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

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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.

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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

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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

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Chapter One
Introduction

When exotic disease incursions occur in livestock populations, animal welfare and business continuity can be dramatically affected. The successful control of infectious disease outbreaks is predicated on having a prior knowledge of the effectiveness of control strategies, built upon a foundation of knowledge about the population at risk, the disease of interest and potential control options.

Simulation models have been used to describe the spread, and evaluate methods to control exotic disease outbreaks in livestock populations, enabling successful control and eradication of disease. Epidemiological methods are commonly used to collect and describe population data for use in simulation models. This thesis presents a series of epidemiological studies describing the New Zealand equine industry, culminating in the development of a stochastic simulation model of control strategies for equine influenza virus (EI) in the New Zealand equine population. This simulation model can be used as a tool to support decisions regarding the implementation of control methods for EI in the New Zealand equine population, in the event of a disease incursion.

1.1 Government industry agreements

Since 2009, the New Zealand Government, through the Ministry for Agriculture and Forestry (MAF), has been developing Government Industry Agreements (GIA) for biosecurity readiness (Anon, 2011c). The aim of GIA is to develop partnerships between the biosecurity policy makers in the New Zealand government; MAF, and the primary industries; agriculture and horticulture, to enable the sharing of decision-making and costs associated with biosecurity readiness and responses to exotic disease or pest incursions. Therefore in the event of an outbreak, the decisions regarding the control of EI in the New

Zealand equine population will be determined by representatives from the equine industry and MAF. The development and availability of an EI disease model evaluating key control methods would be an invaluable tool to enable discussion regarding control, both amongst equine industry representatives and between the equine industry and MAF, before an EI incursion. An EI disease model will allow informed decisions, and subsequent policy, regarding the implementation of control strategies for EI prior to an outbreak.

1.2 The equine influenza outbreak in Australia

In 2007 there was an outbreak of EI in the Australian equine population. Equine influenza is a highly contagious respiratory illness affecting all members of the Equidae family, including horses, donkeys and mules (Guo et al., 1995; Newton et al., 2006). The Australian equine population was naïve and therefore highly susceptible to infection, so disease spread rapidly through the population. Equine influenza entered Australia through the importation of Thoroughbred stallions from Japan in August 2007 (Gilkerson, 2008) and was released from a quarantine centre through the movement of people and equipment (Callinan, 2008; Anon, 2009). Infection was officially detected in the domestic horse population on the 24th of August 2007 in New South Wales and the 26th of August 2007 in Queensland (Callinan, 2008). Prior to the official identification of EI in the Australian horse population, a large equestrian event was held in Maitland (Callinan, 2008; Cowled et al., 2009). The mixing of horses within these events followed by the movement of horses from the events led to the widespread geographical dissemination of EI.

After extensive control efforts, EI was eradicated from Australia. Control measures included complete movement restriction, enhanced biosecurity practices on properties and the implementation of vaccination. During the four months of the outbreak, 76,000 horses were infected, 140,000 horses were vaccinated and 10,000 properties were identified as having infected horses (Anon, 2009). The last case of EI was detected on a property in

Queensland on the 25th of December 2007 and Australia was declared free of EI in December 2008.

1.3 Disease models for the control of equine influenza in New Zealand

Like the Australian equine population prior to EI, horses in New Zealand have never been exposed to EI. Based on the experience from Australia, in the event of an EI outbreak in New Zealand, disease would spread rapidly through the population, causing widespread morbidity. Given the speed with which EI would spread, decisions regarding the implementation of control strategies would need to be made quickly. Decision-making tools, such as disease models, would need to be available before an outbreak occurs. The only way to achieve this is to develop models that simulate the spread and control of disease prior to an EI outbreak.

Some major issues were identified from the EI outbreak in Australia. Firstly, there were limited records regarding the location and number of horses kept in New South Wales and Queensland. Secondly, once the decision to vaccinate was reached, there was a limited availability of vaccine and of people suitably trained to administer vaccine. Both factors led to delays in implementing control strategies, allowing further uncontrolled spread of disease and more delays in the time until EI was controlled.

The issues identified during the Australian outbreak have the potential to impede control measures for EI in New Zealand. Currently, the development of disease models for the control of EI in New Zealand horses is hampered by a lack of information available about the characteristics of the equine population. Information critically important for the development of disease models includes knowledge of the demographic characteristics and movement behaviour of the equine population. As occurred initially during the Australia outbreak, the availability of resources would be limited, but unlike the case in Australia, the emergency use of vaccine in an EI outbreak has been approved (Anon, 2008).

1.4 The New Zealand equine industry

The registration of horses in New Zealand is not mandatory. Consequently, the size of the population is currently unknown, with the number of horses in New Zealand estimated at between 100,000 to 120,000 horses (Rogers and Vallance, 2009). The equine population in New Zealand is divided into two sectors; racing and non-racing (Figure 1.1). The racing industry in New Zealand has two areas, the production of horses for racing (breeding) and the training and racing of racehorses (racing). Both racing and breeding are governed by the New Zealand Racing Board (NZRB) and the NZRB regulates the supply chain continuity and profitability of the racing industry (Anon, 2011a). The production, training and racing of horses for the racing industry in New Zealand accounts for approximately 1% of the national gross domestic product and employs over 16,000 people (Anon, 2010c). The NZRB governs three racing groups; Thoroughbreds, Standardbreds and Greyhounds, although Greyhounds will not be considered within the scope of this thesis. Within the Thoroughbred and Standardbred industries there are breeding and racing sectors. In the racing sector, Thoroughbreds gallop and race in both flat and jump (steeplechase and hurdle) races, while Standardbreds race “in harness” and either pace or trot. Thoroughbred racing is administered by New Zealand Thoroughbred Racing (NZTR), while Standardbred racing is administered by Harness Racing New Zealand (HRNZ). Additionally, the racing industry administers the two largest equine stud books in New Zealand; both of which are closed stud books, as only horses registered within each respective studbook is eligible to race. The importance of the Thoroughbred and Standardbred racing industries to the economy and the documentation required regarding gambling and wagering associated with racing ensures high levels of regulation. Consequently, information on the numbers, size and scope of these industries are readily available (Rogers et al., 2007; Anon, 2010c; Bolwell et al., 2010; Tanner et al., 2010).

Along with an internationally recognised racing industry, New Zealand is recognised for producing competition and sports horses (Friedrich et al., 2011), with both horses and riders successfully competing at an international level. The base for this originates from a high level of domestic equestrian sport participation, as one in four New Zealanders are reported to participate in equestrian sport (Anon, 2011e). Within this sector, there is one main official body, Equestrian Sports New Zealand (ESNZ). Equestrian Sports New Zealand focuses on the registration of horses competing in the Fédération Équestre Internationale (FEI) sports of dressage, show jumping, eventing, endurance and para-equestrian activities. It is estimated that between 4,000 and 5,000 horses are registered with ESNZ (Rogers and Firth, 2005; Creagh et al., 2010).

While data are readily available regarding the characteristics of the equine populations registered with HRNZ, NZTR or ESNZ, there is limited information regarding the unregistered, non-commercial horse population. Data regarding factors important to infectious disease spread and control are even scarcer, and the lack of relevant information occurs for all sectors of the New Zealand equine industry.

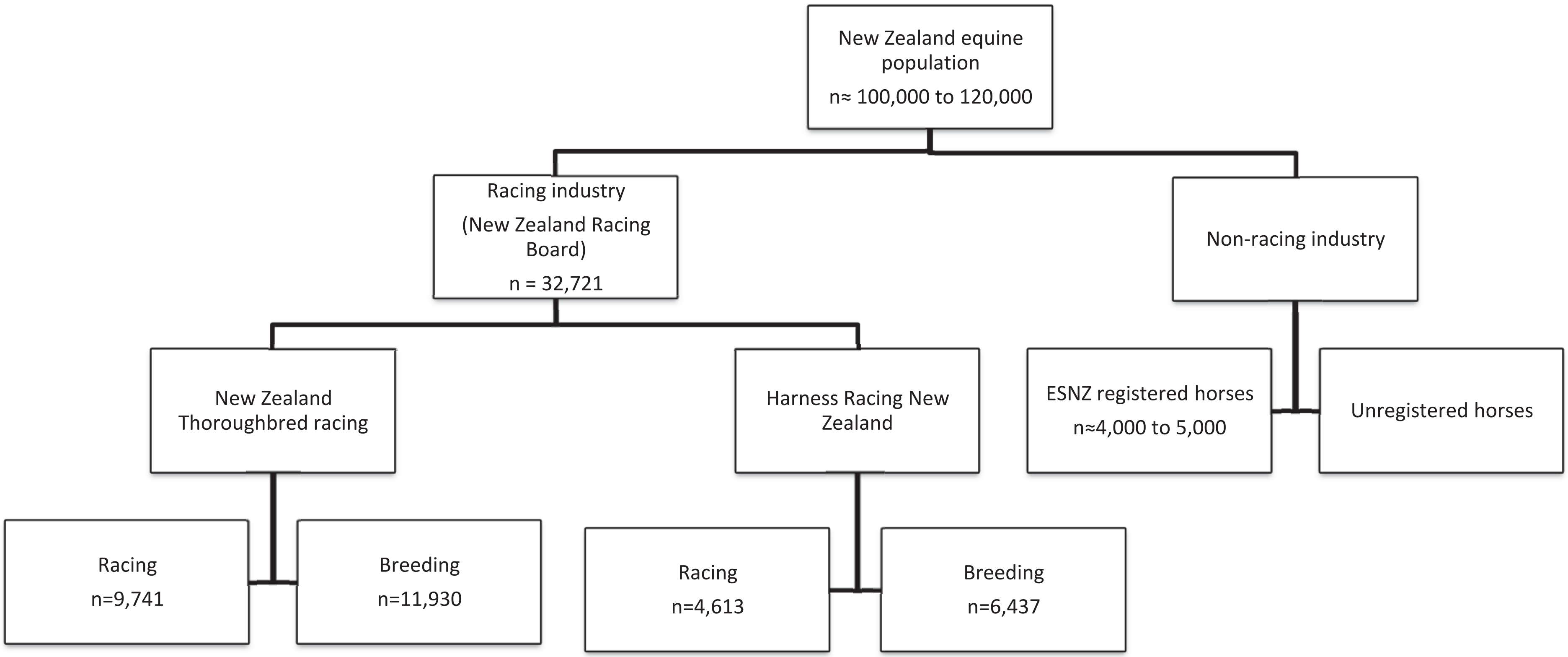

Figure 1.1: A schematic description of the New Zealand equine industry (Data adapted from Anon (2010c), Creagh et al. (2010), Rogers and Vallance (2009) and Rogers and Firth (2005)

1.5 Thesis aim and structure

The aim of this thesis was to develop a disease model, in the form of a spatial, stochastic, simulation model, to inform control strategies in the event of an EI incursion affecting the New Zealand equine industry. In order to meet the primary aim of this thesis, the characteristics and behaviour of the New Zealand equine population that would contribute to the spread and transmission of EI required investigation. The investigation into the equine population was described by three objectives:

1) Describe the features of the New Zealand non-commercial equine industry in relation to disease spread and transmission
2) Describe the movement of horses in the New Zealand racing industry
3) Describe the movement of horses and biosecurity practices of commercial breeders associated with the New Zealand racing industry

Two field studies and one database analysis were conducted to achieve these objectives. The three studies were then collated to achieve the primary aim of the thesis, a disease model on which decisions can be based to assist the control of EI in the New Zealand equine population.

The studies presented in this thesis are in the form of manuscripts prepared for publication in peer review journals. Consequently, there is some replication of background information in each of the chapters. All manuscripts have been standardised to one referencing style throughout the thesis.

In Chapter Two a critical review of the background of disease modelling is presented, in the context of preparing for an equine influenza outbreak affecting New Zealand horses. The aetiology, epidemiology and control of EI is described. The types and uses of available disease models, and the parameters needed to inform models are specifically investigated. These parameters include the availability of accurate information about the population at risk. The review concludes with a summary of the key areas where more data are required for the development of a disease model for the control of EI in New Zealand horses.

The issues explored in the literature review (Chapter Two) highlight a distinct lack of available data regarding the New Zealand equine population, especially for horses not involved in the racing industry. The literature review outlines the difficulty of extrapolating data from research conducted overseas, to the New Zealand commercial and non-commercial horse sectors.

The first manuscript of the thesis, Chapter Three, presents the first of three chapters describing the non-commercial horse population of New Zealand, with data collected by cross-sectional postal survey. The objective of Chapter Three is to describe the demographic characteristics of the non-commercial horse properties, with particular emphasis on the property-level factors of regional location, property size, number and use of horses on the property and the proximity of boundary neighbours with horses. A description of the methodology used to collect these data is also provided.

Chapter Four reports an analysis of the movement behaviour associated with non-commercial horse properties. This chapter expands on the previous chapter as associations between property-level demographic factors and movement behaviour are investigated. There were three outcomes in this study, firstly, the movement status of the property, the total number of movement events on properties and finally, the median distance travelled on properties with movement events. Within this chapter the potential for infectious disease to be disseminated between commercial and non-commercial horse properties through the movement of horses is described.

Chapter Five is the third chapter describing non-commercial horse properties. In this chapter, investigations into biosecurity practices, visitor protocols and the movement of visitors interacting with horses, like veterinarians and farriers, onto non-commercial horse properties are described. The association between property-level factors presented in Chapter Three, movement behaviour presented in Chapter Four and the implementation of biosecurity practices, visitor protocols and visitors interacting with horses are explored. The objective of this study was to identify both the baseline biosecurity strategies used on non-commercial properties and to determine whether these practices would be effective at preventing infectious disease transmission.

The first manuscript investigating the movement behaviour of the commercial sector of the New Zealand equine industry is presented in Chapter Six. Investigations of the movement behaviour of racehorse trainers to race meetings, with data collected from racing industry databases are described. Associations between the Thoroughbred and Standardbred racing codes and movement patterns around premier, regional and trial race meetings are identified and described.

Chapter Seven completes the description of the demographic characteristics, movement behaviour and biosecurity practices of the New Zealand equine population. In this chapter, the movement behaviour and biosecurity practices of commercial stud farms are investigated, using data collected through face-to-face interview. Associations between breed, number and type of horses on the property and the movement characteristics of the stud farm are explored. Additionally, biosecurity practices and visitor protocols implemented on stud farms, and the implications that the identified movement patterns and biosecurity practices would have on the spread of infectious disease are investigated in Chapter Seven.

Chapters Three to Seven collate in a description of the parameters used in the EI disease model in Chapter Eight. The effectiveness of three different vaccination strategies for the control of EI is described, and a comparison between these strategies and a control strategy of only movement restriction is conducted. Movement restriction was implemented on the day EI was detected in the population, while vaccination strategies were implemented on day 14 after the first detection of EI. The effectiveness of each strategy was evaluated by comparing the number of infected properties and epidemic duration to the movement restriction control strategies. The timeliness of vaccination and the effect of enhanced surveillance leading to earlier EI detection was also investigated.

To conclude, in the final chapter of this thesis a discussion is presented of the key findings of the research including the limitations, implications, industry and government applications and recommendations for future research.

Chapter Two
Literature Review

2.1 Introduction

Equine influenza virus (EI) is a highly infectious disease affecting equines and is endemic in the horse populations in countries other than Iceland, Australia and New Zealand (Anon, 2011f). Although New Zealand has stringent biosecurity measures in place at the border to prevent EI from entering (Anon, 2011d), experience from outbreaks of EI in susceptible populations, like Australia in 2007 (Callinan, 2008) and South Africa in 1986 (Guthrie et al., 1999), have highlighted the potential for error within these systems. In Australia, the consequence of a lapse in border biosecurity and the presence of a naïve equine population led to a rapid, widespread outbreak of disease (Callinan, 2008). Prior to an outbreak, policy makers need to have accurate tools to support decisions regarding disease control or eradication. Any tools must be based on the unique characteristics of the population and area of interest, to ensure timely decisions regarding control are made (Tomassen et al., 2002).

This review of published literature focuses on describing the epidemiology, aetiology and control options for EI and describing disease modelling with specific reference to equine populations. This review will form the background for developing a disease model for investigating strategies for the control of EI in the New Zealand equine population.

2.2 Equine influenza

2.2.1 Aetiology

Influenza viruses, of the family *Orthomyxoviridae*, are enveloped, segmented, negative sense, single strand RNA genomes (Alexander, 2007; Alexander and Capua, 2008;

Khanna et al., 2008). There are five genera in this family; *Influenzavirus A, Influenzavirus B, Influenzavirus C, Thogotovirus* and *Isavirus. Influenzavirus A,* or type A influenza, is known to infect a wide range of hosts including humans, horses, pigs and dogs. All subtypes of Influenza A have been isolated from aquatic birds (Daly and Mumford, 2001) (Table 2.1).

Table 2.1: Description of Influenza A subtypes found in birds, horses, pigs, humans and dogs

Species	**Influenza A subtype**
Avian	All subtypes have been identified in birds
	H5N1 (HPAI)
	H7N7 (HPAI)
Horses	H7N7
	H3N8
Pigs	H1N1
	H1N2
	H3N2
Humans	H1N1
	H3N2
Dogs	H3N8

Strain classification

Influenza A has two surface antigens, haemagglutinin (HA) and neuraminidase (NA). Subtypes are classified based on which HA and NA subtypes are present. There are 16 subtypes of HA; HA1 to HA16, and nine subtypes of NA; NA1 to NA9 (Alexander, 2007; Alexander and Capua, 2008; Khanna et al., 2008). Within the Influenza A virus, there is a high potential for genetic diversity due to different combinations of HA and NA antigens. Viruses of the subtype H5 and H7 have been shown to cause highly pathogenic avian influenza (HPAI) (Alexander, 2007; Alexander and Capua, 2008).

There are two influenza A subtypes that have been found to cause disease in equines, H7N7 and H3N8. The H7N7 subtype was first identified in horses in Czechoslovakia in 1956 (Daly and Mumford, 2001). However, this subtype appears to be extinct, as the last time it was reported was in India in 1987 in a concurrent infection with H3N8 (Singh, 1995).

The subtype H3N8 is the most common Influenza subtype that causes EI in horses. This subtype was first isolated in Miami in 1963 (Scholtens and Steele, 1964). Until 1988, this subtype of EI was a single lineage, which is now called pre-divergent (Bryant et al., 2009). After 1988, the H3N8 subtype evolved into two distinct lines based on their geographic distribution (Oxburgh et al., 1998). These lines are referred to as the American and Eurasian lines. The Eurasian line appears to have evolved little since it diverged from the H3N8 strain first isolated in Miami (Bryant et al., 2009). In contrast, the American lineage has continued to evolve and currently comprises three new lineages: Kentucky, South American or Argentinean and Floridian (Lai et al., 2001; Muller et al., 2009) (Figure 2.1). However, there is disagreement as to whether the Argentinean lineage is actually part of the American lineage or a separate lineage (Damiani et al., 2008; Cullinane et al., 2010; Qi et al., 2010). Further work has now identified a division on the Floridian line into two sub-lineages referred to as Floridian Clade 1 and Clade 2 (Lai et al., 2004).

The American and Floridian lineages of H3N8 are not geographically confined within the American continent, with American lineages dominating the Eurasian lineage (Table 2.2). Additionally, strains of EI do not occur in isolation. Strains of EI have been found occurring consecutively or concurrently in the same populations. For example, a study in North America found horses were infected with the American and Floridian lineages in alternating years (Lai et al., 2004). In Ireland between 2007 and 2008, the circulating EI virus in horses was the Floridian Clade 2, but the circulating virus changed to the Floridian Clade 1 between 2009 and 2010 (Gildea et al., 2011b). The American and Floridian Clade 1 and 2 lineages were all identified as occurring in populations in differing geographic locations in the United Kingdom during 2006 and 2007. Only the United Kingdom and North America have active surveillance for EI, and consequently little information is available about strains circulating in other parts of the world, unless the virus causes major outbreaks of disease.

