tumour necrosis factor
95% CI	95% Confidence Interval

List of Tables

Chapter Two

Table 2.1: Description of Influenza A subtypes found in birds, horses, pigs, humans and dogs	12
Table 2.2: Description of the location, year and lineage of equine influenza circulating worldwide.....	15
Table 2.3: Description of EI outbreaks in naïve equine populations and the source of EI infection	17
Table 2.4: Examples of disease models and control options investigated for infectious diseases in livestock and horses.....	43

Chapter Three

Table 3.1: Description of categories used to describe reasons for keeping horses on non-commercial horse properties from postal questionnaire sent in 2009 about the demographics of horses on non-commercial horse properties.....	68
Table 3.2: The number and percentage of properties returning postal questionnaires, stratified by region and property size (n=1,044). Data collected in November 2009 from non-commercial horse properties in New Zealand.....	71
Table 3.3: The number and percentage of reasons for keeping horses on non-commercial horse properties (n=791 ^a) by activity type. Data collected during a postal questionnaire sent in November 2009 of non-commercial horse properties in New Zealand.	74
Table 3.4: The number and percentage of properties by reasons for keeping horses and property size (n=791 ^a). Data were collected in November 2009, during postal questionnaire of non-commercial horse properties in New Zealand.	75

Table 3.5: The number and percentage of participating properties with neighbours that kept horses (n=791^a), stratified by property size, participant’s own horse status and the reason for keeping horses. Data were collected from by postal questionnaire in November 2009 of non-commercial horse properties 77

Table 3.6: Number horses kept on non-commercial horse properties, stratified by property size, region and reason for keeping horses (n=791^a). Data collected during a postal questionnaire sent in November 2009 of non-commercial horse properties in New Zealand 79

Chapter Four

Table 4.1: Description of categories used to describe reasons for keeping horses on non-commercial horse properties from a postal questionnaire sent in 2009 about the demographics of horses on non-commercial horse properties..... 92

Table 4.2: Univariable logistic regression analyses of the association between the movement status of a property and the variables property size, region, number of horses and the reason for keeping horses on the property. Data were collected from a postal questionnaire of non-commercial horse properties in New Zealand (n=791), on movements occurring between November 2008 and November 2009. 98

Table 4.3: The results of the final multivariable logistic regression model, analysing the association between property size, region, number of horses and the reason for keeping horses, and the movement status of a property. Data were collected from a postal questionnaire of non-commercial horse properties in New Zealand (n=791), on movements occurring between November 2008 and November 2009. 100

Table 4.4: The number and percentage of total movement events, in the year prior to survey, of horses on New Zealand non-commercial properties (n=22,050). Data were stratified by property size, region, the number of horses on the property and the reason for

keeping horses. Data were collected from a postal questionnaire of non-commercial horse properties in New Zealand (n=791), on movements occurring between November 2008 and November 2009..... 101

Table 4.5: Description of the frequency of movement events, in the year prior to survey, on New Zealand non-commercial properties that reported the occurrence of movement events (n=488). Data were stratified by number and reason for keeping horses on the property. 102

Chapter Five

Table 5.1: Description of the biosecurity for arriving horses variables that were included in the two outcome variables created for logistic regression analysis, i) general biosecurity practices and ii) clinical signs biosecurity practices. Data were collected during a survey of non-commercial horse properties in New Zealand conducted in November 2009. 115

Table 5.2: The number of properties reporting horse care professionals visiting the property and the frequency of visits, stratified by property size, region, number and reason for keeping horses on the property. Data were collected during a postal survey of non-commercial horse properties in New Zealand in November 2009. 119

Table 5.3: Biosecurity practices applied to newly arriving horses and visitor protocols for people interacting with horses on non-commercial horse properties in New Zealand, presented as counts and percentages. Data were collected during a postal survey of non-commercial horse properties in New Zealand in November 2009. 123

Table 5.4: Univariable logistic regression analysis of the association between general biosecurity practices or clinical signs biosecurity practices and property-level variables on non-commercial horse properties in New Zealand (n=623). Data were collected during a postal survey of non-commercial horse properties in New Zealand in November 2009..... 125

Table 5.5: The results of the final multivariable logistic regression models, for the associations between property-level variables on 1) the presence of any biosecurity practices applied to newly arriving horses or 2) biosecurity practices specific to infectious respiratory disease, on non-commercial horse properties in New Zealand (n=623). Data were collected during a postal survey of non-commercial horse properties in New Zealand in November 2009..... 126