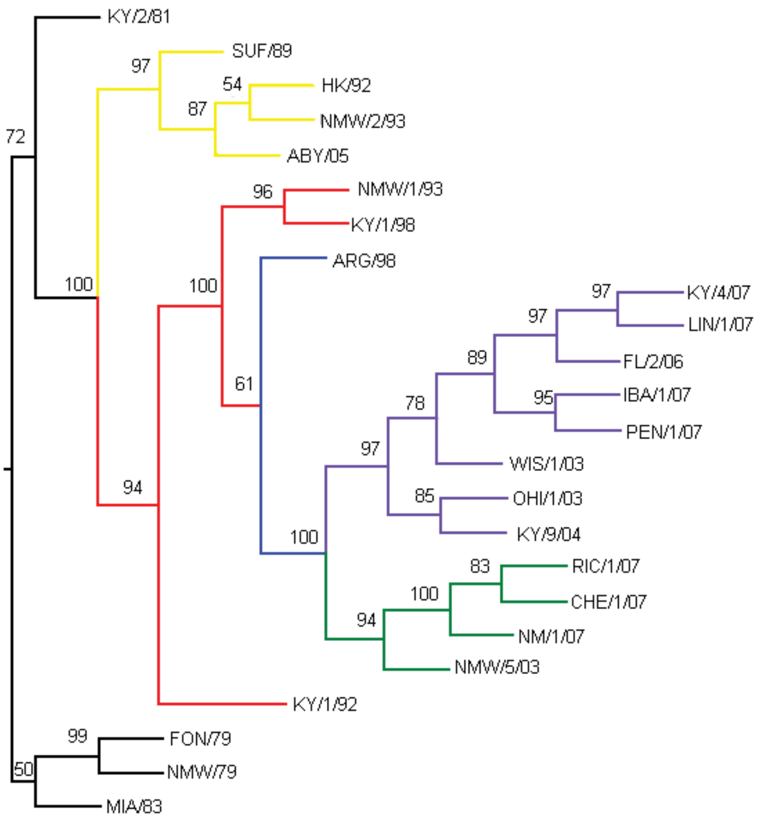

Figure 2.1: Phylogenetic tree of H3N8 viruses responsible for equine influenza based on HA1 nucleotide sequences. Bootstrap values obtained after 100 replicates are shown at the major nodes. Phylogenetic groups are shown by continuous bars on the right and are labelled as appropriate. Black = pre-divergent;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

Table 2.2: Description of the location, year and lineage of equine influenza circulating worldwide

Continent	Country	Year(s)	Lineage	Strain name	Reference
Africa	South Africa	1986	Pre-divergent	A/equine/Johannesburg/1986	(Guthrie et al., 1999)
		2003	Floridian sub-lineage	A/equine/South Africa/4/2003	(Daly et al., 2007)
America	Chile	2006	Argentinean lineage	A/equine/Lonquén/2006	(Muller et al., 2009)
	United States	1963	Pre-divergent	A/equine/Miami/1963	(Scholtens and Steele, 1964)
		2006	Floridian Clade 1	A/equine/Florida/2/2006	(Bryant et al., 2009)
		2007		A/equine/California/1/2007[a]	
Asia	China	2007	Floridian Clade 2	A/donkey/Xinjiang/5/2007	(Qi et al., 2010)
	Japan	2007	Floridian sub-lineage	A/Equine/Ibaraki/1/2007	(Yamanaka et al., 2008)
	India	2008	Floridian Clade 2	A/equine/Katra-Jammu/6/2008[a]	(Virmani et al., 2010)
		2009		A/equine/Ahmedabad/2009	
Europe	Croatia	2004	Floridian sub-lineage	A/equine/Zagreb/2004	(Barbic et al., 2009)
	France	1993	Pre-divergent	A/equine/Grosbois/1/1993	(Manuguerra et al., 2000)
		1998	Eurasian lineage	A/equine/Grosbois/1/1998	
	Ireland	2007	Floridian Clade 2	A/equine/Meath/2007[a]	(Gildea et al., 2011b)
		2009	Floridian Clade 1	A/equine/Donegal/1/2009	
		2010		A/equine/Limerick/1/2010	
	Italy	1999	Eurasian lineage	A/equine/Brescia/1999	(Damiani et al., 2008)

		2003	Floridian sub-lineage	A/equine/Roma/1/2003[a]	
		2004		A/equine/Roma/2004	
		2005		A/equine/Bari/2005	
	Sweden	1993	Eurasian lineage	A/equine/Avesta/1993	(Oxburgh et al., 1998)
		1994	American lineage	A/equine/Soderala/1994	
		1996		A/equine/Bollnas/1996[a]	
	Switzerland	2007	Eurasian lineage	A/equine/Switzerland/2007	(Bryant et al., 2009)
	United Kingdom	2003	Floridian Clade 2	A/Equine/Newmarket/5/2003	(Newton et al., 2006; Bryant et al., 2009)
				A/equine/Cheshire/1/2006	
		2006	American lineage		
				A/equine/Lincolnshire/1/2007	
		2007	Floridian Clade 1		
Oceania	Australia	2007	Floridian Clade 1	A/equine/Sydney/2007	(Bryant et al., 2010; Paillot et al., 2010)

[a] Other strains not included in the table

Studies investigating the phylogenetic development of EI show that the virus is constantly evolving, and consequently continues to circulate in the horse population (Daly and Mumford, 2001; Lai et al., 2001). The constant evolution of the H3N8 subtype of EI has implications for vaccine induced protective immunity (Lai et al., 2001), and has been implicated in outbreaks of EI in vaccinated equine populations in the United Kingdom (Newton et al., 2006) and Japan (Nishiura and Satou, 2010).

The increasing international movement of horses (Sluyter, 2001) could have played a role in broadening the geographical distribution of the American lineages of H3N8. Historically the movement of horses has been implicated in outbreaks, with some of the most devastating epidemics occurring when the virus has been introduced into areas previously free of the disease (Daly and Mumford, 2001) (Table 2.3).

Table 2.3: Description of EI outbreaks in naïve equine populations and the source of EI infection

Year	**Outbreak country**	**Country of origin**	**Reference**
1963	North America	South America	(Scholtens and Steele, 1964)
1986	South Africa	North America	(Guthrie et al., 1999)
2007	Japan	North America	(Yamanaka et al., 2008)
2007	Australia	Japan	(Callinan, 2008)
2009	India	Probably China or Mongolia	(Virmani et al., 2010)

On occasion, influenza in horses can be caused by strains of the virus other than the strains of H3N8 and H7N7 that are normally associated with EI infection. Such an outbreak was recorded in China in 1989. This outbreak was caused by a novel strain of the subtype H3N8, which was found to be more closely related to the avian than to the equine subtype. This novel strain was only isolated in China and has not been identified again since the 1989 outbreak (Guo et al., 1995).

Equine influenza has not been identified as a zoonotic disease nor does it infect animals that have been in contact with infected horses (Guo et al., 1995). However, an influenza virus that is closely related to the EI H3N8 subtype has been found in dogs (Crawford et al., 2005; Daly et al., 2008). The strain of H3N8 in dogs is thought to have evolved from an equine strain. However the dog strain of H3N8 does not appear to spread from infected dogs back to horses, instead it only spreads within dog populations.

2.2.2 Epidemiology

Distribution

Outbreaks of EI have been reported in Europe (Oxburgh et al., 1993; Oxburgh et al., 1998; Van Maanen et al., 2003; Barbic et al., 2009), the United Kingdom (Newton et al., 2000; Newton et al., 2006), Ireland (Gildea et al., 2011a), South Africa (Guthrie et al., 1999), China (Guo et al., 1995; Qi et al., 2010), North and South America (Daly and Mumford, 2001; Muller et al., 2009), Japan (Ito et al., 2008; Nishiura and Satou, 2010), India (Virmani et al., 2010) and Australia (Callinan, 2008; Anon, 2009). It is endemic throughout the world with the exception of New Zealand, Iceland and Australia (Anon, 2011f).

Clinical findings

Investigations of the clinical signs of EI have been conducted in outbreak situations (Barbic et al., 2009; Happold and Rubira, 2011; Kannegieter et al., 2011) and during immunity or vaccine trials (Bryant et al., 2010; Paillot et al., 2010). The clinical signs of EI are most obvious in horses that have not had previous exposure to equine influenza or are unvaccinated, although even in unvaccinated populations the severity of clinical signs can vary between individuals (Happold and Rubira, 2011).

Equine influenza has an incubation period of between one and seven days (Paillot et al., 2006b; Soboll et al., 2010; Happold and Rubira, 2011). The first symptom is pyrexia lasting for up to five days. Pyrexia is followed by a deep dry hacking cough, increased respiration rate, inappetance and a clear nasal discharge (Barbic et al., 2009; Paillot et al., 2010; Happold and Rubira, 2011). The nasal discharge may become mucopurulent, due to secondary bacterial involvement (Happold and Rubira, 2011). The clinical signs of infection resolve between one and 14 days in individual horses (Kannegieter et al., 2011), but once disease enters a property it can take up to 30 days to resolve (Happold and Rubira, 2011).

Infected, unvaccinated horses can start shedding EI in nasal secretions from the first day of infection for between two and ten days (Lunn et al., 2001; Park et al., 2003; Quinlivan et al., 2007; Paillot et al., 2010). In contrast, infected, vaccinated horses typically shed the virus for up to two days, from 24 to 48 hours after infection. The presence of virus in nasal secretions occurs at the time of, or after the appearance of, the first clinical signs of infection (Lunn et al., 2001; Park et al., 2003; Paillot et al., 2006b; Quinlivan et al., 2007).

Equine influenza has high morbidity, but low mortality. In many outbreaks infection rates of up to 100% have been reported (Happold and Rubira, 2011; Kannegieter et al., 2011), but few (<5%) animals die from the disease (Guo et al., 1995; Patterson-Kane et al., 2008; Smyth et al., 2011). Adult horses with no previous health issues recover quickly, usually within two weeks post infection (Guo et al., 1995) and once EI is resolved there is no latent infectious state (Myers and Wilson, 2006). However, one week of complete rest is recommended for every day that a horse has an elevated temperature and coughing can continue after other symptoms have ceased (Daly and Mumford, 2001). Mortality is usually associated with complications due to secondary bacterial infections, like pleuritis, pneumonia or purpura haemorrhagica (Paillot et al., 2006a). These conditions are more common in foals, horses in poor condition and donkeys. During the EI outbreak in Australia in 2007, there were reports of mortality in foals infected with EI (Patterson-Kane et al., 2008). All the foals that died were less than 14 days old and had secondary infections of bronchointerstitial pneumonia. Anecdotally, the occurrence of bronchointerstitial pneumonia in foals of this age group is very uncommon and was attributed to the lack of maternal immunity to the EI virus.

The clinical signs of EI are similar to those of other infectious respiratory diseases affecting horses including Equine Herpes Virus (EHV) or *Streptococcus equi* sub *equi* (strangles) (Pusterla et al., 2011). Equine influenza is differentiated from strangles or EHV by a harsh dry cough (Sherman et al., 1979; Daly and Mumford, 2001; Happold and Rubira, 2011). Both EHV and strangles are endemic in many countries including New Zealand (Dunowska et al., 2002). Differentiating EI from other infectious diseases, based on clinical signs alone, is problematic, particularly in countries where EI is an exotic disease. Clinicians may favour diagnosing illness caused by endemic disease (Poutanen et al., 2003). A similar problem has been identified in the diagnosis of Foot-and-mouth (FMD), a disease with similar clinical signs of disease to other livestock illnesses (Bates et al., 2001), including vesicular stomatitis, bluetongue, bovine viral diarrhoea and foot rot (Anon, 2007).

Immunological response

Infection with EI stimulates both a humoral and cellular immune response (Paillot et al., 2006a; Adams et al., 2011). Antibody responses to viral infection are generated in both serum and in the nasal mucosa. Both Immunoglobulin Ga (IgGa) and Immunoglobulin Gb (IgGb) are found in the serum and Immunoglobulin A (IgA) in the nasal passages after challenge with EI (Nelson et al., 1998; Lunn et al., 2001; Adams et al., 2011). Vaccinated horses when challenged with EI produce significant serum Immunoglobulin G(T) or IgG(T) antibody response (Nelson et al., 1998). Serum samples from infected horses show increased titres to specific virus haemagglutination inhibition assays (Nelson et al., 1998; Adams et al., 2011).

After infection with EI, cell mediated immune responses occur, with changes in pro-inflammatory and anti-inflammatory cytokine levels (Quinlivan et al., 2007; Adams et al., 2011). Coinciding with the clinical signs of pyrexia and viral shedding, peak pro-inflammatory cytokines interleukin (IL)-1β, IL-6 and tumour necrosis factor (TNF) α are seen two days post infection. The production of cytokines in response to influenza infection activates antiviral defence within infected cells and is important for viral clearance. Changes in anti-inflammatory cytokine IL-10 occurs at this time also. Other studies have shown increases in interferon (IFN) γ, IFNγ$^+$CD5$^+$ T cells and IL-2 (Adams et al., 2011). Additionally, during the course of EI infection, there is a reduction in the number of leucocytes or white blood cells (Lunn et al., 2001).

Transmission

Equine influenza is characterised by rapid spread through the population The speed with which EI spreads is greater than other respiratory illnesses in horses, for example EHV or strangles (Sherman et al., 1979; Daly and Mumford, 2001). Figure 2.2 shows a schematic of the contact pattern and potential spread mechanisms of EI between equine properties. The travelling nature of equine populations, compared to other livestock industries, appears to facilitate the transmission of the EI virus. In a study of EI outbreaks in Ireland between 2007 and 2010, 15 out of 16 properties with a confirmed case of EI had reported a movement of horses either on or off the property before the outbreak was detected (Gildea et al., 2011a). The one property that did not report a movement event prior to the outbreak of EI was contiguous with an infected property, highlighting additional importance of local spread. Equine influenza has also been found to spread during the mixing of horses at yearling or other horse sales (Newton et al., 2000; Bryant et al., 2009), equine events (Callinan, 2008; Bryant et al., 2009), and race meetings (Cowled et al., 2009).

The contact patterns enabling disease spread between equine properties were highlighted during an EI outbreak in Newmarket, United Kingdom in 2003 (Newton et al., 2006). The outbreak began at a large training property, but spread to other training properties in the area within two weeks of the official diagnosis on the first property (Wood et al., 2003; Newton et al., 2006). At the conclusion of the outbreak, six weeks later, 21 training properties had horses diagnosed EI positive using enzyme-linked immunosorbent assay (ELISA). The spread within the local population was attributed to the mixing of horses during training gallops. Further spread of the disease beyond the local population was attributed to racing and horse sales out of the area.

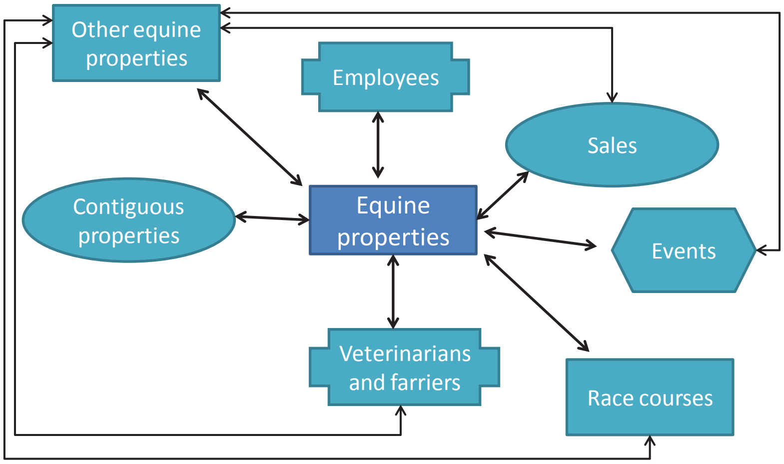

Figure 2.2: Schematic of potential contact patterns of equine properties (Adapted from Brennan et al. (2008))

During the EI epidemic in Australia three phases of spatial-temporal spread were described (Cowled et al., 2009). The first phase, called the dispersal phase, involved the spread of EI virus through the movement of horses and people. During this phase there were few newly identified infected properties, but the outbreak was geographically widespread. During the second phase, the local spread phase, there was a large increase in the number of newly infected properties, with little geographic spread. In the third phase, epidemic fade-out, there were a low number of new cases, indicating control was achieved or there was a lack of susceptible properties.

Influenza virus is found in nasal secretions and can be transmitted to a susceptible host through droplet, airborne and contact routes. Droplet transmission occurs when large drops, created by coughing, are released and land on the mucous membranes of the susceptible host. This is a short distance transmission route as droplets are large and do not stay suspended in the air for very long. In contrast, airborne transmission is characterised by a spray created from coughing and the droplets are smaller and as such can remain suspended in the air for longer periods of time (Bridges et al., 2003; Hayden and Croisier, 2005). Contact transmission occurs either directly or indirectly. Direct contact occurs when two hosts touch and virus is transferred between them. Indirect transmission involves an intermediate contaminated person or object (Bridges et al., 2003; Weber and Stilianakis, 2008). When an object, like equipment or a vehicle, is involved in indirect transmission it is called fomite transmission.

The most common route of transmission for any influenza virus has not been shown. Studies of human influenza suggest that infection via the airborne route has been underestimated; while transmission via the droplet route has been overestimated (Hayden and Croisier, 2005; Weber and Stilianakis, 2008). Both contact and droplet transmission have been shown to take place over short distances of no more than one metre (Brankston et al., 2007).

Similar to human influenza, EI transmission appears to occur via droplet, airborne and contact transmission routes and no studies conclusively point to one mode of transmission. Equine influenza has been found to be transmitted more easily within rather than between racing stables (Satou and Nishiura, 2006). This type of infection is suggestive of both droplet and contact transmission being the dominant transmission routes. In this situation, it is difficult to determine the method of transmission as horses are likely to be in direct contact with infected horses, with the same groom responsible for multiple horses or the same equipment being used within the stable complex. Furthermore, horses kept in this type of situation would be close enough to each other for droplets expelled by coughing to reach a susceptible host.

Airborne and indirect contact transmission has also been shown to occur. Davis et al. (2009) investigated the local spread characteristics of the EI outbreak in the Park Ridge region of Queensland, Australia. Equine properties in the Park Ridge region were isolated from equine properties in other areas, as properties in this area were bounded by an urban area and a horse free area of national park and rural farmland. Local spread occurred between one to three kilometres from an already infected property, but not further than eight kilometres from an infected property. Local spread was greatest over short distances throughout the outbreak, with properties contiguous to infected properties often themselves becoming infected. Two possible spread mechanisms were identified, fomite transmission or airborne transmission. The conclusion of fomite transmission was based on EI occurring on vaccinated properties and properties contiguous to vaccinated properties, one to three days after visitation by vaccination teams. Aerosol spread was also possible due to the weather patterns in the region at the time of the outbreak (Davis et al., 2009).

Risk factors

In vaccinated populations both age and antibody titres have been shown to be risk factors for EI infection. Age has been identified as a risk factor for EI, with older horses showing less severe clinical signs of disease, immunological response to infection and a shorter duration of viral shedding than younger horses (Morley et al., 2000; Adams et al., 2011). Antibody titres have also been shown to be a risk factor for EI, with horses with low antibody titres up to 40 times more likely to become sick (Morley et al., 2000). However, Adams et al. (2011) showed that both vaccinated and unvaccinated older horses (>20 years) had higher antibody titres compared to young naïve horses (<1 year), but in this study horses with low antibody titres were specifically chosen for the naïve group. Consequently, neither study can distinguish the difference between the effect of age or antibody titres on the risk of EI infection. Based on these studies (Morley et al., 2000; Adams et al., 2011), in a completely naïve population the risk of infection is likely to be constant for all age groups, based on an absence of antibody titres to EI. During the Australian EI outbreak, naïve mares, particularly those in the last trimester of pregnancy, were more severely affected by EI than other naïve horses (Happold and Rubira, 2011). Additionally, the risk of complications and mortality from secondary bacterial infections may be higher in animals less than one year old, as in Australia mortality in foals was associated with bronchointerstitial pneumonia (Patterson-Kane et al., 2008).

2.2.3 Control methods

Key methods to control exotic disease outbreaks include movement restriction, vaccination, depopulation or culling and enhanced biosecurity. While depopulation or culling is a key control method for FMD (Yoon et al., 2006), it is generally not considered a method suitable for the control of infectious diseases in horses. Horses are of a higher value than other livestock species in which culling is a suitable strategy, and the infectious diseases that control would be targeted at do not have a long term impact on equine health or productivity. Vaccination is the key method of control in countries where EI is endemic, however the usefulness of vaccination in EI incursion situations is less clear (Cowled et al., 2009; Garner et al., 2011). Enhanced biosecurity practices and movement restrictions are also important strategies for the control of EI, and have been shown to be effective during exotic disease outbreaks (Nishiura and Satou, 2010).

Vaccination

In EI endemic countries vaccination has not led to the eradication of EI, even though populations of horses have been routinely vaccinated since the 1960's. Instead, there have been periodic reports of outbreaks in vaccinated groups of horses (Van Maanen et al., 2003; Newton et al., 2006; Nishiura and Satou, 2010). The reason for this is two-fold. Firstly, the vaccines available for the control of EI do not provide sterile immunity against infection. Instead vaccinated horses can be subclinically infected with EI and be infectious to other horses, even if they are vaccinated. The second reason is the constantly evolving nature of EI, particularly the American lineage of the H3N8 subtype. To be highly efficacious, vaccine strains must contain viral strains that match the circulating viral strain (Borchers et al., 2005). Protection from EI can be offered by vaccine strains that are not too different from the circulating strain of virus, but the magnitude of difference to maintain efficacy has not been quantified (Paillot et al., 2010).

The primary aims of vaccination in countries where EI is endemic are to reduce the clinical signs of disease, and reduce transmission by reducing viral shedding (Paillot et al., 2006a). While reducing the clinical signs of disease is important, during exotic disease outbreaks preventing or reducing transmission rates is critical. Due to the speed that EI spreads through an immunologically naïve population and the short incubation period of EI, to be useful for control, vaccines must stimulate immunity in a susceptible horse rapidly, to prevent the spread of EI to other susceptible horses (Minke et al., 2011). Due to time and resource constraints for vaccination during an outbreak, immunity would need to be stimulated from just one vaccination dose.

Types of vaccines

Traditional vaccines contain either killed, inactivated or subunits of HA or NA antigens with or without adjuvants to improve their potency (Mumford et al., 1994; Crouch et al., 2004; Minke et al., 2004; Paillot et al., 2006a). These vaccines only induce short lived immunity to EI as they do not stimulate the immune system in the same way as natural infection (Minke et al., 2004; Paillot et al., 2006a), although, in subunit vaccines, immuno stimulating complexes have been found to induce circulating IgA and IgG antibodies and enhance the mucosal immune response enough to prevent the clinical signs of disease after challenge with EI (Crouch et al., 2004; Crouch et al., 2005).

The efficacy of traditional vaccines in endemic populations is questionable. In a large study in Colorado, across six properties and including 173 horses, the efficacy of whole virus vaccine was investigated (Mumford et al., 2003). Horses were vaccinated twice, 13 to 18 weeks apart, with a whole virus vaccine and serum samples were collected 14 days after the second of two vaccinations. The results from the blood samples identified that only 2% of the vaccinate horses had seroconverted in response to vaccination. The lack of seroconversion indicates that the vaccine had not stimulated antibody production in the vaccinated horses and consequently would not be efficacious in the event of an EI disease challenge in this group of horses.

In 1986, traditional vaccines were used to control an EI outbreak in South Africa (Guthrie et al., 1999). The outbreak was officially detected on the 12th of December 1986 and vaccine became available for use on the 21st of December. The vaccination of Thoroughbred racehorses was mandatory during the outbreak, and two doses of vaccine were administered to each horse. The time between each dose of vaccine was not reported in the paper by Guthrie et al. (1999), although it was noted that vaccinated horses were not able to be moved from properties until 42 days after the completion of the vaccination schedule. While vaccination was used and eradication was achieved, there has not been a formal analysis to determine the effectiveness of vaccination in obtaining control.