Chapter Six

Table 6.1: The number of premier, regional and trial race meetings held in the 2009 calendar year, stratified by racing code (Thoroughbred and Standardbred) and region where the race meeting was held. Data were collected through data extracted from New Zealand Thoroughbred Racing and Harness Racing New Zealand, 2009..... 142

Table 6.2: Description of the number of horses and trainers attending randomly selected premier, regional, trial and workout race meetings in 2009, stratified by racing code. Data were collected from randomly selected Thoroughbred (n=39) and Standardbred (n=42) race meetings in 2009. 145

Table 6.3: Distance travelled (km) to each type of race meeting, stratified by racing code. Data were collected from randomly selected Thoroughbred (n=39) and Standardbred (n=42) race meetings held in 2009. 147

Chapter Seven

Table 7.1: Number of mares, stallions and foals in the 2009 breeding season in New Zealand and the number and percentage covered by the Thoroughbred and Standardbred operations included a cross-sectional study of Thoroughbred (n=18) and Standardbred (n=9) stud managers in November 2009. 162

Table 7.2: Minimum, percentiles and maximum for the number of stallions and mares reported on stud farms at the time of survey and the number of mares served, stratified by breed. Data collected during a survey of Thoroughbred (n=18) and Standardbred (n=9) stud managers in November 2009. 162

Table 7.3: Minimum, percentiles and maximum for the number of movement events from Thoroughbred (n=18) and Standardbred (n=9) stud farms during 2009, stratified by breed, region, broodmare base, the presence of a shuttle stallion, the number of mares and stallions on the property and month. Data were collected during a face-to-face survey of Thoroughbred and Standardbred stud managers in November 2009 167

Table 7.4: The number of total movement events off Thoroughbred (n=18) and Standardbred (n=9) stud farms, by the distance travelled during the movement events. Data were collected during a face-to-face survey of Thoroughbred and Standardbred stud managers in November 2009 169

Table 7.5: Number and percentage of Thoroughbred and Standardbred stud farms in New Zealand with biosecurity practices for arriving mares and procedures for isolating mares on the stud farm. Data were collected during a face-to-face survey of Thoroughbred (n=18) and Standardbred (n=9) stud managers in November 2009. 172

Table 7.6: Number and percentage of Thoroughbred (n=18) and Standardbred (n=9) stud farms in New Zealand where policies were in place to prevent the spread of disease between groups of horses on the stud farm, in the presence and absence of disease outbreaks. Data were collected during a face-to-face survey of Thoroughbred and Standardbred stud managers in November 2009. 173

Chapter Eight

Table 8.1: Description of categories used to describe horse properties and race tracks in the equine influenza InterSpread Plus model 185

Table 8.2: The probability of infection through the local spread of equine influenza, based on the distance from an infected property and days since property was infected, used in the equine influenza InterSpread Plus model.	187
Table 8.3: Description of the control strategies investigated in the InterSpread Plus equine influenza model.....	189
Table 8.4: Descriptive statistics for the duration of an equine influenza outbreak by control strategy. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato.	195
Table 8.5: Descriptive statistics for the number of infected properties in an equine influenza outbreak by control strategy. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato.....	196
Table 8.6: Descriptive statistics for the number of vaccinated properties in an equine influenza outbreak by control strategy. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato.	197
Table 8.7: Duration of an equine influenza epidemic, in days, in an equine influenza outbreak by control strategy. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato.....	198
Table 8.8: Number of infected properties during an equine influenza epidemic, stratified by vaccination control strategies implemented on days seven, 14 or 21 since official EI detection. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato.	199
Table 8.9: Number of vaccinated properties in an equine influenza outbreak by control strategy. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato.	200
Table 8.10: The predicted number of days until detection, predicted epidemic duration and predicted number of infected properties for the movement restriction only	

control strategy and for the same strategy under enhanced surveillance, so equine influenza was detected two and seven days earlier than the movement restriction strategy. Data from an InterSpread Plus model with 100 iterations per control strategy and seed property located in the Waikato. 201

Appendices

Table A.1: Description of movements types from general horse, Thoroughbred and Standardbred stud farms, and Thoroughbred and Standardbred training properties used in the equine influenza InterSpread Plus model. 258

Table A.2: Description of the probability of a movement event, the number of contracts from a movement event and the probability of equine influenza transmission from general horse, Thoroughbred and Standardbred stud farms, and Thoroughbred and Standardbred training properties used in the equine influenza InterSpread Plus model. ... 259