The next generation of vaccines are modified live virus vaccines and canary-pox vectored vaccines. Modified live virus vaccines closely mimic the body's own immune response to influenza infection and offer better protection against disease than traditional or subunit vaccines (Chambers et al., 2009). Modified live virus vaccines are attenuated by cold adaption, and therefore unable to replicate at body temperature. The advantage of these vaccines in an outbreak situation is that while they do not offer sterile immunity, some protection from vaccination occurs rapidly, with protection identified two weeks, one month and three months after a single dose of vaccine (Chambers et al., 2001; Lunn et al., 2001). While modified live vaccines have been shown to decrease the clinical signs of infection, compared to unvaccinated control horses, viral shedding still occurs, although for vaccinated horses the duration and amount of virus shed was less than unvaccinated controls (Townsend et al., 2001).

Experimentally, the canary-pox vectored vaccine has been found to offer protection against EI infection. Horses vaccinated twice and then challenged at either two weeks, five months or 12 months post vaccination had shorter duration of pyrexia and viral shedding, compared to control horses (Minke et al., 2007). Vaccinated horses did not show any other clinical signs of disease. Horses vaccinated once and challenged 14 days after vaccination also showed reduced clinical signs of disease and viral shedding, compared to unvaccinated controls (Soboll et al., 2010). Minke et al. (2011) identified that vaccinated mares showed high antibody levels after vaccination and that foals could also produce an antibody response to canary-pox vaccination. Vaccinated mares produced an antibody response from nine to 35 days after a single vaccination. However, in this study horses were not exposed to EI, so the protection offered by vaccination was not investigated.

The efficacy of canary-pox vaccine was investigated during the Australian EI outbreak in 2007, and the results were similar to vaccine trials. Kannegieter et al. (2011) identified that one dose of the canary-pox vaccine offered protection to racehorses exposed to EI as soon as seven days after being vaccinated. Vaccinated racehorses showed less severe clinical signs of disease and had less viral shedding than similar groups of racehorses kept at another location, which had not been vaccinated. Additionally, while the proportion of infected horses, as measured by clinical signs, in the unvaccinated racehorse group was 100%, in the vaccinated group the proportion of infected horses was 48%. Similarly, Perkins et al. (2011) noted that that horses had less severe clinical signs of EI infection if exposed to the virus seven to eight days after vaccination.

Regardless of the vaccine used, inactivated, modified live or canary-pox vectored, complete control of EI might not be possible as vaccinated horses may potentially pose a risk to naïve horses. A feature of all vaccines is suppressed clinical signs of disease and viral shedding post EI exposure, so horses are infective but difficult to detect. The level of viral shedding during an outbreak situation may be lower than during a vaccine trial, due to the dose of EI received, but the impact of the dose of virus and viral shedding has not been investigated (Minke et al., 2007). In an outbreak in Japan, subclinically infected horses have been found to cause secondary infections in a vaccinated racehorse population (Nishiura and Satou, 2010).

Emergency vaccination strategies

During an exotic disease outbreak there are several vaccination options available depending on the size of the outbreak, the resources available for vaccination and the importance of controlling EI in a timely manner. Emergency vaccination strategies include protective, suppressive, targeted and mass vaccination (Garner et al., 2011; Perkins et al., 2011). Suppressive vaccination strategies target properties in a radius around an infected property. In contrast, protective vaccination, also called ring vaccination, targets properties in a ring around identified infected properties, at a distance that will prevent disease from spreading beyond the ring (Bates et al., 2003b). Targeted vaccination focuses on properties within a radius of an infected property, which meet a certain selection criteria. If the mass vaccination strategy is chosen, all properties with susceptible animals are vaccinated, regardless of infection status or proximity to infected properties. During a rapidly spreading disease outbreak, mass vaccination may not be possible due to limitations on resources.

During the 1986 EI outbreak in South Africa, a targeted vaccination strategy was chosen, with only Thoroughbred racehorses vaccinated (Guthrie et al., 1999). In contrast, during the 2007 EI outbreak in Australia, targeted ring and mass vaccination strategies were attempted at some point during the outbreak (Anon, 2009; Perkins et al., 2011). In New South Wales, ring vaccination was implemented in areas called buffer zones, created using a combination of geographical barriers and areas with no horse use. There were five zones: purple, red, amber, green and white, with all but the purple zone acting as vaccination buffer zones (Figure 2.3). Horses within these areas were required to be vaccinated or moved closer to infection. A suitable distance from areas of known infection was chosen so that immunity in vaccinated horses had time to develop before being challenged with EI. The aim of ring vaccination was to vaccinate 85% of horses within each ring.

The targeted vaccination of horses involved in the racing industry, police horses, horses involved in Riding for the Disabled, donkeys and horses deemed to be high risk, was carried out during the outbreak. The targeted vaccination strategy was aimed at horses deemed to be at a high risk of spreading EI. The vaccination of racehorses did allow for the resumption of race meetings in December 2007. Later in the outbreak, mass vaccination was implemented in an area that was surrounded by areas of ring vaccination and that had a low density of horse properties (Anon, 2009; Perkins et al., 2011).

In Queensland, ring vaccination was initially implemented in a similar fashion to New South Wales. However, two weeks into the emergency vaccination response, this strategy was abandoned in favour of one large ring of vaccination around the whole infected area. This ring was set at 30 kilometres from the nearest infected property (Anon, 2009; Perkins et al., 2011).

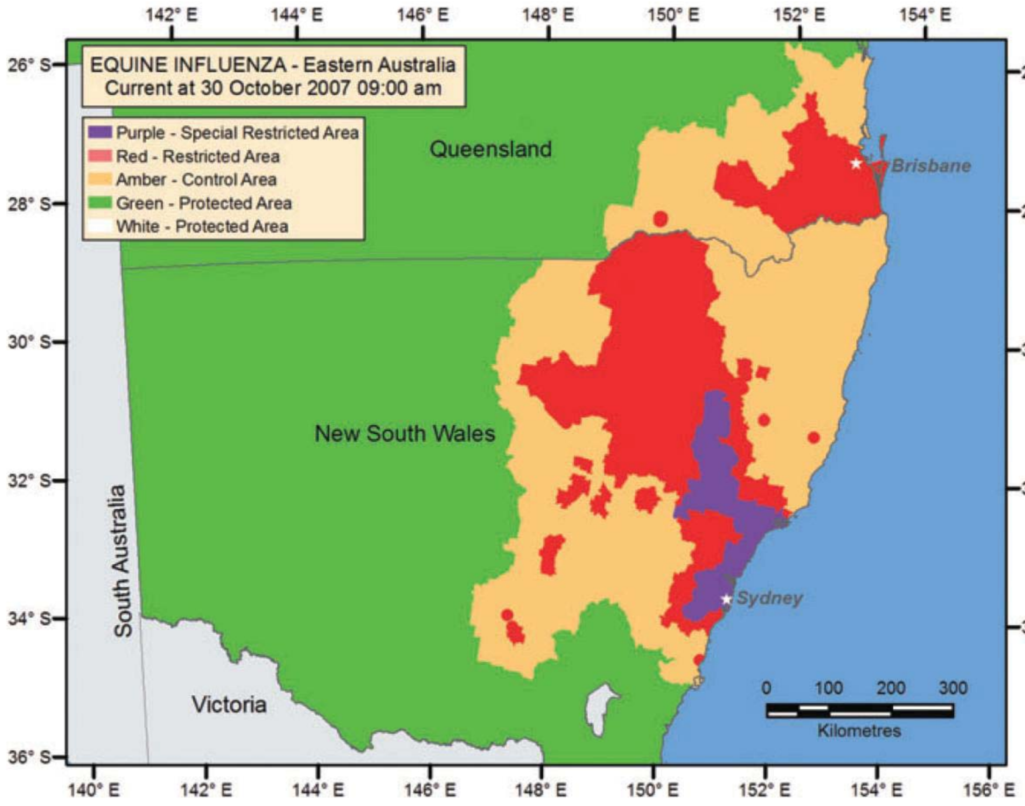

Figure 2.3: Vaccination zones implemented on October 30th 2007, during the EI outbreak in New South Wales and Queensland, Australia. Adapted from Moloney (2011)

Biosecurity practices

Biosecurity aims to prevent the transmission of disease between infected and susceptible animals, eliminate reservoirs for disease spread and increase a susceptible animal's resistance to disease (Smith, 2002). Biosecurity can be used to prevent the transmission of disease both between and within properties. As the purpose of biosecurity during an EI outbreak would be to prevent transmission between properties, this section of the literature review will focus on those methods that prevent the spread of EI between properties rather than the within a property.

Because EI is transmitted through direct horse-to-horse contact, through indirect human-to-horse contact or through fomites, biosecurity is achieved using measures that include isolating newly arriving animals and the vaccination of susceptible animals (Dargatz et al., 2002). As EI can be spread indirectly, the application of biosecurity practices to people and vehicles is equally important, as the movement of people and vehicles between and within farms can amplify the spread of infection. Visitor protocols include reducing access that visitors have to susceptible animals, showering, changing clothing or equipment, and hand or boot washing (Barrington et al., 2002; Barrington et al., 2006).

Biosecurity practices have been shown to be effective at limiting the spread of disease in equine populations (Kohn et al., 2006; Firestone et al., 2011a; Gildea et al., 2011a). However, there is limited research regarding current biosecurity practices for equines or equine properties and few studies have been conducted elucidating effective control strategies. Comparisons between studies investigating the biosecurity practices on horse properties is difficult, due to varying definitions of biosecurity practices and the broad range of practices that could be encompassed by the term.

One year after the EI outbreak in Australia, Schemann et al. (2011) conducted a cross-sectional study of horse owners to determine biosecurity practices and perceptions, with data collected by online questionnaire. Sixteen biosecurity measures were evaluated on a five point scale of implementation (every time to never). Practices ranged from personal, visitor and equipment hygiene, limiting the sharing of equine equipment with non-resident horses, records of horse health and visitors to the property and the isolation of newly arriving horses. The median response value for each respondent was then indexed as high, medium or low and analysed by ordinal regression. Half of the respondents had high biosecurity compliance, while 30% had low compliance. Low compliance with biosecurity practices was associated with younger people, people with more children and those with no involvement in the equine industry. Use of an online questionnaire makes it difficult to calculate response rates or make comparison between the surveyed population and the underlying population. Responder bias may have been an issue in this study. People with an interest in biosecurity would have been more likely to respond, and therefore were more likely to have biosecurity practices. Therefore, the findings of Schemann et al. (2011) may have overestimated of the proportion of people that implemented biosecurity practices. In addition, this study reported the proportion of responders with biosecurity practices, accounting for biosecurity at an individual-level. The proportion of respondents reporting biosecurity practices may have been lower if data were collected at the property-level, as more than one individual can manage horses on a single property.

In a study of commercial Thoroughbred breeders in New Zealand, Rogers and Cogger (2010) identified that only 32% of stud managers routinely isolated stallions. In the week prior to survey, only 18% of stud managers had isolated newly arriving mares, although 89% of stud managers had isolated mares in the past. On stud farms where newly arriving mares had ever been isolated, mares were isolated for ill thrift or illness, if they were from an unknown or untrustworthy source, or if they were from Australia. Of the surveyed stud mangers, 57% reported having visitor protocols for veterinarians to follow before interacting with resident horses. Visitor protocols included changing clothes, cleaning or changing shoes or equipment, and washing hands. This study was conducted prior to the EI outbreak in Australia, in a country with few endemic equine diseases (Anon, 2011f). Additionally, the study was a convenience sample of selected Thoroughbred stud farms found in the North Island. While the Thoroughbred stud book is the largest stud book in New Zealand (Rogers et al., 2009), the Standardbred stud book is the second largest and contributes significantly to the commercial breeding industry. Therefore, this study may not be a true representation of biosecurity practices on commercial stud farms after the EI outbreak, as awareness of the importance of biosecurity may have been heightened.

A study of the general horse population in North America reported that 80% of horse owners either did not have, or did not know about, biosecurity practices where their horses were kept (Vanderman et al., 2009). It was not clear from the study what percentage of respondents did not know about biosecurity measures and what percentage did not have biosecurity practices.

In an earlier study of the general horse population in North America (USDA, 2006), less than 25% of properties ever isolated newly arriving horses, got health certificates or had a veterinarian to examine horses on arrival. Less than 20% of the surveyed respondents had any biosecurity requirement for visitors that interacted with horses (USDA, 2006). Traub-Dargatz et al. (in press) used data collected in the American general horse survey (USDA, 2006). Properties were categorised into three levels, based on a risk of disease entry via the movement of horses onto the property, in the year prior to survey. Properties in the high risk category had a horse visit the property or a new horse introduced onto the property. Properties in the medium risk category had resident horses leave the property, interact with non-resident horses off the property and then return to the property.

Properties in the low risk category did not have any contact with horses from outside the property in the 12 months prior to survey. Overall, 79% of properties were in the high or medium risk categories. There were significant differences between the implementation of biosecurity practices, including vaccination, maintenance of health records, isolation of newly arriving or returning horses and infection control and risk level, with high and medium risk properties more likely to implement practices. Overall, 80% of medium and high risk properties isolated returning or newly arriving horses and 49% had infection control practices for people, including the changing of clothes or shoes and hand washing.

While biosecurity is assumed to control disease, there have been very few studies investigating the effectiveness of different intervention. In Australia, the effectiveness of biosecurity measures implemented during the EI outbreak were investigated in a retrospective case control study (Firestone et al., 2011a). The study selected participants from areas in New South Wales, Australia, that were affected by EI during the Australian outbreak and compared biosecurity practices on case and control farms. The study found the use of footbaths was associated with a 73% reduction in the odds of a property being infected with EI. The study also found that people keeping daily records of the clinical signs EI in their horses more likely to have infected horses. However, it is possible that this result was due to surveillance bias rather than truly increased risk. Other factors investigated were fomite vectors, visitor protocols and personal hygiene, the disposal of manure and the source of feed and gear. The study by Firestone et al. (2011a) did not specifically investigate the isolation of horses or the effectiveness of isolation of arriving or sick horses for preventing EI from affecting other horses resident on the property. The practice of isolating sick or in-contact horses, or preventing contact between resident and newly arriving horses, has been identified as being effective at preventing the spread of EI (Nishiura and Satou, 2010; Gildea et al., 2011a).

Movement restriction

During an infectious disease outbreak, the restriction or prohibition of the movement of animals is important for limiting the transmission of infectious diseases. Movement restriction is important to control the long distance spread of disease (Taylor et al., 2004). Movement restriction, and the cancellation of equine events, has been shown to be effective at controlling EI during outbreaks in susceptible populations in South Africa (Guthrie et al., 1999), Australia (Cowled et al., 2009) and Japan (Nishiura and Satou, 2010).

2.3 Disease modelling

Models that simulate the spread of infectious disease in animal or human populations, herein called disease models, provide a framework to express and describe systems that are often highly complex (Green and Medley, 2002; Keeling, 2005). Disease models can be used to understand the magnitude of possible outbreaks and investigate the effectiveness of strategies for the control of infectious disease (Garner et al., 2007; Francis et al., 2010). Once developed, disease models can be used as tools to inform decisions and policies regarding the implementation of control strategies, in the event of a disease outbreak. As such, disease models are developed for specific diseases affecting specific populations, making generalisabilty across diseases or populations difficult (Woolhouse, 2011).

To simulate an epidemic, it is necessary to consider how a disease spreads throughout a population in the absence of control measures and, to examine how control measures influence the subsequent course of disease spread (Anon, 2010a). In this respect, disease models can be predictive, if used in areas where disease is not present (Garner and Lack, 1995; Bates et al., 2003a; Ward et al., 2009; Martínez-López et al., 2011a) or used retrospectively after an outbreak has occurred (Yoon et al., 2006; Garner et al., 2011) to investigate the control strategies not implemented during the outbreak. If a disease model has been developed for a disease or an area, and an outbreak subsequently occurs, models can be used to predict the course of the outbreak based on real-time outbreak data (Dickey et al., 2008).

The premise of disease models is that the population of interest can be divided into mutually exclusive disease states. In their simplest form, disease models describe the population as transitioning through states of infection, with the population defined at the property-, farm-, market- holding-, or animal-level. The most basic model has three mutually exclusive states: susceptible (S), infected (I) and recovered or removed (R). The name of this basic model is based on the first letter of each of the states, SIR (Green and Medley, 2002; Keeling and Rohani, 2007). During an epidemic, the susceptible individual transitions through the state where they are susceptible to disease, to being infected. Once an individual is in the infected state then they can infect other individuals in the susceptible state. If the disease has a high mortality, then individuals will be removed from the population through death. Those that survive can gain immunity and conclude the epidemic in a recovered (R) state. Alternatively, they may not gain immunity and return to the susceptible state (Figure 2.3). A model where individuals do not gain immunity is called an SIS model. A basic SIR model can be used to investigate the persistence of infection within a population (Keeling and Rohani, 2007).

Complexity can be added to the basic SIR model, to allow more detailed descriptions of different infectious agents and populations of interest. A model, which includes a latent period between becoming infected and being able to transmit disease to other susceptible individuals, is called either the SLIR or SEIR, with the latent period is denoted either as latent (L) or exposed (E) (Figure 2.3). More advanced state transition models add further complexity by including other states, like trigger (T), which are positively diagnosed individuals (Kiss et al., 2005), or (M) passively immune individuals

(Louz et al., 2010). Regardless of the complexity, the outputs include the number of individuals in each state in the population, the duration of the epidemic and the basic reproduction number R_0. R_0 denotes how infective the disease is in the susceptible population by calculating the number of secondary contacts infected by one infected individual (Heffernan et al., 2005). If at any time R_0 is less than one, infection is said to be clearing from the population.

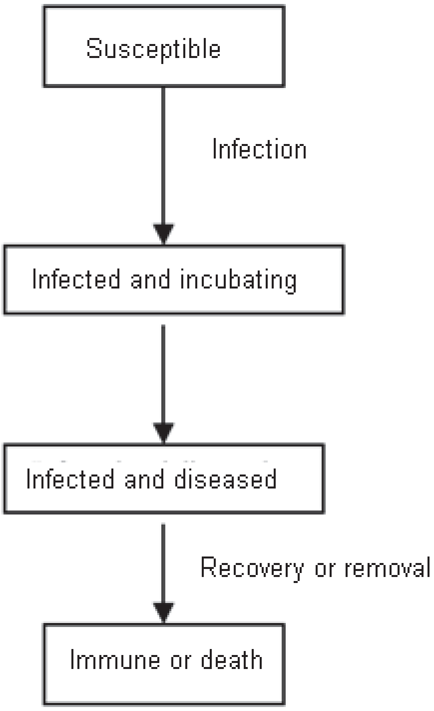

Figure 2.4: Description of mutually exclusive state transitions that an individual animal or property can move through during a susceptible, infectious, recovered (SIR) model. Figure from Green and Medley (2002)

Models can be described as either deterministic or stochastic. Deterministic models do not account for variability or randomness, even though variability is an intrinsic factor of an infectious disease outbreak (Louz et al., 2010). Unless the model parameters are changed, the results from a deterministic model will be the same each time a model is run. The main purpose of deterministic models is to increase understanding and knowledge of the infection transmission process and describe effects and rates of change (Green and Medley, 2002). Unlike deterministic models, stochastic models account for randomness and uncertainty by integrating a probability function for the transitioning of individuals between states. The results from stochastic models change each time a model is run, and generally multiple model iterations are used to describe the probability of events occurring (Morris et al., 2001; Cowled and Garner, 2008). The advantage of stochastic models compared to deterministic models is that stochastic models can account for differences within the population at risk and uncertainty in the model parameters (Garner et al., 2007).

While stochastic SIR models allow the uncertainty and variability inherent in model inputs to be captured, the model outputs are still only temporal and provide no information about the spatial distribution of an infectious disease outbreak. If a highly infectious exotic disease enters a naïve population, a national response would be required to achieve control. Consequently, the lack of spatial output limits the usefulness of SIR models as tools to support decisions regarding the implementation of nationwide control strategies (Mikler et al., 2007). Therefore, more advanced stochastic models have been developed that account for the transmission of infection across a time and space and are described as spatial, temporal state transition models. Since the outbreak of FMD in the United Kingdom in 2001, a number of the spatial, temporal state transition models have been developed (Rorres et al., 2011).

Three commonly used spatial, temporal stochastic modelling tools for animal diseases are InterSpread Plus (Sanson, 1993; Morris et al., 2001), AusSpread (Garner and Beckett, 2005) and North American Animal Disease Spread Model (NAADSM) (Harvey et al., 2007). These models can account for multiple movement and spread mechanisms from multiple farm types and different control methods including surveillance, contact tracing, limited vaccination resources, depopulation, and movement restriction and different vaccination strategies. The spread of disease occurs through the movement of animals and people, either from farm to farm, on set routes or through areas where animals mix, like sales yards. A local spread parameter describes the spread of disease through factors other than movement from infected properties (Figure 2.4). The outputs of spatial, temporal state transition models include a temporal aspect with duration of the epidemic and number of infected properties and a spatial aspect with location of infected properties. North American Animal Disease Spread Model differs from AusSpread and InterSpread Plus in that it incorporates an economic modelling feature which is import in accounting for the consequence of disease outbreaks and evaluating control options (Rich et al., 2005b; Garner et al., 2007).

Due to the complexity of spatial, temporal state transition models, they are computationally expensive and take longer to develop and run than more simple SIR type models (Keeling, 2005). Therefore models developed using spatial, temporal state transition models need to be available before disease outbreaks occur.

While each of the three stochastic state transition models; InterSpread Plus, AusSpread and NAADSM, have been used to describe the spread and control of FMD, all three models have much wider applications. Each provides a framework to build a model of infectious disease spread, given knowledge of the population of interest, disease spread characteristics and possible control strategies. AusSpread has been used to evaluate the effectiveness of control strategies for EI (Garner et al., 2011). InterSpread Plus has been used to simulate the control of classical swine fever (CSF) (Boklund et al., 2009) and has been modified to match specific livestock, production, movement, policy and geographic circumstances (Mourits et al., 2002; Velthuis and Mourits, 2007). A summary of model types and uses are described in Table 2.4.

In order to use models to support decisions in the event of a disease incursion, there must be confidence in the reliability of disease models. To increase confidence in model parameters, the outputs of InterSpread Plus, AusSpread and NAADSM have been compared (Dubé et al., 2007; Sanson et al., 2011). Using the same, simplified set of model parameters, a hypothetical outbreak of FMD-like infection was modelled in the same hypothetical geographical area with six different baseline scenarios and five models with control strategies including movement restriction, vaccination and depopulation (Dubé et al., 2007). The main disease processes; the mechanisms of transmission and the movement of animals, and control methods used in each model were systematically evaluated. When the outputs of all three models were evaluated, there were significant differences between the number of infected properties, duration of the epidemic and the area affected by the epidemic. Modelling using the AusSpread and InterSpread Plus tools lead to larger outbreaks than the NAADSM tool.