Table A.3: Probability table of the distance travelled during movement events from Thoroughbred and Standardbred stud farms, and Thoroughbred and Standardbred training properties for spelling used in the equine influenza InterSpread Plus model. 259

Table A.4: Probability table of the distance travelled during movement events from Thoroughbred and Standardbred training properties for training and racing and the movement of racehorses returning from race meetings, used in the equine influenza InterSpread Plus model. 259

Table A.5: Probability table of the distance travelled during movement events from general horse properties used in the equine influenza InterSpread Plus model. 260

Table A.6: Probability of a movement event originating on a general horse, Thoroughbred or Standardbred stud farm, or training properties, terminating on any horse property defined in the equine influenza InterSpread Plus model. 260

List of Figures

Chapter One

Figure 1.1: A schematic description of the New Zealand equine industry (Data adapted from Anon (2010c), Creagh et al. (2010), Rogers and Vallance (2009) and Rogers and Firth (2005))..... 6

Chapter Two

Figure 2.1: Phylogenetic tree of H3N8 viruses responsible for equine influenza based on HA1 nucleotide sequences. Bootstrap values obtained after 100 replicates are shown at the major nodes. Phylogenetic groups are shown by continuous bars on the right and are labelled as appropriate. Black = pre-divergent; Yellow = Eurasian; Red = American; Blue = Argentina sublineage; Purple = Florida sublineage Clade 1; Green = Florida sublineage Clade 2. Image from Cullinae et al. (2010)..... 14

Figure 2.2: Schematic of potential contact patterns of equine properties (Adapted from Brennan et al. (2008)) 22

Figure 2.3: Vaccination zones implemented on October 30th 2007, during the EI outbreak in New South Wales and Queensland, Australia. Adapted from Moloney (2011) 31

Figure 2.4: Description of mutually exclusive state transitions that an individual animal or property can move through during a susceptible, infectious, recovered (SIR) model. Figure from Green and Medley (2002) 38

Figure 2.5: Diagram showing the set states defined within InterSpread Plus: susceptible, infected, and not at risk (Anon, 2010a) 42

Chapter Three

Figure 3.1: Gaussian edge corrected kernel intensity function of the of the number of non-commercial horse properties (n=17,430) (A) and those properties responding to survey with horses (n=791) (B) per 10 km² in New Zealand 65

Figure 3.2: Adaptive log-relative risk based on the underlying Agibase^(TM) non-commercial equine population and the properties selected for sampling (n=2,912) (A) and the properties responding to questionnaire with horses (n=791) (B). 72

Chapter Four

Figure 4.1: Graphical representation of the second order fractional polynomial transformations of the association between the number of horses on a property and the odds of a movement event occurring on that property. The estimated odds of a movement event was adjusted for region, the size of the property, and keeping horses for competition, racing, recreation and as pets. The fractional polynomials transformations were (number of horses/100)⁻² and (number of horses/100)⁻² x LN(number of horses)..... 96

Chapter Five

Figure 5.1: Boxplot of the frequency that horse care professionals visited non-commercial horse properties in New Zealand (n=625), stratified by horse care professional (P<0.001). Outliers >50 visits per year were removed (n=4). Data were collected during a postal survey of non-commercial horse properties in New Zealand in November 2009. ... 118

Chapter Six

Figure 6.1: The number of Thoroughbred (A) and Standardbred (B) race meetings held in the 2009 calendar year, stratified by type of race meeting, premier, race or trial. Data were collected from Harness Racing New Zealand and New Zealand Thoroughbred Racing. 144

Figure 6.2: The distance travelled (km) by trainers to premier, regional and trial race meetings held in New Zealand in 2009, stratified by the racing code. Data were collected from randomly selected Thoroughbred (n=39) and Standardbred (n=42) race meetings..... 146

Chapter Seven

Figure 7.1: Percentage of Thoroughbred (■) or Standardbred (◆) stud farms with mare arrivals, by month of arrival. Data collected during a face-to-face survey of Thoroughbred and Standardbred stud managers in November 2009. 164

Chapter Eight

Figure 8.1: Gaussian edge corrected kernel intensity function of the number of infected horse properties on the day of EI detection (median=21) (A) and infected properties on day 180 of the epidemic (median=3,136) (B) for the movement restriction control strategies. Data described as infected properties per 10 km² in New Zealand. X marks the location of the seed property in the Waikato..... 194

Figure 8.2: Epidemic curve of the median (dark line) and 25th and 75th (grey lines) of the number of infected properties on each day when movement restriction alone was implemented. Data from an InterSpread Plus model with 100 iterations and the seed property located in the Waikato 195