A second validation exercise was conducted to simulate the potential spread of FMD-like infection in the Republic of Ireland (Sanson et al., 2011). The second validation exercise differed from the first in that real population data rather than hypothetical data were used. Like the hypothetical outbreak, the outputs of all three modelling tools varied significantly, with NAADSM predicting larger outbreaks of disease.

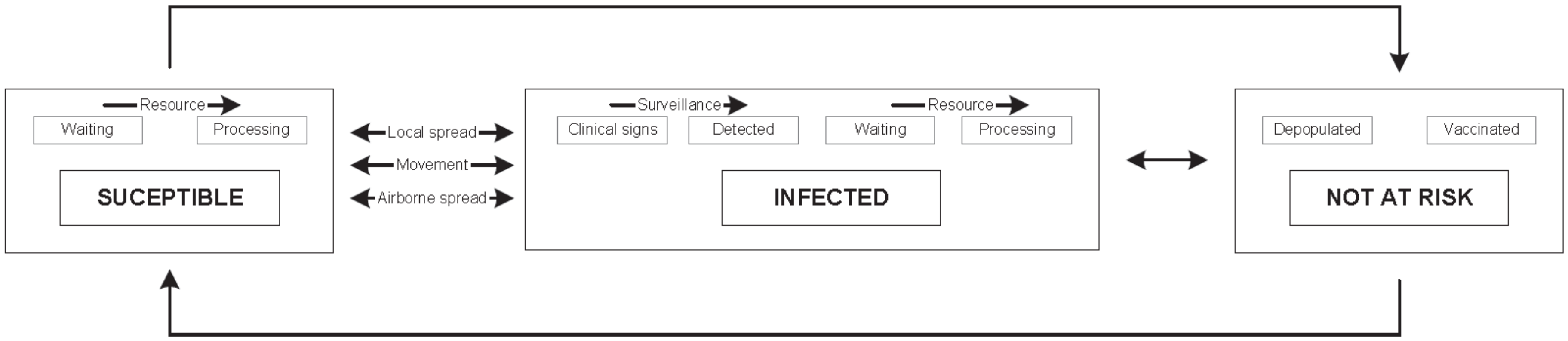

Figure 2.5: Diagram showing the set states defined within InterSpread Plus: susceptible, infected, and not at risk (Anon, 2010a)

Table 2.4: Examples of disease models and control options investigated for infectious diseases in livestock and horses

Country	Disease	Species	Type of model	Control Strategies investigated	Predictive or retrospective	Reference
Australia	Equine influenza	Horses	AusSpread	Vaccination Movement restriction	Retrospective, based on outbreak data	(Garner et al., 2011)
Denmark	Classical swine fever	Pigs	InterSpread Plus	Depopulation Enhanced surveillance Enhanced biosecurity	Predictive, included an economic component	(Boklund et al., 2009)
Korea	Foot-and-mouth disease	Cattle Sheep Pigs	InterSpread Plus	Enhanced surveillance Vaccination Depopulation	Retrospective, based on outbreak data	(Yoon et al., 2006)
The Netherlands	Classical swine fever	Pigs	InterCSF based on InterSpread Plus	Depopulation Movement control	Retrospective, based on outbreak data	(Jalvingh et al., 1999)
	Bovine herpesvirus type I	Cattle	InterIBR based on InterSpread plus	Biosecurity Movement restriction Depopulation Vaccination	Predictive, included an economic component	(Noordegraaf et al., 2000)
New Zealand	Foot-and-mouth disease	Livestock	InterSpread Plus	Enhanced surveillance Vaccination Depopulation	Predictive	(Owen et al., 2011)
QUADS*	Foot-and-mouth disease -like infection	Livestock	InterSpread Plus AusSpread NAADSM	Movement restriction Ring vaccination Ring depopulation	Theoretical Comparison of all three models	(Dubé et al., 2007; Sanson et al., 2011)
Spain	Classical swine fever	Pigs	Spatial stochastic	Movement restriction		(Martínez-López et al.,

			model Be-FAST	Depopulation Tracing		2011a)
United Kingdom	Foot-and-mouth disease	Cattle, pigs, sheep	InterSpread Plus	Depopulation vaccination	Retrospective, based on outbreak data	(Morris et al., 2001)
	Equine influenza	Horses	Two tier stochastic SEIR model	Vaccination	Based on outbreak data	(Baguelin et al., 2010)
United States of America	Foot-and-mouth disease	Beef, dairy, swine, small ruminants	Spatially explicit, stochastic simulation	Different contact patterns	Theoretical	(Dickey et al., 2008)
	Foot-and-mouth disease	Cattle	AusSpread	Early detection Enhanced surveillance Vaccination	Predictive	(Ward et al., 2009)

*QUADS Quadrilateral countries (Australia, Canada, New Zealand, and United States of America)

In both model evaluation studies, the outputs from all three modelling tools would have led to the same control decisions (Dubé et al., 2007; Sanson et al., 2011). Therefore the use of any of these modelling tools to simulate the spread and control of disease is a valuable tool to aid in supporting disease control decisions, although direct comparisons between models would not be possible unless using exactly the same data to populate each model.

2.3.1 Disease modelling of equine populations

Prior to the EI outbreak in Australia in 2007 (Anon, 2009), the modelling of the spread or control of EI in equine populations had been limited to very specific groups in a population of horses where EI is endemic. Stochastic SEIR and SIR models have been used to investigate the spread of EI through Thoroughbred training yards and the effectiveness of vaccination, in New York, based on data collected during the 1963 outbreak in America (Glass et al., 2002) and in the United Kingdom (de la Rua-Domenech et al., 2000; Park et al., 2003). All three models identified that vaccination dramatically reduced the size and likelihood of an EI outbreak within Thoroughbred training yards. These models examined the infection dynamics of single Thoroughbred training yards over a time scale of one year, assuming the mixing and contact patterns of horses in these yards was homogenous. An assumption of homogenous mixing and contact of horses in a training yard is unrealistic. In a training yard, a horse will be nearer to some horses compared to others, through physical proximity and through shared grooms and gear. Therefore, the actual rate of spread would have been overestimated in some groups and underestimated in others.

Baguelin et al. (2010) extended the SEIR model developed to describe the spread of EI within Thoroughbred training yards (Park et al., 2004) by considering the effect of the between yard spread of disease. Using a SEIR model based on an outbreak of EI in Newmarket in 2003 (Newton et al., 2006), a two tier model, simulating the spread of disease between as well as within yards, was developed (Baguelin et al., 2010). The results showed that the final size of the outbreak was positively associated with the number of horses at the training yard where the outbreak began. Additionally, there was a benefit to trainers having their whole yard vaccinated. Although the full benefit of vaccination was not achieved if neighbouring trainers did not vaccinate their horses. This SEIR model was acknowledged by the authors to be a simple approximation of EI spread in this population, as no account was made of the geographic distribution of Thoroughbred racehorse training yards within the Newmarket area. Furthermore, the S(E)IR models did not account for the movement of horses to race meetings, an area where contact with infectious animals and the subsequent spread of disease is likely to occur (Christley and French, 2003; Nishiura and Satou, 2010).

The S(E)IR models of the within yard spread of EI have been important for developing vaccination regimes for outbreak prevention in endemic countries. However, these models are not useful when describing the spread of disease during nationwide epidemics, nor the effectiveness of control strategies in completely naïve populations. Furthermore, the spread of disease described in these studies cannot be generalised beyond single Thoroughbred training yards in the United Kingdom or New York.

After the EI outbreak in Australia, Garner et al. (2011) used a spatial stochastic simulation model (AusSpread) to determine the potential effectiveness of vaccination, if it had been implemented earlier. Previous studies suggested that vaccination began too late in the Australian EI outbreak to have been an effective tool for control (Cowled et al., 2009). Garner et al. (2011) used data collected during the EI outbreak, and compared the effectiveness of movement restriction and suppressive, protective or targeted vaccination strategies implemented seven days after the detection of EI. Suppressive vaccination involved vaccination at either a one or three kilometre radius around identified infected properties. Protective vaccination involved vaccination at a seven to ten kilometre band around an identified infected property. The targeted vaccination strategy involved vaccination at a 20 kilometre radius of an infected property targeted at properties with more than ten horses. All vaccination strategies were modelled with movement restriction. Additionally, Garner et al. (2011) modelled the implementation of vaccine with optimal and limited human resources available for the administration of vaccination. The latter was done to simulate the true shortage of manpower that occurred during the EI outbreak (Anon, 2009). All vaccination strategies, if implemented at seven days after the outbreak was officially declared, resulted in shorter epidemic with fewer infected properties than movement restriction alone (Garner et al., 2011). With optimal human resources, the most effective strategy was a three kilometre ring of vaccination around infected properties. If resources were limited then the most effective strategy was a ring of vaccination one kilometre around infected properties.

Hayama et al. (2011) described the potential for Equine Infectious Anaemia to spread through the Japanese non-racing population, and the effectiveness of enhanced surveillance. Using stochastic simulation at the individual horse-level, the spread of Equine Infectious Anaemia was modelled at weekly intervals and disease was seeded in each of the sectors identified in the non-racing industry in Japan; equestrian, private owner, exhibition and fattening (Hayama et al., 2010). The disease spread patterns varied when disease was seeded in different sectors of the non-racing industry. The greatest dissemination of Equine Infectious Anaemia was from properties involved in the equestrian sector. This was due to the higher number of horses and higher frequency of horse movements from this property type, compared to other properties in the non-racing industry. The model created was very specific for developing better surveillance strategies for Equine Infectious Anaemia in the Japanese horse population, and was based on population data very specific to this industry. Therefore, the generalisabilty of this study to horse populations other than the one found in Japan would be difficult, although the model could be modified to investigate the spread and control of other equine infectious diseases within this population.

2.3.2 Population parameters

The accuracy of disease models are predicated on accurate data regarding the population of interest. In order to accurately model an epidemic over large geographical areas, an understanding of the demographic of the horse population, characters of the properties and movement patterns are required (Mikler et al., 2007) because these factors have implications on disease spread. In livestock populations, the recording of individual animal identification is common in some countries (Bigras-Poulin et al., 2006; León et al., 2006; Ortiz-Pelaez and Pfeiffer, 2008). In 2012, the National Animal Identification and Tracing (NAIT) scheme will be deployed for food production animals in New Zealand to enhance biosecurity response, and provide lifetime animal traceability (Anon, 2012d). This system requires the mandatory registration of cattle and deer and the recording of animal movement. However, horses are currently not included in this mandate.

The ability to record animal-level data linked to individual animal identification enables animals to be followed from birth to slaughter. Additionally, all movement events throughout the animal's lifetime can be recorded; linked to an individual animal identification. The recording of animal-level information linked to individual animal identification offers ability to develop disease control strategies relevant to the current population, and the potential for the rapid implementation of control strategies and tracing of movement events and animals in contact with infectious individuals during an outbreak. The rapid implementation of control or contact tracing could limit the size and duration of a disease outbreak, reducing financial and animal welfare impacts. However, collection these type of data for equine populations, particularly non-racing horses, is not commonplace

One of the reasons for this is that the identification of properties with horses or individuals owning horses is extremely difficult. For example, Kaneene et al. (1997) used several sources to compile a sample list to survey owners of equine properties. This survey was conducted investigating the health and economic impacts of horses in Michigan in the United States of America. The source of addresses for the sample list included the telephone book, breed associations, the Michigan horse council, the Michigan Department of Agriculture and a list of equine properties that was used in a previous survey. Even though many sources of property information were used for a cross-validation, 23% of respondents did not have horses on their properties at the time of survey. Despite the difficulties associated with assembling a sampling frame, if infectious disease models are to be created it is important that researchers have information about the characteristics of horses, horse properties and horse movement data.

Mandatory registration, recording or reporting is one way that data regarding the equine population are collected. In New South Wales and Queensland, Australia, the registration of horses was enforced during the EI outbreak in 2007 (Cowled et al., 2009). However, maintaining this database post outbreak has proved difficult. The United Kingdom has a passport system to record horse identity (Robin et al., 2010), although to date no infectious disease outbreaks have occurred that would require the testing of the accuracy of the system for locating horses. It would be expected that although registration or passports are regulated, some horse owners would chose not to register their horses unless the benefit of having a registered horse, or the penalties for not registering, were high. In Spain, information about equine demographics as well as every movement of horses is recorded (Martínez-López et al., 2011b).

For most equine populations there is no census data nor are there mandatory identification systems. Therefore, in a number of cross-sectional studies (Mellor et al., 1999; Cole et al., 2005; Ireland et al., 2011b) horse owners have been selected through client lists supplied by participating veterinary surgeries. The use of veterinary client lists allows researchers to identify individuals that are likely to have horses, in a relatively cost effective way. However, selection of horses in this manner may result in the selection of a sample that is not representative of the underlying horse population because not all horses or horse owners would have current registration with a veterinarian and not all veterinary surgeries would be willing to participate. In countries like New Zealand, with a low level of endemic equine disease and a perceived low level of routine horse vaccination, these limitations are further exacerbated.

A study on Prince Edward Island identified horse owners by randomly calling people listed in the telephone book (Christie et al., 2004a). This method work reasonably well on Prince Edward Island, which has a small population of approximately 150,000 people, but in larger populations, random selection from a phone book is likely to be an ineffective method. For example in a study on pet ownership by Toribio et al. (2009), 2,768 people were randomly selected from the phone book. This study found only 0.8% of the respondents (4/884) kept horses (Toribio et al., 2009). Other methods of sample selection include the use of insurance databases to investigate the incidence of colic in Swedish horses (Egenvall et al., 2008), however this technique relies on a proportion of the equine population being insured, which is unlikely to be the case in New Zealand.

Property-level information

For investigations into the spread and control of infectious disease, the unit of interest is typically the property rather than an individual horse (Davis et al., 2009; Firestone et al., 2011b; Garner et al., 2011). Of greatest importance for the spread of infectious disease between properties is the density or proximity of a property to its nearest neighbour (Cowled and Garner, 2008; Firestone et al., 2011a). In Australia, the proximity to the nearest neighbour with a poultry farm was a risk factor for Newcastle-disease virus, with risk increasing as distance decreased (East et al., 2006). Similarly, in the United Kingdom in 2001, the local spread of FMD, once the movement of animals had been restricted, was attributed to the nearness of properties to each other and fomite transmission (Taylor et al., 2004). The risk of FMD on uninfected properties due to closeness to an infected property was twofold; firstly risk increased when a property was closer to an infected property and secondly as the density of infected properties increased. The reason for the increased risk due to proximity could be due to airborne spread or a greater number of similar contacts on farms that are near each other, for example, people, vehicles or fomites. However neither study investigated the difference between these factors.

A similar phenomenon was identified during the 2007 EI outbreak in Australia. In an investigation of the local spread characteristics of EI within the Park Ridge region of Queensland, properties contiguous with, or within three kilometres of, an infected property were more likely to be infected with EI (Davis et al., 2009). The nearness of horse properties as well as the density of horse properties were associated with the likelihood of a property becoming infected with EI. In areas with a greater density of infected horse properties had increased infection rates, compared to lower density areas. Additionally, there was an association between the number of horses on a property and EI infection, with properties with more horses were more likely to be infected than properties with fewer horses.

As horse density is important during an EI outbreak, studies investigating the ownership and management of horses can be used as a proxy for horse density. Ownership characteristics have been shown to vary by geographic location as well as the group of horses investigated. Studies have found that the numbers of horses kept per owner was a median of 2 to 3 in the United Kingdom (Mellor et al., 1999; Hotchkiss et al., 2007; Ireland et al., 2011b) or 2 in Australia (Cole et al., 2005) or an average of 2.93 horses per owner in Canada (Christie et al., 2004a). From property-level data collection, the median number of horses was between 3 and 9 per property in Australia (Davis et al., 2009) and North America (Kaneene et al., 1997).

Although data about the New Zealand situation could be extrapolated from a combination of data available, particularly from Australia and the United Kingdom, the unique demographic characteristics of the New Zealand population would remain unknown. Furthermore, previous studies suggest that equine population parameters are very specific to the area, reason for collecting data and the sampling frame used. Even in studies in the same country or area, differences in demographic characteristics have been identified (Mellor et al., 1999; Ireland et al., 2011b).

Movement

Movement and the mixing of infected and susceptible animals is the highest risk activity for the spread of disease (Bates et al., 2001; Ortiz-Pelaez et al., 2006; Cowled and Garner, 2008; Dubé et al., 2008). Internationally, the movement of horses and horse products have been identified as key for spreading disease between countries (Sluyter, 2001; Herholz et al., 2008; Robin et al., 2010), and many EI outbreaks in susceptible populations have occurred through the importation of infected horses (Scholtens and Steele, 1964; Guthrie et al., 1999; Callinan, 2008; Anon, 2009). Domestically, movement is recognised as being an important characteristic of horse ownership (Vanderman et al., 2009; Robin et al., 2010) and the movement of horses between properties, sale yards, race meetings and competitions have been implicated in the spread of EI (Guthrie et al., 1999;

Van Maanen et al., 2003; Bryant et al., 2009; Firestone et al., 2011a; Gildea et al., 2011a). During the EI outbreak in Australia, keeping horses on a property for recreation or having horses that attended an equestrian event were associated with EI infection on a property (Firestone et al., 2011a). Despite the importance of movement in the spread of infectious disease in horses, few studies have investigated horse movement at a national level.

Martinez-Lopez et al. (2011b) analysed the potential for African horse sickness to spread via the movement of horses originating from outside the Castile and Leon region of Spain. In Spain, the recording of horse movements between properties is mandatory. The records included information on the location and production type of the origin and destination properties, as well as the number of horses and size of the destination property. Information regarding property type allowed movement to be described by each sector within the equine industry in Spain; production, entertainment, game or sports facility, free-grazing, markets, dealers, slaughterhouses, bullrings and non-specified. The study found movement heterogeneity between different sectors of the equine industry, with the number of movement events onto properties within the region varying by property type. The largest number movements on a region were for entertainment, game or sports facilities, which received 33% of all movement events, followed by production farms with 28%. One major advantage of the study by Martinez-Lopez et al. (2011b) was the availability of accurate data regarding movement behaviour, due to the mandatory reporting of movement events. However, the study was limited by the scope of the project, as only movements from outside the region were analysed. The study did not account for the within region movements and therefore potential to spread disease through within-region movement behaviour. This study is also difficult to compare to the New Zealand equine industry, as in Spain there was a large competitive and production sectors, but no racing industry, whereas in New Zealand the racing industry is economically important (Anon, 2010c).

Hayama et al. (2010) investigated the movement of non-racing horses in Japan, using data collected via a cross-sectional survey. Like the study in Spain (Martínez-López et al., 2011b), the equine industry was divided into different sectors for analysis. Each sector had different movement characteristics and there were linkages between the sectors of the Japanese equine industry. However, this study did not include racing industry movements, other than the movement of horses from the racing industry joining the non-racing population.

From September the 21st 2007, the restrictions on the movement of horses were gradually eased in New South Wales. While movement restrictions were eased, the registration of horses attending events with either 10 or more horses, or with horses from three or more properties was mandatory (Bell and Drury-Klein, 2011). This requirement continued until December 2008. In total, 9,356 events were reported of which 38% were for horses to attend pony club, 17% to attend race meetings, 13% to attend competitions and 19% to attend lessons or social activities. The median number of horses attending these events was 30 (inter quartile range 14 horses). Three quarters of movement events were reported to be within the same post code area. While this study reported the distance travelled by horses to an event, the distance was calculated based on the centroid of the postcode that the movement originated from, rather than the actual property address. Therefore, no distance could be calculated for movement events occurring within postcodes, and no information was provided about the areas of postcodes in New South Wales. The distance travelled for 20% of movement events were outside the postcode and up to 200 kilometres. The movement of horses to events was reported from and to all Australian regions. From this study, the different groups of the Australian equine industry identified as moving more frequently to events, like horses kept for racing, competition and pony club, would have different disease risk characteristics, compared to those moving less frequently or not at all. This observation was shown during the early stages of the EI outbreak in Australia, where the movement of horses around a competitive event led to the rapid dissemination of disease throughout New South Wales and to Queensland (Callinan, 2008; Anon, 2009).

Other studies have investigated the movement behaviour of horses as secondary aims of research projects. In a cross-sectional survey in the United Kingdom, Ireland et al. (2011b) found that 25% of owners of horses older than 15 years of age (geriatric horses) moved their horse. However, these respondents reported that 57% of horses kept on the property had been moved in the same time period. The authors of this study did not define the time period or frequency of travel. In another cross-sectional survey of horse owners in the United Kingdom, 87% of owners reported attending shows or events where their horse mixed with other horses (Mellor et al., 2001). These owners reported moving horses a median of 12 times per year.

The movement characteristics of horses in the United Kingdom were similar to that reported in North America, where 84% of surveyed horse owners reported moving their horses for racing or competition in the 12 months prior to survey (Vanderman et al., 2009). Additionally, of the owners reporting movement events, 36% reported that movement occurred at least once a month. Similarly, in North America, 90% of properties keeping horses for competition reported movement events compared to half of properties keeping horses for pleasure or work (USDA, 2006). In a cross-sectional study of 64 equine boarding facilities in Colorado, North America, half of the responding property managers reported that they had new horses arriving on a regular basis, although the authors did not define the frequency associated with the term ‘regularly’ (Kirby et al., 2010).

Previous studies show that movement patterns vary with the reason for owning horses. However, the comparison of studies investigating the reason horses are kept is difficult because the categorisation of reasons for owning horses varies between studies. A study in Australia identified horses were kept predominantly for breeding, pleasure, stockwork and dressage, but owners also kept unbroken or retired horses (Cole et al., 2005). In another Australian study horses kept for pleasure, recreation, competition and as companion animals were all defined as recreational horses (Firestone et al. (2011a). Ireland et al. (2011) used hacking, Christie et al. (2004a) used the term general riding and Kaneene et al. (1997) used the term pleasure to describe horses kept for riding but not for competitive activities. Competitive activities have been defined as jumping (Christie et al., 2004a), dressage, show jumping (Ireland et al., 2011b) and showing (Kaneene et al., 1997; Ireland et al., 2011b). With the exception of Firestone et al. (2011a), all other studies included a category called pets or retired horses for horses that were not kept to be ridden.

While previous studies outbreak investigations have identified the importance of the movement of people and vehicles in spreading disease through indirect contacts for EI (Davis et al., 2009), there are no studies available in horses about the movement of people around horse properties. Studies in food production animals have identified that there were up to 140 visitors per month on cattle farms in North West England (Brennan et al., 2008). Whilst some studies in horses have identified that visitors go to horse properties (Rogers and Cogger, 2010; Ireland et al., 2011c), none have directly investigated the frequency that these visitors attend properties and interact with horses on the properties.

All the previous studies of the movement behaviour of horses have identified heterogeneity between different groups, and the differences between frequency and distance of movement events highlights the importance of understanding equine movement behaviour by each sector within the industry. Previous studies highlight that the application of data regarding the domestic movement of horses, from other countries, to the equine population in New Zealand would not necessarily reflect the true movement behaviour of the New Zealand population. As movement is a high risk factor for disease spread, and the accuracy of any disease modelling as a tool for disease control is predicated upon movement input parameters, the New Zealand EI model must be based on data unique to the New Zealand situation.

2.4 Conclusions

This literature review has described the importance of designing disease models to support decisions regarding control strategies prior to an outbreak of infectious disease. This review demonstrated different modelling tools and the importance of populating these models using parameters that accurately reflect the population and disease of interest. This review showed the value of a disease model for outbreaks of highly infectious, rapidly spreading disease in naïve populations, as would occur during an EI outbreak in the New Zealand equine population. Models can be used to evaluate control methods, including vaccination, movement restriction and enhanced biosecurity prior to disease outbreaks. While models of EI spread within yard populations have been developed, the most effective way to evaluate control strategies, in the context of EI in New Zealand, would be to use a stochastic model that accounts for both spatial and temporal aspects of outbreaks. A model investigating the effectiveness of vaccination for the control of EI has been developed in Australia, after the EI outbreak in 2007. This model used data from the Australian outbreak to investigate different vaccination strategies, applied earlier than what actually happened in the outbreak. While interesting for comparison, this model would not be acceptable to inform New Zealand EI control policies.

Vaccination has been a highly effective strategy for managing outbreaks in endemic countries, although outbreaks still occur due to constant evolution of EI. Movement restriction, enhanced biosecurity and vaccination have also been effective in exotic disease outbreaks. The effectiveness of vaccination in exotic disease outbreaks is dependent on how quickly vaccines are effective, and the ability to minimise clinical signs and viral shedding.

In the development of an EI disease model, it is important to understand the demographic characteristics and the movement behaviour of the population to be able to model spread and evaluate control strategies. Previous studies regarding horse demographics and movement have all been similar, but different enough that it would be a risk to apply those data to New Zealand disease modelling, especially as model accuracy relies on accurate input data. In New Zealand there is limited information available about the demographics of the non-racing population, and no readily available movement data.

The use of data regarding herd size, type and number of contacts from FMD outbreaks in other countries was not applicable to FMD outbreaks in the United State due to the variation in these parameters (Bates et al., 2003a). Similarly, data regarding the equine population, movement patterns, biosecurity and EI transmission from other countries and EI outbreaks are not applicable to the New Zealand situation. The heterogeneity of equine demographic characteristics and movement patterns, as well as the immunity status of the New Zealand equine population, identified in this literature review are not conducive to an accurate disease model to predicate the control of EI in the New Zealand equine population. Therefore, this thesis aims to address the issues of lack of available data regarding the demographics, movement and biosecurity practices in the New Zealand equine industry, to enable the development of a model to evaluate the control of EI in New Zealand.

Chapter Three

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

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Chapter Three presents the first of three chapters describing non-commercial horse properties using data collected via cross-sectional survey. The generalised random-tessellation stratified sampling method used to select the non-commercial horse population for sampling is described. The results included in Chapter Three include the proximity of horse properties to each other, the number and reason for keeping horses and the representativeness of the sampling method. This chapter was prepared for submission for Preventive Veterinary Medicine and has been accepted for publication.

3.1 Abstract

We conducted a cross-sectional survey to determine the demographic characteristics of non-commercial horses in New Zealand. A sampling frame of properties with non-commercial horses was derived from the national farms database, AgriBase$^{(TM)}$. Horse properties were stratified by property size and a generalised random-tessellated stratified (GRTS) sampling strategy was used to select properties (n=2,912) to take part in the survey. The GRTS sampling design allowed for the selection of properties that were spatially balanced relative to the distribution of horse properties throughout the country. The registered decision maker of the property, as identified in AgriBase$^{(TM)}$, was sent a questionnaire asking them to describe the demographic characteristics of horses on the property, including the number and reason for keeping horses, as well as information about other animals kept on the property and the proximity of boundary neighbours with horses. The response rate to the survey was 38% (1,044/2,912) and the response rate was not associated with property size or region. A total of 5,322 horses were kept for recreation, competition, racing, breeding, stock work, or as pets. The reasons for keeping horses and the number and class of horses varied significantly between regions and by property size. Of the properties sampled, less than half kept horses that could have been registered with Equestrian Sports New Zealand or either of the racing codes. Of the respondents that reported knowing whether their neighbours had horses, 58.6% (455/776) of properties had at least one boundary neighbour that kept horses. The results of this study have important implications for New Zealand, which has an equine population that is naïve to many equine diseases considered endemic worldwide. The ability to identify, and apply accurate knowledge of the population at risk to infectious disease control strategies would lead to more effective strategies to control and prevent disease spread during an exotic, infectious disease outbreak, but could also highlight groups within the population that require targeted surveillance.

3.2 Introduction

Outbreaks of infectious disease in domestic animal populations can have severe consequences in terms of productivity and animal welfare. The negative economic and welfare impacts associated with disease outbreaks can be reduced through the application of disease surveillance, control, treatment and prevention strategies that are targeted to high risk populations (Sanson, 2005; León et al., 2006). However, the success of these strategies is predicated on having a detailed knowledge of the demographic characteristics of the population at risk and where that population resides.

In August 2007, the Australian equine population experienced its first outbreak of equine influenza (EI), leading to a national disease control effort (Callinan, 2008; Anon, 2009). The lack of knowledge regarding the susceptible population impeded control, particularly the effective implementation of vaccination (Cowled et al., 2009; Davis et al., 2009). Consequently during the EI outbreak, the registration of horses on a central database was mandatory in Australia for the purpose of forming disease control strategies and recording horse population information.

Currently, New Zealand is in a similar situation to Australia prior to the EI outbreak, concerning the lack of availability of accurate demographic data regarding the equine population. While the racing industry is important to New Zealand's economy and all horses involved in the industry must be registered (Anon, 2011b), there is limited information about non-racing horses. Therefore, designing and then implementing effective treatment and control strategies for infectious disease outbreaks would be seriously inhibited by a lack of knowledge of the characteristics of the susceptible population, particularly horses not involved in the racing industry.

A major difficulty with obtaining data on the equine populations, particularly the non-racing or non-commercial sectors of the equine industry, has often been how to identify the properties or individuals of interest. Previous studies in the United Kingdom (Mellor et al., 1999; Ireland et al., 2011b) and Australia (Cole et al., 2005) have selected horse owners through client lists from participating veterinary surgeries. Participants were selected randomly, based on the proportion of clients listed for each veterinary surgery as a proxy for spatial representation. This method of sample selection may have allowed for selection bias through the selection of a sample that was not representative of the underlying horse population. Not all horses or horse owners would have current registration with a veterinarian and not all veterinary surgeries were willing to participate. In countries like New Zealand, with a low level of endemic equine disease and a perceived low level of routine horse vaccination, the limitations of recruiting participants through veterinary surgeries are further exacerbated.

If an outbreak of EI was to occur in New Zealand, a nationwide effort to control and eradicate infection would be mounted. Therefore, spatially explicit demographic data would be required to forming disease controls strategies and to allow for control targeted at more at risk properties in the population. A common method used to select spatially balanced probability samples in the field of environmental science is the generalised random-tessellation stratified (GRTS) design (Stevens and Olsen, 2003; Stevens and Olsen, 2004). The emphasis of the GRTS sampling method is on selecting spatially balanced samples by accounting for the underlying spatial aggregation of the population of interest. A spatially balanced sample is achieved by using the geographic area as a selection variable, and selecting each individual in the sample based on the underlying population distribution. Random-tessellated sampling methods have been shown to be more effective than random sampling methods for the selection of spatially balanced samples (Barabesi and Franceschi, 2011; Grafstrom, 2012).

This chapter is the first of a series of manuscripts regarding the collection of data for, and the development of, a model to evaluate the effectiveness of control strategies for EI in New Zealand. This chapter presents a descriptive analysis of the demographic characteristics of the New Zealand non-commercial horse population and the methodology used to collect these data. The objective of this study was to identify the characteristics of the non-commercial equine population at the property-level, and to outline the importance of these characteristics in the context of the prevention and control of infectious disease. Property-level information included details of the number and type of horses kept, purposes horses were kept for, other animals kept on the property and the proximity of neighbours with horses. The spatial representativeness of the GRTS sampling method, when compared to the underlying population of non-commercial horse properties in this study, will also be evaluated.

3.3 Materials and Methods

The study was a cross-sectional postal survey of premises defined as non-commercial horse properties, conducted in New Zealand in November 2009. Property data were obtained from the official agricultural property and livestock database (AgriBase$^{(TM)}$ 2008, AssureQuality Limited, New Zealand). This database is described as a national, spatial, multi-sectoral record of rural land use information in New Zealand, containing 105,000 rural properties. Properties in AgriBase$^{(TM)}$ were first identified through an agricultural census. The information in the database has been updated using a variety of sources including data collected directly from farmers and veterinarians, industry databases, such as Agricultural and Pastoral associations, and schemes to control tuberculosis and brucellosis (Sanson and Pearson, 1997; Sanson, 2005). From this database, 18,329 properties were identified as having horses.

3.3.1 Sampling frame

The AgriBase$^{(TM)}$ database classified horse properties into one of eight types: training or racing, breeding, work, sports, leisure, agistment (otherwise known as livery service or the keeping of horses for money), other and undifferentiated. Each horse property was classified as one type only. The focus of the survey was non-commercial and non-racing properties, therefore, properties identified in the dataset as breeding or training and racing were deemed ineligible for selection. Eligible properties were those classified in Agribase$^{(TM)}$ as work, sports, leisure, agistment and undifferentiated types and are subsequently referred to as non-commercial properties. Horse properties that were identified as being ineligible for selection were removed from the sampling frame. In total, 899 properties were identified as being racing or breeding properties and were excluded from selection, resulting in a sampling frame of 17,430 properties (Figure 3.1A).

3.3.2 Sample size calculation

The current chapter was part of a larger research project to develop a stochastic simulation model for the control of EI in New Zealand. Key data regarding the movement of horses from non-commercial horse properties in New Zealand were required, for the development of a model. Consequently, the sample size calculation was based on the predicted number of movement events from this type of property. The number of movement events per year was estimated through preliminary investigations of participants in attendance at equestrian events (data not published) and was calculated assuming a true mean of two movements per year with a variance of four. The number of properties for the survey (n=827) was derived by calculating the number of properties required to determine that the number of reported off-property movements of horses per month was within 5% of the true population value.

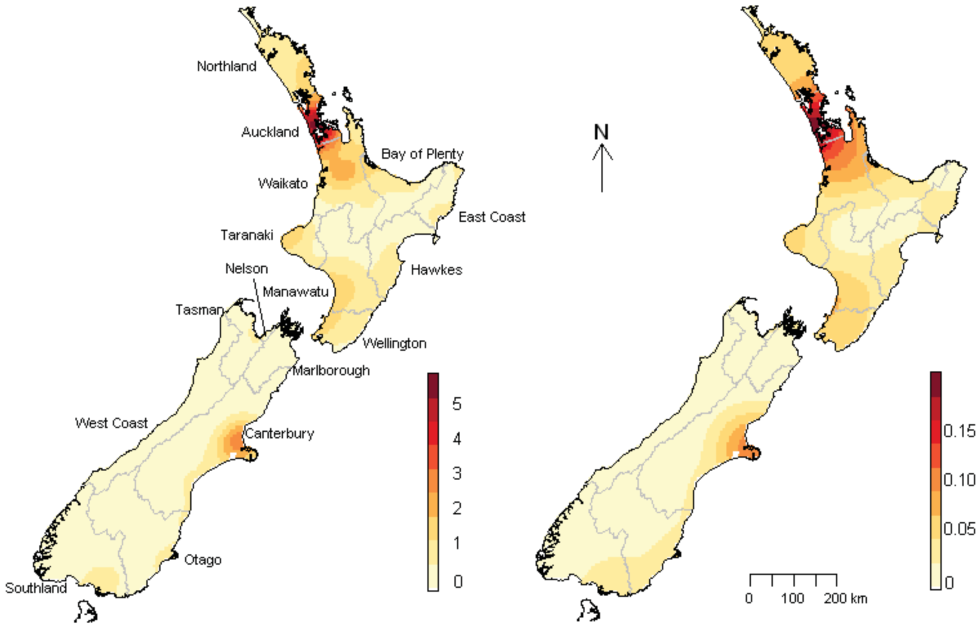

Figure 3.1: Gaussian edge corrected kernel intensity function of the of the number of non-commercial horse properties (n=17,430) (A) and those properties responding to survey with horses (n=791) (B) per 10 km^2 in New Zealand

3.3.3 Generalised random-tessellation stratified sampling design

The GRTS sampling design was chosen for sample selection as it enabled the selection of a spatially balanced sample of horse properties in New Zealand. Additionally, the GRTS sampling method includes stratification and provision for an oversample within the methodology (Stevens and Olsen, 2003; Stevens and Olsen, 2004). For the current study, properties in the sampling frame were classified, based on the quartiles of property size in hectares (Ha), as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha) or large (>169 Ha). This stratification step was included in the GRTS design, to enable the selection of properties based on *a priori* assumptions regarding differences in demographic characteristics between property sizes. Additionally, the GRTS sampling method enabled the selection of an oversample, that is, the selection of more properties than the sample size calculation. In the current study, the GRTS oversample feature was used to select 70%

more properties than were calculated using the sample size calculation to allow for the non-response of selected participants. A response rate of 30% was expected in the current study, based on the response rates attained in previous studies (Brennan and Charbonneau, 2009). Therefore, in total, 3,000 properties were selected using the GRTS sampling method.

The GRTS sampling design is a multi-stage process of sample selection. Firstly, the geographical area of New Zealand was divided into a randomly tessellated surface of polygons. A hierarchical grid with hierarchical addressing was constructed, with each polygon randomly assigned a number, and each property within that polygon assigned a number. In the second step, each number from each polygon is selected in hierarchical random order, and the numbers are taken from the two dimensional map space into one dimension, to form a line. In the third step, starting at n, a random sample is selected, based on the calculated sample size, and the selected properties are then reordered in reverse hierarchal order, to ensure spatial balance between contiguous sites. A more detailed explanation of GRTS is found in (Stevens and Olsen, 2003; Stevens and Olsen, 2004). For each property size strata, the GRTS process was repeated, with a 70% oversample until all 3,000 samples were selected. The sample size calculation and sample selection was performed using R version 2.10.1 (R development core team, Vienna, Austria) using the packages “spsurvey”(Kincaid and Olsen, 2011) and “epiR” (Stevenson et al., 2009).

3.3.4 Address validation

As an internal control to reduce return to sender rate, the addresses provided by AgriBase$^{(TM)}$ were screened using SendRight$^{(TM)}$ (New Zealand Post, New Zealand) and properties that could not be identified via this method were then manually searched for using Google maps (www.google.co.nz) and the New Zealand Whitepages (www.whitepages.co.nz). Following address screening, all the property names were checked for associations with the racing industry, by a researcher familiar with this industry (SR), to remove any commercial properties that were misclassified by AgriBase$^{(TM)}$. At the end of this screening stage there were 2,912 non-commercial horse properties with valid addresses remaining in the sample.

3.3.5 Data collection and questionnaire design

The questionnaire was divided into five sections (Appendix A). The first section of the questionnaire required the respondent to verify the address of the property, asked for property-level information and about boundary neighbours with horses. If there were no horses on the property then the questionnaire was terminated at this point. The second section sought information about the age and sex of horses on the property, ownership of the horses and purpose for keeping horses. Sections three and four investigated the movement behaviour of the property between November 2008 and November 2009. Section three focused on the movement characteristics of horses on the property and when movements occurred. The fourth section contained a series of questions about visits from horse professionals such as veterinarians, farriers, and riding instructors to the property in the previous 12 months. The final section of the questionnaire contained a series of questions relating to the biosecurity protocols followed on the property. The findings from the movements and biosecurity sections of the questionnaire are described in subsequent chapters.

The questionnaire was pilot tested four times with a total of 26 people involved in the equine industry. None of the individuals who were involved in pilot testing were then included in the final sample list.

The selected properties were sent a survey pack addressed to the person designated as registered decision maker of the property, as listed in AgriBase$^{(TM)}$. The survey pack contained a covering letter describing the survey, confidentiality and ethics status of the research, a set of instructions, the questionnaire, a return pre-paid envelope and a token of appreciation (a tea bag and a chocolate bar). Surveys were all posted in a three day time span. All returned surveys were entered into, and managed in, a purpose built relational database, Microsoft Access 2007 (Microsoft Corporation, Redmond, WA, USA).

3.3.6 Variables and data handling

Property-level variables included property size, region (location), presence or absence of horses, number of horses on the property, the reasons for keeping horses and the presence of neighbours with horses. Information on the reasons for keeping horses was grouped into breeding, competition, pets, racing, recreation, unbroken horses and work, and the description of these groupings can be found in Table 3.1.

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

Reason for keeping horses	Description and/or inclusions
Breeding	One or more horses on the property kept for any breeding activity not associated with the racing industry
Competition	One or more horses on the property participated in ESNZ[a] registered events or unregistered competitive events including dressage, show jumping, eventing, endurance, para-equestrian, showing, hunting, competitive trail riding (CRT), western, polo or polocrosse and driving
Pets	One or more horses on the property that did not attended competitive events and were not used for recreational activities. Generally horses that were not used for riding
Racing	One or more horses on the property that participated in Standardbred or Thoroughbred racing (training) or breeding activities
Recreation	One or more horses on the property that was used for non-competitive riding activities such as hacking, trekking, riding lessons, breeds (i.e. Clydesdale), pony club or adult riding club horses
Unbroken	One or more horses on the property not broken to saddle or harness and generally expected to be less than 2 years old
Work	One or more horses on the property used for work related activities such as stock work, work, and other commercial activities

[a] Equestrian Sports New Zealand

3.3.7 Statistical analysis

Descriptive statistics were used to summarise the response rates and the property and horse-level variables. Continuous outcome variables were all non-normally distributed and summarised using minimum, maximum, percentiles. Nominal and ordinal data were presented as count, percentages and 95% confidence intervals (95% CI). Confidence intervals were based on the normal distribution. All variables were presented stratified by property size, region, demographic characteristics of the horses and reason for keeping horses. The significance of the association between number of horses and each of these variables were assessed using the non-parametric Kruskal-Wallis test. The significance of associations between categorical variables was assessed using Chi-squared tests. The level for statistical significance was $P<0.05$. All descriptive statistics were performed using Stata version 11.2 (Statacorp LP, College Station, Texas, USA).

3.3.8 Spatial analysis

Descriptive spatial analyses were conducted to describe the distribution of the non-commercial horse population throughout New Zealand. Easting and northing coordinates of the farm centroid was available for all properties listed in the AgriBase$^{(TM)}$ database. As the density of horse properties varied across New Zealand, adaptive edge corrected Gaussian kernel density estimation was used to smooth the location data (Bowman and Azzalini, 1997). This smoothing facilitated visualisation of the geographical clustering of horse properties, as using point data alone was not useful due to high property density (Benschop et al., 2008; Pfeiffer et al., 2008). The smoothing technique was used to visualise the number of properties in the sampling frame, the number of properties selected for sampling and the number of responding properties.

The evaluation of the representativeness of the GRTS sampling design was conducted using bivariate kernel density estimation and an estimation of spatial risk. The bivariate kernel density estimation technique (Davies et al., 2011) was used to find the relative of disease in an area, given the underlying population at risk, called a relative risk surface. In the context of this paper, the technique investigated the probability of a property being selected for sampling or responding to the questionnaire, given the underlying population in AgriBase$^{(TM)}$. The co-ordinates of properties selected for sampling and responding properties with horses were plotted individually against the underlying properties that were listed in the AgriBase$^{(TM)}$ database, and the relative risk of selection or responding to the questionnaire was calculated. The adaptive bandwidth, edge corrected, bivariate kernel density estimation used was an isotropic smoothing parameter, based on over smoothing. The log relative risk of selection was reported, with a zero being an equal risk for selection or response to the underlying population, based on the geographical distribution of the underlying population.

All maps were created using R version 2.13.0 (R Development Core Team, Vienna, Austria). The relative risk surface was created using the library “sparr” (Davies et al., 2011) and the kernel density estimations using the library “spatstat” (Baddeley and Turner, 2005).

3.4 Results

3.4.1 Response rates

Questionnaires were mailed to 2,912 properties identified as having horses. A total of 168 (5.8%) were returned due to unknown or unregistered addresses. The remaining questionnaires were assumed to have been received by the registered decision maker of the property (n=2,744). Overall, 1,044 questionnaires were returned completed. Of the returned questionnaires, 791 respondents kept horses on the property, resulting in a response rate of sent questionnaires of 27.2% and received questionnaires of 29.0%. The response characteristics of property size and region are shown in Table 3.2. A total of 52.7% (417/791) of respondents with horses on their properties came from Auckland, Waikato, Manawatu or Canterbury regions (Figure 3.1B). Region (P=0.21) and property size (P=0.99) were not significantly associated with response rates.

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.

		With Horses		No Horses		
Variable	**Category**	**No.**	**% (95% CI)**	**No.**	**% (95% CI)**	**P value[a]**
Property size[b]	Lifestyle	201	75.6 (10.4-86)	65	24.4 (5.9-30.3)	0.988
	Small	203	76.0 (10.5-86.5)	64	24.0 (5.9-29.9)	
	Medium	190	75.1 (10.7-85.8)	63	24.9 (6.1-31)	
	Large	197	76.4 (10.7-87.1)	61	23.6 (5.9-29.5)	
Region	Auckland	123	75.0 (13.3-88.3)	41	25.0 (7.7-32.7)	0.21
	Bay of Plenty	43	68.3 (20.4-88.7)	20	31.7 (13.9-45.6)	
	Canterbury	112	83.0 (15.4-98.4)	23	17.0 (7.0-24)	
	East Coast	25	83.3 (32.7-116)	5	16.7 (14.6-31.3)	
	Hawkes Bay	37	71.2 (22.9-94.1)	15	28.8 (14.6-43.4)	
	Manawatu	76	67.3 (15.1-82.4)	37	32.7 (10.5-43.2)	
	Northland	64	73.6 (18-91.6)	23	26.4 (10.8-37.2)	
	Otago	52	82.5 (22.4-104.9)	11	17.5 (10.3-27.8)	
	Southland	37	77.1 (24.8-101.9)	11	22.9 (13.5-36.4)	
	Taranaki	38	74.5 (23.7-98.2)	13	25.5 (13.9-39.4)	
	Waikato	106	75.7 (14.4-90.1)	34	24.3 (8.2-32.5)	
	Wellington	42	84 (25.4-109.4)	8	16.0 (11.1-27.1)	
	West Coast/ Tasman	36	75 (24.5-99.5)	12	25.0 (14.1-39.1)	

[a] Chi-square test

[b] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

3.4.2 Representativeness of GRTS sampling method

When the properties that were selected to participate (n=2,192) were compared to the underlying AgriBase$^{(TM)}$ population (n=17,430), there was a decreased probability of being selected in Southland. The probability of properties being selected for sampling from the AgriBase$^{(TM)}$ population ranged from -0.2 to 0.2 (Figure 3.2A).

When the responding properties (n=791) were compared to the underlying AgriBase$^{(TM)}$ population, there were areas in the West Coast and Otago at an increased probability of being represented compared to the underlying population. Overall, the probability of properties responding to the survey, compared to the underlying population ranged from -0.4 to 0.4 (Figure 3.2B).

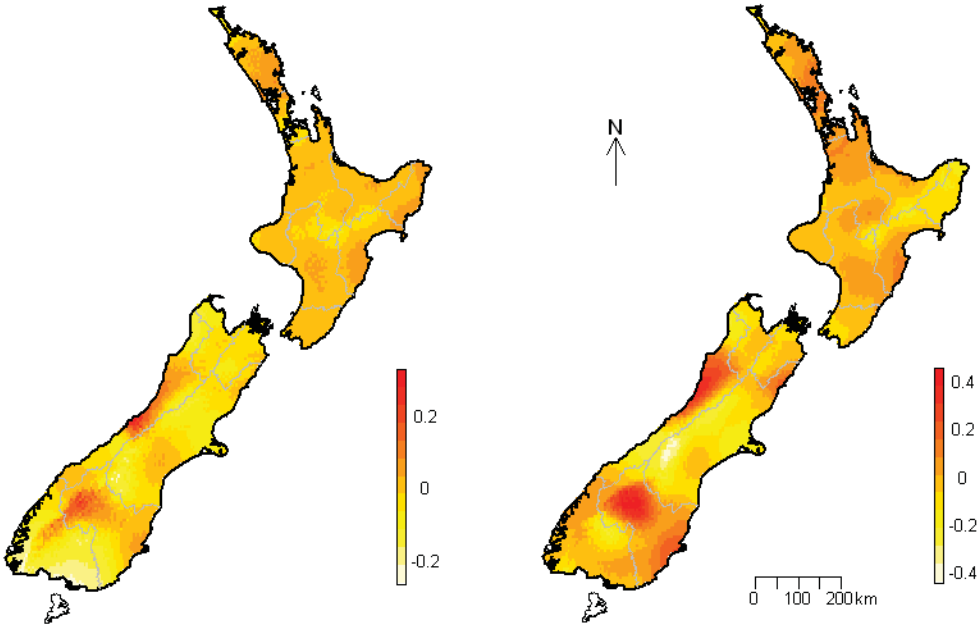

Figure 3.2: Adaptive log-relative risk based on the underlying Agibase$^{(TM)}$ non-commercial equine population and the properties selected for sampling (n=2,912) (A) and the properties responding to questionnaire with horses (n=791) (B).

3.4.3 Reason for keeping horses

Thirteen surveys were returned with missing values for the reason for keeping horses, leaving 778 usable surveys. On any one property, horses could be kept for multiple purposes. Property size was not associated with whether a property had multiple reasons for keeping horses (P=0.15), but this association did vary significantly by region (P<0.001).

In total, 57.1% (444/778) properties kept horses for just one reason, of which 36.5% (162/444) kept horses for recreation, 18.9% properties (84/444) kept horses as pets, 16.4% (73/444) for competition, 14.0% (62/444) for work and 11.7% (52/444) for racing. Horses were kept for two purposes on 27.9% (217/778) of properties, of which the most common combination was competition and recreation (46.1%, 100/217). Horses were kept for multiple purposes on 15% (117/778) of properties. Competition, recreation, breeding and any other activity encompassed 32.5% (38/117) of this multi-use group. On 75.5% (586/787) of the properties, all horses were owned by the registered decision maker of the property.

More than half of the properties kept horses for recreation (395/778), while 39.8% (310/778) kept horses for competition (Table 3.3). Of the properties that kept horses for competition, 32.9% (102/310) kept horses competing in ESNZ disciplines. Even though commercial racing properties were excluded from the sampling frame, 120 properties (15.4%) still kept horses for either Standardbred or Thoroughbred racing or breeding activities. Thirteen percent of the properties surveyed (101/778) kept horses for work, mainly stock work (98/101, 97.0%).

The reasons for keeping horses differed significantly by property size ($P<0.001$). More horses were kept for work on large properties (67/194, 34.5%) compared with lifestyle properties (2/199, 1.0%). Fewer large properties kept horses as either pets (14/194, 7.2%) or for the racing industry (11/194, 5.7%) than the other property sizes, while lifestyle properties kept more horses for recreation (113/199, 56.8%) and medium properties kept more horses for breeding (32/186, 17.2%) than the other property sizes (Table 3.4).

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.

Activity [c]		**Number**	**% (95% CI)**
Breeding		**105**	**13.5 (2.6-16.1)**
Competitive	Dressage	130	16.7 (2.9-19.6)
	Show jumping	121	15.6 (2.8-18.4)
	Eventing	93	12 (2.4-14.4)
	Showing	84	10.8 (2.3-13.1)
	Hunting	88	11.3 (2.4-13.7)
	Endurance/CTR [b]	32	4.1 (1.4-5.5)
	Western	12	1.5 (0.9-2.4)
	Other	35	4.5 (1.5-6.0)
	Total	**310**	**39.8 (4.4-44.2)**
Recreation	Pony club	102	13.1 (2.5-15.6)
	Adult riding club	81	10.4 (2.3-12.7)
	Trekking/hacking	174	22.4 (3.3-25.7)
	Breeds	42	5.4 (1.6-7.0)
	Other	110	14.1 (2.6-16.7)
	Total	**395**	**50.8 (5.0-55.8)**
Pets		**116**	**14.9 (2.7-17.6)**
Racing	Thoroughbred Racing	61	7.8 (2.0-9.8)
	Standardbred racing	41	5.3 (1.6-6.9)
	Thoroughbred Breeding	56	7.2 (1.9-9.1)
	Standardbred breeding	36	4.6 (1.5-6.1)
	Total	**120**	**15.4 (2.8-18.2)**
Unbroken		**128**	**16.5 (2.9-19.4)**
Work	Stock work	98	12.6 (2.5-15.1)
	Other work	3	0.4 (0.4-0.8)
	Total	**101**	**13 (2.5-15.5)**

[a] 13 missing values due to incomplete surveys for this section (n=778)
[b] CTR = Competitive trail riding
[c] Each property could keep horses for more than one reason

The reasons for keeping horses differed significantly by region (P<0.001). On the East Coast 52.0% (13/25) of properties kept horses for work, whilst 26.6% (17/64) of properties in Northland and 23.7% (18/76) of properties in the Manawatu kept horses for work.

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.

	Property size[b]							
	Lifestyle (n=199)		**Small (n=199)**		**Medium (n=186)**		**Large (n=194)**	
Reason for keeping horses[c]	**Number**	**% (95% CI)**	**Number**	**% (95% CI)**	**Number**	**% (95% CI)**	**Number**	**% (95% CI)**
Breeding	24	12.1 (4.8-16.9)	24	12.1 (4.8-16.9)	32	17.2 (6.0-23.2)	25	12.9 (5.1-18.0)
Competition	84	42.2 (9.0-51.2)	77	38.7 (8.6-47.3)	79	42.5 (9.4-51.9)	70	36.1 (8.5-44.6)
Pets	39	19.6 (6.2-25.8)	41	20.6 (6.3-26.9)	22	11.8 (4.9-16.7)	14	7.2 (3.8-11.0)
Racing	27	13.6 (5.1-18.7)	39	19.6 (6.2-25.8)	43	23.1 (6.9-30.0)	11	5.7 (3.4-9.1)
Recreation	113	56.8 (10.5-67.3)	93	46.7 (9.5-56.2)	95	51.1 (10.3-61.4)	94	48.5 (9.8-58.3)
Unbroken	23	11.6 (4.7-16.3)	40	20.1 (6.2-26.3)	42	22.6 (6.8-29.4)	23	11.9 (4.9-16.8)
Work	2	1 (1.4-2.4)	9	4.5 (2.9-7.4)	23	12.4 (5.1-17.5)	67	34.5 (8.3-42.8)

[a] 13 missing values due to incomplete surveys for this section (n=778)

[b] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[c] Each property could keep horses for more than one reason

3.4.4 Neighbours with horses

There were seven surveys that were returned with missing values for the number of neighbours with horses, while eight respondents did not know if their neighbours kept horses. Of the respondents that reported knowing whether their neighbours had horses, 58.6% (455/776) of properties had at least one boundary neighbour that kept horses. A property having boundary neighbours with horses was significantly associated with the size of the responding property ($P<0.01$), and reason for keeping horses ($P<0.001$). Region was significantly associated with having boundary neighbours with horses ($P<0.05$). Overall, 52.0% (237/776) of responding properties with at least one neighbour with horses were located in Auckland, Waikato, Manawatu and Canterbury. Large properties had a greater number of neighbours with horses (131/187, 16.9%) than the other property sizes (Table 3.5).

Of the properties that did have boundary neighbours with horses, 82.4% (451/455) had between one and two neighbours who kept horses, and 2.9% (13/455) had more than four neighbours with horses. Five respondents did not know how many of their neighbours had horses (1.1%), although they did know that they had neighbours with horses.

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

		Neighbours				
		With Horses		Without Horses		
Variable	**Category**	**Number**	**%(95% CI)**	**Number**	**%(95% CI)**	**P value[b]**
Property size [c]	Lifestyle	112	14.4 (2.7-17.1)	86	11.1 (2.3-13.4)	0.01
	Small	118	15.2 (2.7-17.9)	84	10.8 (2.3-13.1)	
	Medium	94	12.1 (2.4-14.5)	95	12.2 (2.5-14.7)	
	Large	131	16.9 (2.9-19.8)	56	7.2 (1.9-9.1)	
Region	Auckland	69	8.9 (2.1-11)	53	6.8 (1.8-8.6)	0.05
	Bay of Plenty	25	3.2 (1.3-4.5)	18	2.3 (1.1-3.4)	
	Canterbury	65	8.4 (2.0-10.4)	45	5.8 (1.7-7.5)	
	East Coast	21	2.7 (1.2-3.9)	2	0.3 (0.4-0.7)	
	Hawkes bay	20	2.6 (1.1-3.7)	13	1.7 (0.9-2.6)	
	Manawatu	44	5.7 (1.7-7.4)	31	4 (1.4-5.4)	
	Northland	40	5.2 (1.6-6.8)	24	3.1 (1.2-4.3)	
	Otago	27	3.5 (1.3-4.8)	24	3.1 (1.2-4.3)	
	Southland	22	2.8 (1.2-4.0)	15	1.9 (1.0-2.9)	
	Taranaki	24	3.1 (1.2-4.3)	14	1.8 (0.9-2.7)	
	Waikato	59	7.6 (1.9-9.5)	44	5.7 (1.7-7.4)	
	Wellington	27	3.5 (1.3-4.8)	15	1.9 (1.0-2.9)	
	West Coast/ Tasman	12	1.5 (0.9-2.4)	23	3 (1.2-4.2)	
Reason for keeping horses [d]						
	Breeding	54	6.9 (1.8-8.7)	52	6.7 (1.8-8.5)	0.01
	Competition	368	47.3 (4.8-52.1)	226	29 (3.8-32.8)	
	Pets	55	7.1 (1.9-9.0)	58	7.5 (1.9-9.4)	
	Racing	278	35.7 (4.2-39.9)	224	28.8 (3.8-32.6)	
	Recreation	111	14.3 (2.7-17.0)	83	10.7 (2.3-13.0)	
	Unbroken [c]	73	9.4 (2.2-11.6)	55	7.1 (1.9-9.0)	
	Work	75	9.6 (2.2-11.8)	23	3 (1.2-4.2)	

[a] Seven missing values and eight respondents did not know if their neighbours had horses (n=776)
[b] Chi-square test
[c] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)
[d] One property could keep horses for multiple reasons

3.4.5 Number of horses

There were 14 surveys returned with the information about the number of horses kept on the property missing, leaving 777 usable surveys. In total, 5,322 horses were identified on the surveyed properties. Medium sized properties had the greatest number of horses with 2,216 (41.6%). Medium and large sized properties had the highest median number of horses with four, while properties classified as lifestyle and small had three. The median number of horses per property varied significantly by property size (P<0.001) and region (P<0.01). The reason for keeping horses had a significant association with the number of horses on that property (P<0.001). Properties that kept horses as pets had the lowest median number of horses and the highest median number of horses was on properties involved in racing (Table 3.6).

3.4.6 Other animals

There were 23 surveys that were returned with missing data for other animals on the property, leaving 768 surveys with usable data regarding other animals kept on the property. In total, 19 responding properties (2.4%) only kept horses, and 53% (10/19) of these properties were lifestyle properties and 58% (11/19) were in Auckland, Canterbury, Manawatu or Waikato. Livestock were kept on 90.9% (698/768) of horse properties. Of the properties that kept livestock, cattle were kept on 80.2% (560/698) of the properties, sheep on 63.0% (440/698), and 42.3% (295/698) kept poultry. Cats and dogs were the most common types of companion animals and were found on 79.8% (627/786) of properties.

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

Variable	Category	No. of horses	% (95% CI)	Min	Percentiles			Max	P value
					25th	Median	75th		
Property size [b]									<0.001
	Lifestyle	792	14.9 (1.0-15.9)	1	2	3	5	26	
	Small	1,157	21.7 (1.3-23)	1	2	3	6	60	
	Medium	2,216	41.6 (1.7-43.3)	1	2	4	10	493	
	Large	1,157	21.7 (1.3-23)	1	2	4	6	55	
Region									0.01
	Auckland	1,167	21.9 (1.3-23.2)	1	2	3	6	493	
	Bay of Plenty	163	3.1 (0.5-3.6)	1	2	3	4	16	
	Canterbury	878	16.5 (1.1-17.6)	1	3	5	9	60	
	East Coast	214	4 (0.5-4.5)	1	2	5	9	33	
	Hawkes Bay	139	2.6 (0.4-3.0)	1	1	3	6	14	
	Manawatu	345	6.5 (0.7-7.2)	1	2	3	6	30	
	Northland	372	7 (0.7-7.7)	1	2	3	5	57	
	Otago	204	3.8 (0.5-4.3)	1	2	3	5	16	
	Southland	154	2.9 (0.5-3.4)	1	1	3	7	20	
	Taranaki	240	4.5 (0.6-5.1)	1	2	4	8	25	
	Waikato	830	15.6 (1.1-16.7)	1	2	3	7	140	
	Wellington	373	7 (0.7-7.7)	1	2	4.5	9	125	
	West Coast/ Tasman	243	4.6 (0.6-5.2)	1	2	3.5	5	55	

Reason for keeping horses [c d]								0.001
	Breeding	106	13.8 (2.6-16.4)	1	6	9	15	125
	Competition	596	77.5 (6.2-83.7)	1	4	9	16	420
	Pets	116	15.1 (2.7-17.8)	1	1	2	3	50
	Racing	509	66.2 (5.8-72.0)	1	6	12	22	986
	Recreation	194	25.2 (3.5-28.7)	1	2	4	9	140
	Unbroken	128	16.6 (2.9-19.5)	1	5	8	14.5	125
	Work	101	13.1 (2.6-15.7)	1	2	3	6	54

[a] 14 missing values due to incomplete surveys for this section

[b] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[c] 22 missing values as either reason for keeping horses or number of horses on the property information not competed

[d] One property could keep horses for more than one reason

3.5 Discussion

To the best of our knowledge, the study reported here is the first to investigate the features of non-commercial horse properties in New Zealand using the GRTS sampling method. The study found that 24% of properties identified in the database as having horses did not actually have a horse and the median number of horses on properties with horses was three to four. The median number of horses per property is consistent with studies conducted in other countries (Kaneene et al., 1997; Hotchkiss et al., 2007; Davis et al., 2009). The lack of reliable data about the location of horses would be problematic in a response to an exotic disease such as EI. Although it is noteworthy that this problem is not unique to New Zealand, as Kanneene et al. (1997) found that 23% of properties in Michigan that were expected to have horses did not.

Properties selected for survey showed a similar pattern of spatial aggregation compared to the AgriBase$^{(TM)}$ population. The probability of a property being selected was homogenous for all of the country except for Southland, which had a decreased probability of having properties selected for sampling. The probability of being a responding property was homogenous in the North Island, as well as most of the South Island. However, there were small areas in the West Coast and Otago regions that were different from the underlying population, suggesting care should be taken when interpreting the results specific to these areas. These areas were small, not near urban centres and had low densities of both equine properties and number of equines. Therefore, overall, the GRTS sampling strategy was found to select a spatially representative sample.

The current study found that most non-commercial horse properties kept horses for recreation or competition. Interestingly, of the properties that kept horses for competition, only 33% competed in the ESNZ disciplines of dressage, eventing, show jumping, endurance or para-equestrian. However, this does not mean that all horses competing in these disciplines would have been registered with ESNZ, as unregistered competitions are also held. As it has been estimated that the number of horses registered with ESNZ is between 4,000 and 5,000 (Rogers and Firth, 2005; Creagh et al., 2010), and only 30% of horses in the current study could have been registered with ESNZ, the current findings indicate there is a significant population of horses competing that are not registered with ESNZ. Similarly, high numbers of horses were kept for recreational activities in the current study. Horses kept exclusively for recreation may be recorded by clubs in which their riders participate, like pony club, but otherwise these horses would be unlikely to be registered or recorded. Unregistered competition and recreation horses are not easily identifiable. Therefore, sampling horse properties from AgriBase$^{(TM)}$ provided a means of collecting information about this hard to find population.

Many horses identified in the current study were kept for stock work on non-equine focused commercial farms, to help with livestock movement. In the event of an infectious disease outbreak that impacted on the equine industry and rendered horses used for stock work unable to perform their function on these commercial farms, the productivity of the agricultural sector would be negatively affected. The impact to the agricultural sector of the illness of stock horses cannot be determined in economic terms from this study; however, finding linkages between the equine industry and the agricultural industry with regards to the use of horses for stock work is an important finding.

The effective control of infectious diseases like EI cannot be expected if the commercial sector is targeted exclusively for control in the event of an outbreak. In the current study, 15% (n=120) of properties defined as non-commercial on the AgriBase$^{(TM)}$ database kept horses for the racing industry. This finding underlines the need for attention to both the racing industry and non-commercial sector when designing strategies to control EI. In agricultural industries, disease control measures focus almost exclusively on the commercial producers within the sector, rather than on hobby farmers, even though both groups keep animals that are equally susceptible to infection (Van Steenwinkel et al., 2011). The same approach is likely to be taken by the New Zealand racing industry, in the event of an EI outbreak. In addition, the infectious disease risk profiles of non-commercial properties that keep horses for the racing industry and properties keeping horses solely for the racing industry will be different. That is, these two property types will have different motivations for achieving effective or just satisfactory control of infectious disease.

The proximity of horse properties to each other identified in the current study has disease control implications. Firstly, by identifying one horse property, the aggregation of these properties would ensure that other properties would be identified. Therefore, by finding one property with registered horses, there is potential to find more properties with horses, aiding in disease control and tracing. Therefore, even if the whole population is not registered, many properties would be identified through the snowball effect. Secondly, as non-commercial properties are aggregated, the potential for the local spread of disease is higher, through direct contract, wind and vector transmission (Davis et al., 2009). Properties contiguous with infected properties are a central component of disease spread during an outbreak and consequently on the effectiveness of tracing and control strategies (Kiss et al., 2005; Shirley and Rushton, 2005). The importance of contiguous properties is emphasised by foot-and-mouth disease (FMD). The effectiveness of strategies designed to control the spread of FMD are dependent on identifying animals that share a boundary with properties identified as having infected animals (Sanson, 1994) to enable these animals to be treated in the same manner as the originally infected property (Shirley and Rushton, 2005).

The findings of the current study must be considered in terms of the limitations created by the study design. While the current study was spatially representative of the underlying AgriBase$^{(TM)}$ population, based on the low response rate, it is assumed that there are differences between those that responded to the survey and those that did not (Armstrong and Overton, 1977). Sample selection was calculated assuming a 30% response rate, based on previous studies using incentives to stimulate response (Brennan and Charbonneau, 2009). In the current study a 38% response rate was achieved, however not all respondents kept horses, leading to a 29% response rate of respondents with horses. Therefore, care must be taken when interpreting the results because of the presence of non-response bias. Selected participants may have chosen not to respond to the survey as it was not relevant to them (Etter and Perneger, 1997); they may not have had horses on the property or were not interested in EI or the control of infectious disease.

In the current study, 24% of respondents reported not having horses on their property at the time of survey. If all of the selected property owners had responded to survey, this result may actually have been higher, as selected property owners without horses may have chosen not to respond as they did not think the survey was important to them. Additionally, within the equine industry, non-commercial horse owners potentially will bear less financial impact than other sectors, if there was an EI outbreak. Therefore, the incentive to participate in a survey regarding the control of EI may be lower than if other sectors of the industry had been included in the sampling frame. The perceived lack of importance or impact to participants of the current study could have led to lower response rates.

For property owners that kept horses, specific factors may have contributed to non-response bias. Non-commercial horse properties owners with large numbers of horses, and property owners that leased their land to horse owners and did not actively participate in the equine industry themselves, may have found the survey difficult to complete; resulting in an underestimate of the true number of horses identified in the current survey. The mixing of horses, as may occur on a property leased by multiple horse owners, may also add a different aspect to the disease profile of New Zealand horses; data that were not captured in the current study. An overestimate of the true number of horses may have also occurred. Property owners that kept horses for pets, particularly those keeping only one horse, with no movement events and no perceived need for biosecurity, may not have responded to survey.

The study population consisted of properties from the AgriBase$^{(TM)}$ database that were selected using a GRTS sample (Stevens and Olsen, 1999, 2004), to ensure a representative sample of the underlying non-commercial horse population. However, selection bias may have occurred as not all properties that kept horses in New Zealand would have been listed in the AgriBase$^{(TM)}$ database, as the registration of properties keeping horses is not mandatory. AgriBase$^{(TM)}$ targeted rural trading properties and those with larger land parcels (Sanson and Pearson, 1997), therefore smaller properties, those recently subdivided or properties that did not use their AgriBase$^{(TM)}$ identification number for trading purposes would be less likely to be in the database. Not all properties listed on the database would have recorded the presence of horses on the property, particularly for properties where the main business focus was for other commercial farming operations, as this was the target population of AgriBase$^{(TM)}$ (Sanson and Pearson, 1997). In the current study, only 19 properties exclusively kept horses, rather than other livestock or companion animals, and most of these properties were lifestyle-sized properties.

Overall, lifestyle properties and owners with one or two horses are likely to be underrepresented in the current study, based on the combined effects of non-response and selection bias. Lifestyle properties would be less likely to be included in the AgriBase$^{(TM)}$ database, if the property had recently been subdivided. However, more respondents from lifestyle properties reported keeping pets, and horses kept for this purpose will be in less frequent contact with horses from other properties, thereby limiting the potential of this type of horse for spreading disease.

3.6 Conclusion

This study described the property-level demographic characteristics of non-commercial horse properties and found that the number of horses on the property varied by property size and region. Most of the properties in the survey kept horses for recreation and competition and as such were unlikely to have horses that were registered with ESNZ or either of the racing codes. Although non-commercial horse properties were targeted for survey, properties where horses were kept for the racing industry were also identified. Furthermore, this study highlighted the closeness of horse properties to each other. These findings have important implications for the control of infectious diseases, both in the non-commercial sector, and the racing industry.

The current study is an important first step to developing strategies for the control of infectious disease, particularly EI in the New Zealand equine population. While there were clear biases created by the postal survey design with non-response and selection bias, the GRTS sampling method allowed for the selection of a spatially representative sample of the population.

Chapter Four

The analysis of horse movements from non-commercial horse properties in New Zealand

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In Chapter Four the description of the non-commercial horse properties that began with Chapter Three is continued. The movement behaviour of horses from non-commercial horse properties is described. This chapter was prepared for the New Zealand Veterinary Journal and has been submitted for publication.

4.1 Abstract

Aims: To investigate property-level factors associated with the movement of horses from non-commercial horse properties, including the size and location of the property, and the number and reason for keeping horses.

Methods: Using a cross-sectional survey, 2,912 questionnaires were posted to randomly selected non-commercial horses properties listed in a rural property database. The survey collected information about the number, and reasons for keeping horses on the property, and any movement of horses in the previous 12-months. Three property-level outcomes were investigated; the movement status of the property, the frequency of movement events, and the median distance travelled from a property. Associations were examined using logistic regression and the non-parametric Kruskal-Wallis test.

Results: In total, 62.0% (488/791) of respondents reported at least one movement event in the year prior to survey, for a total of 22,050 movement events. The number of movement events from a property varied significantly by the number of horses on the property ($P<0.02$), while the median distance travelled per property varied significantly by both region ($P<0.03$) and property size ($P<0.01$). Region, property size, the number of horses kept, and keeping horses for competition, recreation, racing or as pets were all significantly associated with movement status in the multivariable analyses ($P<0.001$).

Conclusion and clinical relevance: This study showed that there are characteristics of non-commercial horse properties that influence movement behaviour. During an exotic disease outbreak the ability to identify properties with these characteristics for targeted control will enhance the effectiveness of these measures.

4.2 Introduction

International horse travel is now commonplace; with large scale seasonal movements of breeding stock, and the frequent movement of competition and racing stock (Sluyter, 2001; Herholz et al., 2008; Robin et al., 2010). This extensive worldwide movement has major implications for disease spread between countries. Within a country, the movement of horses is recognised to occur frequently and is a fundamental characteristic of the equine industry (Vanderman et al., 2009; Robin et al., 2010).

The 2007 outbreak of equine influenza virus (EI) in Australia highlighted the important role that horse movements have on the spread of infectious diseases. Ultimately, the magnitude of the Australian EI outbreak was attributed not only to a fully susceptible population, but also to the movement of horses from a single equestrian event (Callinan, 2008; Cowled et al., 2009). Consequently, accurate information about the movement patterns of a population is extremely important because it allows disease control authorities to understand potential spread of disease and the assessment of strategies aimed at the prevention, treatment, control and eradication (Sanson, 2005).

In contrast to food production industries, which have predominately unidirectional animal movements (Bigras-Poulin *et al.* 2006; León *et al.* 2006; Lockhart *et al.* 2010), the movement of horses is two-way or return (Robin *et al.* 2010). Studies of general horse populations have shown between 61% (Hayama *et al.* 2010) and 64% (USDA 2006) of properties with moving horses reported return trips. In a cross-sectional survey of owners of geriatric horses in the United Kingdom, Ireland et al. (2011b) found that 25% of owners reported moving their geriatric horse. In addition, 57% of the owners reported that other horses moved on or off the property where the horse was housed. The frequency and time period that the movement information was collected over was not defined by the authors of this survey. In a cross-sectional study of 64 equine boarding facilities in Colorado, North America, half of the responding property managers reported that new horses arrived on a regular basis, although the authors did not define the frequency associated with the term 'regularly' (Kirby et al., 2010). Additionally, studies have found that horses kept for competition and racing are moved more frequently than horses kept for other reasons. A survey of horse owners in North America reported that 84% of horses moved in the 12 months prior to survey to racing or competition events (Vanderman et al., 2009). Additionally, of the owners reporting movement events, 36% reported that movement occurred at least once a month. Similarly, in North America, 90% of properties keeping horses for competition reported movement events compared to half of properties keeping horses for pleasure or work (USDA 2006). In Spain, the largest number of incoming horse movements were to equine sports facilities (Martínez-López *et al.* 2011). It is also noteworthy that the different sectors of the equine industry are linked. Hayama et al. (2010) demonstrated movement linkages between different sectors of the non-racing industry in Japan. These sectors included the equestrian sector, private owner sector, equine facilities, fattening, racing sector and horse event sites. Furthermore, the number of movements to different sectors varied depending on the sector where horses had originated.

There are a number of differences between the New Zealand equine industry and those found in other countries. This means the results from other studies are not directly comparable to the New Zealand equine industry. To the best of the authors' knowledge there are no published reports of the frequency of movements onto and off premises with horses in New Zealand. To address this knowledge gap, this paper presents the results of a questionnaire regarding the movement of horses off non-commercial horse properties. Our objective was to describe the movement behaviour of horses from non-commercial horse properties. Additionally, this paper investigates property-level factors that are associated with the movement of horses from these properties, including the size and location of the property and the reason for keeping horses on the property.

4.3 Materials and methods

4.3.1 Study design and data collection

Details of the design of the cross-sectional study and the description of the demographic characteristics of the study population have been described previously (Rosanowski et al., 2011a [Chapter Three]). In brief, a postal questionnaire was sent to selected properties (n=2,912) listed as a horse property in the 2008 Agribase$^{(TM)}$ rural database, but did not keep horses for either Thoroughbred or Standardbred racing or breeding. That is, the survey was sent to properties that kept horses for non-commercial reasons, although the property may have been classified as either commercial agricultural or horticultural farming operations. The questionnaire was sent to properties in November 2009 and was divided into five sections: i) details of property information, ii) the demographic characteristics of the horses on the property, iii) the movement of horses off the property in the previous 12 months, iv) the movement of horse professionals onto the property in the previous 12 months and v) biosecurity practices. The current paper describes the results from section iii, while results from other sections are covered in companion papers (Rosanowski et al., 2011a [Chapter Three]; 2011b [Chapter Five]). A copy of the survey can be found in Appendix A.

Properties in the non-commercial Agribase$^{(TM)}$ horse dataset were stratified, based on property size (Ha); lifestyle (≤5 Ha), small (6 up to 20 Ha), medium (21 up to 169 Ha) or large (≥170 Ha). Properties in each stratum were selected in a spatially balanced manner, using a generalised random-tessellation stratified (GRTS) sampling method (Stevens and Olsen, 2004). As part of the GRTS sampling method, sample size calculation and selection of properties was carried out using the contributed packages spsurvey (Kincaid and Olsen, 2011) and epiR (Stevenson et al., 2009) implemented within R version 2.10.1 (R development core team, Vienna, Austria). In total, 2,912 properties were selected and sent questionnaires in November 2009. A total of 1,044 questionnaires were completed and returned. Of the responding properties, 791 had horses.

4.3.2 Explanatory variables

Property-level explanatory variables included property size, region (location), the number of horses on the property, and the reasons for keeping horses. The reasons for keeping horses were described by binary variables called breeding, competition, pets, racing, recreation, unbroken horses and work. To illustrate, if a property had one or more horses kept for breeding then the variable "breeding" was coded one, otherwise zero if no breeding horses were on the property. Table 4.1 provides the criteria used to code each of the variables. When using this system it was possible that a single property could have more than one reason for keeping horses. For example, the variable "breeding", "pets" and "recreation" could all be coded one for one property.

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

Reason for keeping horses	Description and/or inclusions
Breeding	One or more horses on the property kept for any breeding activity not associated with the racing industry
Competition	One or more horses on the property participated in ESNZ[a] registered events or unregistered competitive events including dressage, show jumping, eventing, endurance, para-equestrian, showing, hunting, competitive trail riding (CRT), western, polo or polocrosse and driving
Pets	One or more horses on the property that did not attend competitive events and were not used for recreational activities. Generally horses that were not used for riding
Racing	One or more horses on the property that participated in Standardbred or Thoroughbred racing (training) or breeding activities
Recreation	One or more horses on the property that were used for non-competitive riding activities such as hacking, trekking, riding lessons, breeds (i.e. Clydesdale), pony club or adult riding club horses
Unbroken	One or more horses on the property not broken to saddle or harness and generally expected to be less than 2 years old
Work	One or more horses on the property used for work related activities such as stock work, work, and other commercial activities

[a] Equestrian Sports New Zealand

4.3.3 Outcome variables

Three property-level outcome variables were considered in this analysis: i) the movement status of the property (coded one if more than one movement was recorded over the past 12 months and zero otherwise), ii) the total number of movement events per year, and iii) the median distance travelled from each property by horses during movement events in the year prior to survey, herein called median distance. The total number of movement events per year was the sum of all movement events recorded. When calculating the median distance travelled in a year only those properties with one or more movements were considered. The respondent could enter the distance travelled as either kilometres (km) or hours travelled one-way. The hours travelled were converted into kilometres, assuming the speed of travel was 90 km per hour. Ninety kilometres per hour was selected because this is the open road speed limit imposed on vehicles that transport horses in New Zealand (Anon, 2010b).

4.3.4 Statistical analysis

Univariable and multivariable analytical methods were used to separately examine the association between a number of independent variables and the three outcome variables.

Logistic regression was used to determine those factors that were associated with the movement status of the property. Potential explanatory variables were screened using univariable logistic regression and those with $P<0.25$ were included in a multivariable model. A preliminary multivariable model was built using a backwards method of elimination in which variables were retained in the model if the likelihood ratio test statistic was significant at $P<0.05$. The linearity of the continuous variable number of horses in the preliminary model was assessed by plotting regression coefficients against the mid-points of the quartiles (Hosmer and Lemeshow, 2000). If any variable showed evidence of non-linearity it was entered into the model as a fractional polynomial. To determine the appropriate fractional polynomial, the variable was transformed using first and second order fractional polynomials with powers between -3 and 3 (Royston et al., 1999). The best fitting transformations of both first and second order fractional polynomials were selected by comparing the model deviances to the null and linear models, assuming a Chi-squared distribution and a significance of $P<0.05$. Biologically plausible two way interaction terms between the main effect variables were considered for inclusion in the multivariable models. Significance was assessed using the likelihood ratio test statistic. Model diagnostics were conducted using summary measures of the goodness-of-fit of the final model included the estimation of the Hosmer-Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow, 2000) and the Receiver Operating Characteristic (ROC) curve. The logistic regression diagnostics included the evaluation of the standardised Pearson's residuals and leverage scores. All statistical analyses were performed using Stata version 11.2 (Statacorp LP, College Station, Texas, USA).

In the analysis, the total number of movement events, and median distance travelled are reported only for those properties reporting movement events (n=488), with the number and percentage of total movement events, stratified by the property-level variables. The number of movement events and median distance travelled were non-normally distributed and were presented as minimums, maximums and percentiles. The nonparametric Kruskal-Wallis test was used to quantify the unconditional relationship between property-level variables and these two movement outcomes.

4.4 Results

The complete dataset from the cross-sectional survey contained information from 791 non-commercial equine properties, representing a total of 5,322 horses. Between

November 2008 and November 2009, 62% (488/791) of non-commercial horse properties reported the occurrence of at least one off-premises movement event.

The results of the univariable logistic regression analysis are presented in Table 4.2. All the variables screened were significant and eligible for inclusion in the multivariable model. In the final multivariable model, whether a property reported a movement event was significantly associated with region, property size, the number of horses on a property and whether a property used horses for competition, recreation, racing or if the property kept horses as pets (P<0.001) (Table 4.3). The odds of a movement event on properties that kept horses for competition were 10.5 (95% CI 6.3 to 17.3) times that of those that did not keep horses for competition. The best fit in the multivariable model for the number of horses on the property was with a fractional polynomial, due to the non-linearity of the continuous variable of number of horses. An initial increase in the likelihood of a movement event with increasing number of horses up to between five and six horses was followed by a slower rise in odds ratios with increasing numbers of horses (Figure 4.1). The Hosmer-Lemeshow goodness-of-fit test statistic was non-significant (P=0.12) indicating that the model provided a suitable fit to the data. This was supported by 0.87 as the area under the ROC curve for the final model. No properties had leverage greater than 0.25, indicating that they could be outliers based on the calculation provided in Dohoo et al. (2010 pg. 357). There were four properties (0.5%) that had Pearson's standardised residuals between -5 and -11. The properties with high residuals were properties with more than five competition horses but that did not report a movement event. Properties with high leverage did not have high residual values. These properties were retained in the dataset used for modelling.

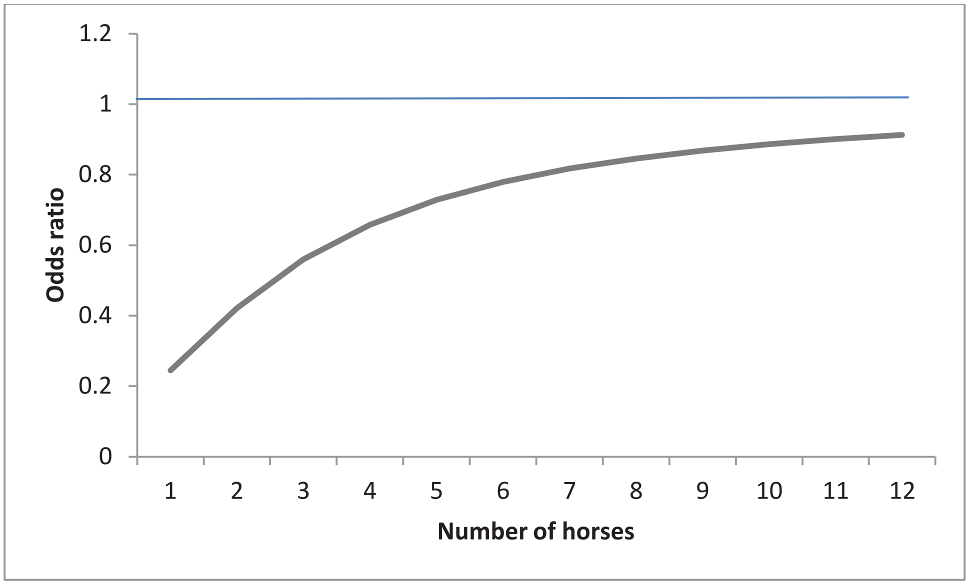

Figure 4.1: Graphical representation of the second order fractional polynomial transformations of the association between the number of horses on a property and the odds of a movement event occurring on that property. The estimated odds of a movement event was adjusted for region, the size of the property, 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)

In total, 22,050 movement events were reported. For properties that reported a movement event (n=488), the greatest number of movement events were reported on small properties and the fewest number on large properties. Properties that kept horses for competition and recreation had the greatest number of movement events, while properties keeping horses for work, or as pets, had the lowest number of movement events (Table 4.4). The median frequency of movement events per year was 22.5 (IQR 5 to 56). Region (P=0.22) and property size (P=0.36) were not significantly associated with the frequency of movement events. The number of movement events varied significantly by the number of horses on the property (P<0.02), with properties with one or two horses having the lowest median number of movement events, compared to those keeping more than two horses. There were significant differences in the number of movement events from properties that kept horses for competition (P<0.001), recreation (P<0.01), work

(P<0.01) or as pets (P<0.001), compared with properties that did not keep horses for these reasons. Properties that kept horses for competition had a median of 34 movement events over the previous 12 months (IQR 14 to 74) compared with a median of 6 movement events (IQR 2 to 24) for properties that did not keep horses for competition (Table 4.5).

For the analysis of median distance travelled by horses from properties in the year prior to survey, four properties had missing value for distance and were excluded from analysis, leaving 484 properties with complete distance data. There were significant associations between the median distance travelled, property size (P<0.01) and region (P<0.03). The median distance travelled was highest for medium sized properties and lowest for small sized properties (Table 4.6).

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.

Variable	Category	Move n (%)	No move n (%)	OR	95% CI	P value [a]
Property size (n=785) [b]						**0.005**
	Lifestyle	135 (17.2)	63 (8.03)	Reference		
	Small	131 (16.7)	71 (9.04)	0.86	0.57 - 1.30	0.48
	Medium	120 (15.3)	69 (8.79)	0.81	0.53 - 1.24	0.33
	Large	101 (12.9)	95 (12.1)	0.50 [c]	0.33 - 0.75	0.001
Region (n=785)						**0.006**
	Auckland	67 (8.5)	56 (7.1)	Reference		
	Bay of Plenty	27 (3.4)	16 (2.0)	1.41	0.69 - 2.88	0.34
	Canterbury	77 (9.8)	31 (3.9)	2.08	1.20 - 3.59	0.009
	East Coast	10 (1.3)	15 (1.9)	0.56	0.23 - 1.34	0.19
	Hawkes Bay	22 (2.8)	14 (1.8)	1.31	0.62 - 2.80	0.48
	Manawatu	41 (5.2)	35 (4.5)	0.98	0.55 - 1.74	0.94
	Northland	30 (3.8)	33 (4.2)	0.76	0.41 - 1.40	0.38
	Otago	34 (4.3)	18 (2.3)	1.58	0.81 - 3.09	0.18
	Southland	27 (3.4)	10 (1.3)	2.26	1.01 - 5.06	0.05
	Taranaki	26 (3.3)	12 (1.5)	1.81	0.84 - 3.91	0.13
	Waikato	75 (9.6)	31 (3.9)	2.02	1.17 - 3.50	0.01
	Wellington	30 (3.8)	12 (1.5)	2.09	0.98 - 4.46	0.06
	West Coast/ Tasman	21 (2.7)	15 (1.9)	1.17	0.55 - 2.48	0.68
Horse numbers (n=785)						**<0.001**
	<2	47 (6.0)	106 (13.5)	Reference		
	2 to 3	131 (16.7)	121 (15.4)	2.44	1.60 - 3.73	<0.001
	4 to 6	154 (19.6)	37 (4.7)	9.39	5.71 - 15.43	<0.001
	>6	155 (19.7)	34 (4.3)	10.28	6.20 - 17.05	<0.001
Reason for keeping horses (n=778)						
Breeding	No	393 (50.5)	280 (36)	Reference		**<0.001**
	Yes	93 (12.0)	12 (1.5)	5.52	2.97 - 10.27	<0.001
Competition	No	205 (26.3)	263 (33.8)	Reference		**<0.001**
	Yes	281 (36.1)	29 (3.7)	12.43	8.14 - 18.99	<0.001
Pets	No	461 (59.3)	201 (25.8)	Reference		**<0.001**
	Yes	25 (3.2)	91 (11.7)	0.12	0.07 - 0.19	<0.001
Racing	No	394 (50.6)	264 (33.9)	Reference		**<0.001**
	Yes	92 (11.8)	28 (3.6)	2.20	1.40 - 3.46	<0.001
Recreation	No	210 (27.0)	173 (22.2)	Reference		**<0.001**
	Yes	276 (35.5)	119 (15.3)	1.91	1.42 - 2.56	<0.001

Unbroken	No	378 (48.6)	272 (35.0)	Reference		**<0.001**
	Yes	108 (13.9)	20 (2.6)	3.89	2.35 - 6.42	<0.001
Work	No	446 (57.3)	231 (29.7)	Reference		**<0.001**
	Yes	40 (5.1)	61 (7.8)	0.34	0.22 - 0.52	<0.001

[a] P values shown are Likelihood ratio test (bold text, left inset) and Wald test (right inset)

[b] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[c] Interpretation of the odds ratio for property size: for large properties the odds of the occurrence of a movement event was 0.5 times (95% CI 0.33-0.75) that for lifestyle properties

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.

Variable	Category	Coefficient	SE	OR	95% CI	P value [a]
Property size [b]	Lifestyle	Reference		1.00 [c]		**<0.001**
	Small	-0.3	0.28	0.74	0.42 - 1.29	0.28
	Medium	-0.83	0.3	0.44	0.24 - 0.78	0.01
	Large	-1.13	0.3	0.32	0.18 - 0.58	<0.001
Region	Auckland	Reference				
	Bay of Plenty	0.82	0.49	2.28	0.86 – 6.00	0.1
	Canterbury	0.58	0.37	1.79	0.86 - 3.73	0.12
	East Coast	-0.8	0.64	0.45	0.13 - 1.58	0.21
	Hawkes Bay	0.77	0.57	2.16	0.71 - 6.56	0.18
	Manawatu	0.41	0.4	1.50	0.68 - 3.32	0.31
	Northland	0.04	0.44	1.04	0.44 - 2.44	0.93
	Otago	0.93	0.46	2.53	1.03 - 6.18	0.04
	Southland	1.36	0.54	3.89	1.36 - 11.14	0.01
	Taranaki	0.39	0.51	1.48	0.55 - 3.99	0.44
	Waikato	0.98	0.38	2.68	1.26 - 5.68	0.01
	Wellington	0.83	0.51	2.30	0.85 - 6.27	0.1
	West Coast/ Tasman	0.27	0.5	1.31	0.49 - 3.50	0.59
Number of horses 1[d]		-0.003	0.0008	0.9971	0.9955 - 0.9987	<0.001
Number of horses 2 [e]		-0.001	0.0002	0.9994	0.9991 - 0.9998	0.001
Reason for keeping horses						
Competition	No	Reference				
	Yes	2.35	0.26	10.47	6.32 - 17.35	<0.001
Pets	No	Reference				
	Yes	-1.07	0.32	0.34	0.18 - 0.64	0.001
Racing	No	Reference				
	Yes	0.99	0.33	2.68	1.40 - 5.13	0.003
Recreation	No	Reference				
	Yes	0.78	0.23	2.18	1.39 - 3.41	0.001

Incomplete data for 24 properties (n=767).

[a] P values shown are Likelihood ratio test (bold text, left inset) and Wald test (right inset)

[b] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[c] Interpretation of the odds ratio: for large properties the odds of the occurrence of a movement event was 0.32 times that of lifestyle properties

[d] Fractional polynomial transformation of number of horses: $(\text{number of horses}/100)^{-2}$

[e] Fractional polynomial transformation of number of horses: $(\text{number of horses}/100)^{-2} \times \text{LN}(\text{number of horses})$

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.

		Number of movements	
Variable	**Category**	**n**	**% (95% CI)**
Property size [a]	Lifestyle	5,957	27.0 (26.3-27.7)
	Small	7,033	31.9 (31.2-32.6)
	Medium	5,893	26.7 (26.0-27.4)
	Large	3,167	14.4 (13.9-14.9)
Region	Auckland	4,683	21.2 (20.6-21.8)
	Bay of Plenty	842	3.8 (3.5-4.1)
	Canterbury	3,986	18.1 (17.5-18.7)
	East Coast	201	0.9 (0.8-1.0)
	Hawkes Bay	626	2.8 (2.6-3.0)
	Manawatu	1,519	6.9 (6.6-7.2)
	Northland	1,700	7.7 (7.3-8.1)
	Otago	961	4.4 (4.1-4.7)
	Southland	877	4.0 (3.7-4.3)
	Taranaki	1,071	4.0 (3.7-4.3)
	Waikato	3,681	16.7 (16.2-17.2)
	Wellington	1,753	8.0 (7.6-8.4)
	West Coast/ Tasman	150	0.7 (0.6-0.8)
Number of horses [b]	1 to 2	3,847	17.5 (16.9-18.1)
	3 to 5	7,063	32.2 (31.4-33)
	6 to 8	4,722	21.5 (20.9-22.1)
	9 plus	6,297	28.7 (28.0-29.4)
Reason for keeping horses [c d]	Breeding	4,205	19.1 (18.5-19.7)
	Competition	15,269	69.4 (68.3-70.5)
	Pets	648	2.9 (2.7-3.1)
	Racing	5,762	26.2 (25.5-26.9)
	Recreation	12,777	58.0 (57.0-59.0)
	Unbroken	5,437	24.7 (24.0-25.4)
	Work	1,023	4.6 (4.3-4.9)

[a] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[b] Missing values for number of horses (n=21,929 movements)

[c] Missing values for reason for keeping horses (n=22,012 movements)

[d] Values greater than 100% as one property can keep horses for multiple purposes

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.

Variable	Category	No. of properties	Min	25th	Median	75th	Max	P value[a]
Horse numbers[b]								
	1 to 2	107	1	3	15	49	315	0.02
	3 to 5	162	1	5	23	56	315	
	6 to 8	90	1	8	30	64	330	
	9 plus	103	1	8	26	57	409	
Reason for keeping horses[c d]								
Competition	No	202	1	2	6	24	409	<0.001
	Yes	281	1	14	34	74	384	
Pets	No	458	1	6	24	57	409	<0.001
	Yes	25	1	2	7	9	315	
Recreation	No	206	1	4	15	39	409	0.01
	Yes	277	1	6	27	62	315	
Work	No	443	1	6	24	58	409	0.01
	Yes	40	1	2	10	34.5	227	

[a] P value shown are the Kruskal-Wallis analysis of variance

[b] 26 properties with incomplete data for either total movement or number of horses (n=461)

[c] One property can keep horses for multiple purposes

[d] Seven properties with incomplete data for either total movement or reason for keeping horses (n=487)

Table 4.6: Description of the median distance travelled (in kilometres) per property during movement events, in the year prior to survey, on New Zealand non-commercial properties where movement events occurred (n=488[a]). Data were stratified by property size and region.

Variable	Category	No. of properties	Min	25th	Median	75th	Max	P value[b]
Property size[c]	Lifestyle	129	1	15	40	100	810	0.01
	Small	126	1	15	35	103	720	
	Medium	115	1	30	90	100	4,320	
	Large	97	1	35	80	150	150	
Region	Auckland	64	1	12	30	90	270	0.03
	Bay of Plenty	27	1	20	70	90	1,800	
	Canterbury	75	2	20	50	100	360	
	East Coast	10	5	35	80	150	630	
	Hawkes Bay	20	1	15	34	90	360	
	Manawatu	38	1	30	90	270	4,320	
	Northland	28	1	15	15	99	270	
	Otago	33	1	20	90	180	270	
	Southland	26	4	30	90	120	720	
	Taranaki	26	5	35	90	103	450	
	Waikato	72	1	20	65	102	2,500	
	Wellington	28	1	17.5	45	85	270	
	West Coast/Tasman	20	5	30	82.5	270	490	

[a] 21 properties with incomplete data (n=467)

[b] P value shown are the Kruskal-Wallis analysis of variance

[c] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

4.5 Discussion

This survey found that there was an increased odds of movement from non-commercial properties when horses were kept for racing and competition purposes, compared with properties that did not keep horses for these reasons. An intrinsic part of membership into these two groups is the attendance at race meetings and competitive events, and consequently attendance defines a racing or competition horse. Previous studies have found an increase in movement from properties keeping horses for racing and competition purposes, compared to other reasons for keeping horses (USDA, 2006). Similar to the movement status of a property, both the frequency of movement events and the distance travelled were found to be associated with property-level factors.

A total of 62% of questionnaire respondents indicated that horses had been moved off the property on at least one occasion during the past 12 months. This is in agreement with studies of geriatric horses in the United Kingdom (Ireland et al., 2011b) and horse populations in North America (USDA, 2006; Kirby et al., 2010) and Japan (Hayama et al., 2010). The proportion of properties with movements in this study was lower than other studies conducted on general horse populations in the United Kingdom (Mellor et al., 1999) and North America (Vanderman et al., 2009). Comparisons across studies are difficult for two reasons. Firstly, several of the studies sampled owners of horses rather than properties with horses, as was done in the current study. Some properties have horses from multiple owners and as such these two are not equivalent. The second reason is that Thoroughbred and Standardbred breeding and training operations were specifically excluded from the current study population. That is, we removed those sectors of the population known to have a large number of movements. In contrast, previous studies have sampled all equine properties or owners (Mellor et al., 1999; Vanderman et al., 2009) or a subset of horse owners, for example geriatric horses in the Ireland et al. (2011) study.

The collection and analysis of movement data predicates the development of effective infectious disease control strategies. As a general premise, for the control of infectious diseases in domestic animal populations the property, rather than the individual, is the unit of interest (Davis et al., 2009; Firestone et al., 2011b; Garner et al., 2011). The movement status of a property, the distance travelled during each movement event, as well as the number of movement events from a property contribute to the ability of disease to disseminate from an infected property to another property with susceptible animals. Infected horses that travel further from their property of origin during a movement event, or move more frequently, would lead to more widespread transmission of disease, if there was an outbreak. The importance of accounting for the frequency and distance travelled when identifying property-level horse movement characteristics is highlighted by the movement behaviour of horses kept on larger properties. Large properties were significantly less likely to have horse movement events and had fewer movement events overall, compared with lifestyle, small and medium sized properties. Therefore, a targeted disease control strategy based on the frequency of movement and property size would have not have focussed on large sized properties. However, the median distance travelled by horses leaving large sized properties was further than horses travelling from lifestyle and small sized properties, indicating that horses moving from large properties, although moving less often, are potentially capable of disseminating disease further than horses moving from lifestyle and smaller sized properties. Therefore, a disease control strategy targeting only lifestyle and small sized properties would be less effective at controlling disease than one that included large sized properties.

While the significance of identified property-level factors on the movement behaviour of non-commercial horse properties in New Zealand is an important finding in the context of infectious disease control, other factors must be considered. One such factor is the finding that region where the property was located was significantly associated with the distance travelled during movement events, as well as the movement status of the property. Control strategies targeting regions with high numbers of horse properties, and an aggregation of horse properties could inhibit disease from spreading beyond regional boundaries, thereby restricting disease outbreaks to local areas. The use of a targeted disease control strategy could be conducted with little further specific property-level information, making this an effective strategy with which to implement disease control. Furthermore, property-level information, like the number and reason for keeping horses combined with region information, could be used to target properties with a more active movement profile, to decrease the logistic and resource input required during the implementation of an infectious disease control strategy.

Limitations in the current study relating to selection and non-response bias, for the overall sampling method, and survey design have been covered in a companion paper (Rosanowski et al., 2011a [Chapter Three]). However, there are two limitations that apply specifically to the current study: non-response bias for the movement section (item non-response bias) of the questionnaire and recall bias, although item non-response bias is associated with the overall non-response bias for the survey (Yan and Curtin, 2010). Item non-response bias could have resulted in either an over or underestimation in the proportion of properties that had horses moving from the property. The proportion of properties with movements would have been overestimated if respondents who did not have horses moving from their property did not take the time to complete the movement section of the survey, as it was less applicable to them. Previous studies have shown that respondents more interested in a topic are more likely to respond (Etter and Perneger, 1997), leading to overestimates of proportion of properties with moving horses in the current study. It is also possible that people with a large number of movement events may have chosen not to respond. However, this was considered less likely because respondents with more movement events may have felt that the survey was more applicable to them and therefore would want to answer questions about the movement patterns of their horses. Rather, those with a high number of movements may not have entered all movements, resulting in an underestimation of the number of movement events.

In this study, it is not known whether the lack of information regarding movement events from a property was due to item non-response or a true lack of movement events. No response regarding movement events was coded as a zero for logistic regression modelling, regardless of the reason for the lack of response. The inability to differentiate between item non-response or no movement events in the logistic regression analysis would have led to an underestimation in the true difference between properties with at least one movement event and those without movement events. Therefore, the magnitude of the association between property size, region, number of horses on the property and keeping horses for recreation, competition, racing or as pets would have been higher, had that data not included missing values.

Additionally, the number of movement events may have been underestimated due to error in recall instead of item non-response bias. Differential recall bias would have been present as respondents with many horse movement events from the property would have been less likely to recall all of these events, compared to those with no, or few movement events. Fewer movement events from a property would have been more memorable than many movement events. This would have led to an underestimation in the total number of movement events, consequently the difference between properties with a movement status, or a high movement frequency would appear more similar to properties with no movement events than is truly the case. Additionally, the distance travelled during a movement event may have been an overestimate of the true distance travelled, due to the conversion of the hours travelled into distance in kilometres. This conversion may have lead to the reported distances being further than was actually travelled during the movement events. Whilst other statistical models could have been used for analysing the data, and have been used in previous studies (Sanson, 2005), logistic regression was found to be the most robust technique for the current data set.

4.6 Conclusion

This study has identified property-level factors on non-commercial horse properties, which are significantly related to the occurrence of horse movement events from those properties. Movement events were more likely to occur on lifestyle sized properties compared to small, medium or large properties, properties with higher horse numbers and those that kept horses for competition, racing or recreation. This study has identified property-level factors associated with these movement events that could potentially influence the spread of disease in the non-commercial horse sector, including the geographical location of the property. This information could lead to the development of control strategies implemented at a regional level. These results have important implications for the control of infectious diseases within the non-commercial horse sector of New Zealand.

Chapter Five
The implementation of biosecurity practices and visitor protocols on non-commercial horse properties in New Zealand

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Chapter Five is the final chapter to describe non-commercial horse properties in New Zealand. Biosecurity practices, visitor protocols and the movement of visitors onto the property are described. Associations between property-level factors and the implementation of biosecurity practices for newly arriving horses are analysed using logistic regression. Chapter Five has been accepted for publication in Preventive Veterinary Medicine.

5.1 Abstract

A survey was conducted to investigate biosecurity practices on non-commercial horse properties, to describe the number of visits by horse professionals and any protocols that visitors were required to follow before interacting with resident horses. Data were collected in November 2009 during a cross-sectional study of non-commercial horse properties, in New Zealand, selected using generalised random-tessellated stratified design and a self-administered postal questionnaire. Data were described and the associations between property-level factors and biosecurity practices were analysed using logistic regression analysis. In total there were 791 respondents from non-commercial horse properties, of which 660 (83%) answered at least one question relating to biosecurity practices. Of the respondents, 95% had at least one biosecurity practice for arriving horses. Only 31% of properties isolated horses for more than four days, and few respondents checked for pyrexia or other clinical signs of infectious disease in new horses. Moving horses from a property was associated with the implementation of biosecurity practices and practices specific to the clinical signs of respiratory disease. Overall, 79% of properties had horse professional's visit, but only 33% of respondents reported biosecurity protocols for these visitors. Most properties had some knowledge about newly arriving horses, but the effectiveness of these practices for biosecurity were questionable, as few practices would stop disease spread to resident horses. Horse professionals are likely candidates for disease spread due to contact with horses, limited visitor protocols and the frequency of visits. The development of a plan to improve biosecurity for endemic and exotic disease is recommended.

5.2 Introduction

The implementation of biosecurity practices on a farm can be the critical difference between an infectious disease outbreak or maintaining the health and welfare of the herd (Boklund et al., 2004). Biosecurity aims to prevent the transmission of disease between infected and susceptible animals, eliminate reservoirs for disease spread and increase a susceptible animal's resistance to disease (Smith, 2002). This is achieved through measures that include isolating newly arriving animals or those with the clinical signs of disease, and the vaccination of susceptible animals (Dargatz et al., 2002). The application of biosecurity practices to people and vehicles is equally important, as the movement of people and vehicles between and within farms can amplify the spread of infection. Practices that prevent contact between resident animals and people reduce the disease transmission risk (Barrington et al., 2002; Barrington et al., 2006). Visitor protocols include reducing access that visitors have to susceptible animals, showering, changing clothing or equipment, and hand or boot washing. The isolation of newly arriving or infected horses has been shown to protect resident horses from equine herpes virus type 1 (EHV-1) (Kohn et al., 2006) and equine influenza virus (EI) (Gildea et al., 2011a). Additionally, having footbaths in place on a farm decreased the likelihood of infection with EI during the outbreak in Australia in 2007 (Firestone et al., 2011a).

Despite the importance of biosecurity practices in the control of common, infectious, respiratory illnesses of horses including S*treptococcus equi* sub *equi* (strangles), EI, EHV-1 and equine herpes virus type 4 (EHV-4) (Waller and Jolley, 2007; Pusterla et al., 2011), there is limited information about how often, and which practices are implemented for non-resident horses arriving on a new property. On commercial stud farms in New Zealand, 89% of respondents reported that in the past they had isolated newly arriving mares, although in the week prior to survey only 15% had actually isolated any newly arriving mares. On 38% of these stud farms, visitor protocols, including changing clothes before interacting with horses, were practiced (Rogers and Cogger, 2010). In a sample of Thoroughbred trainers in Australia, 40% isolated new racehorses, while 80% of trainers isolated racehorses with clinical signs of illness, including nasal discharge or a cough (Bailey et al., 1997). In a study of the general horse population in North America (USDA, 2006), less than 25% of properties ever isolated newly arriving horses, got health certificates or had a veterinarian to examine horses on arrival. Less than 20% of these properties had any biosecurity requirement for visitors that interacted with horses (USDA, 2006). Another study of the general horse population in North America reported that 80% of horse owners either did not have, or did not know about, biosecurity practices where their horses were kept (Vanderman et al., 2009). It was not clear from this study what percentage of respondents did not know about biosecurity measures and what percentage did not have biosecurity practices.

The current study aimed to investigate biosecurity practices relating to newly arriving horses employed on non-commercial equine properties in New Zealand, using data collected by postal questionnaire. The first objective of the study was to examine i) the biosecurity practices relating to the arrival of horses onto a property, ii) those practices specifically relating to the identification of respiratory disease in newly arriving horses, and iii) analyse property-level factors relating to these practices. The second objective was to describe the movement of visitors who interact with horses onto the properties and any biosecurity protocols these visitors were required to follow.

5.3 Materials and methods

5.3.1 Study design and data collection

Details of the design of the cross-sectional study, the demographic characteristics (Rosanowski et al., 2011a [Chapter Three]) and movement behaviour of the study population (Rosanowski et al., 2012b [Chapter Four]) have been previously described. Briefly, in November 2009 a questionnaire was sent to properties listed on the AgriBase$^{(TM)}$ rural database (Sanson and Pearson, 1997) not identified as either Thoroughbred or Standardbred breeding or training properties. Using a generalised random-tessellated stratified (GRTS) sampling technique (Stevens and Olsen, 1999, 2004), 2,912 properties were selected after stratification for property size, in hectares (Ha), lifestyle (≤5 Ha), small (6 up to 20 Ha), medium (20 up to 169 Ha) or large (>169 Ha), and location. Sample size calculation and sample selection was conducted using R version 2.10.1 (R development core team, Vienna, Austria) using the packages epiR (Stevenson et al., 2009) and spsurvey (Kincaid and Olsen, 2011).

The selected properties were termed non-commercial horse properties, although the property itself may have been part of a commercial agricultural farming operation (i.e. sheep and beef or dairy). The current paper relates to the biosecurity practices employed on these non-commercial horse properties and the movement of people interacting with horses onto these properties, between November 2008 and November 2009. The questions were in three sections, i) the frequency of visits to the property of horse professional visitors who interacted with horses, ii) biosecurity protocols for visitors interacting with horses, and iii) biosecurity practices for arriving horses including the history available about arriving horses, isolation of arriving horses and health checks conducted on arriving horses. A copy of the survey is found in Appendix A.

5.3.2 Types of visitors

Information on the visitors to the property who interacted with horses, herein called horse professionals, were grouped into veterinarians, farriers, equine dentists, riding instructors, saddle fitters, therapists, trainers and a group called “other”. Horse therapists were defined as non-veterinarians who charged for therapeutic services conducted on horses resident on the property, for example equine chiropractors and massage therapists. Riding instructors and trainers differed, as riding instructors were focused on the rider or teaching riding, while trainers were focused on the horse. The “other” category included float drivers, freeze branders, people using equine services available at the property and groups of people or friends. A new outcome variable was created to describe a subset of horse professionals that included veterinarians, farriers and equine dentists. This new outcome variable was called health professionals. All properties that did not answer were assumed to have not had a visit by a horse professional and were disregarded from further analysis.

5.3.3 Biosecurity practices for newly arriving horses

Two new binary variables were created to describe biosecurity practices implemented when new horses arrived on the property. The first was whether a property had any biosecurity practices relating to new horses arriving onto the property, herein referred to as general biosecurity. Any respondent who had replied positively to any question regarding history of, checks, or the isolation of newly arriving horses, were summed and coded as one, while those that had no biosecurity practices overall, were coded as a zero. The second new outcome variable was whether a respondent practiced any biosecurity that would identify the clinical signs of respiratory illness in newly arrived horses, herein referred to as clinic signs biosecurity. If the respondent answered yes to any of the following, checking new horses for a cough, abnormal discharge from eyes or nose, pyrexia, calling the veterinarian immediately if a horse was unwell, or isolating a horse for more than four days after arrival, it was coded as a one, while respondents that did not have any of the listed practices were coded as a zero. The variables included in either any biosecurity practice outcome or clinical signs biosecurity outcome are shown in Table 5.1.

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.

General biosecurity practices	Clinical signs biosecurity practices
History	Discharge from eyes or nose
Origin	Pyrexia
Previous medical history	Coughing
Strangles vaccination history	Isolation of more than 4 days
Tetanus vaccination history	Call veterinarian immediately if new horse appears unwell
Worming history	
Health Checks	
Discharge from eyes or nose	
Treated for internal parasites	
Gait or lameness	
Pyrexia	
Ill thrift	
Isolation	
Any isolation practice	

5.3.4 Statistical analysis

The percentage of survey respondents that answered one or more questions in the biosecurity section of the survey was determined. Results were presented stratified by a number of property-level variables. The property-level variables were property size (Ha), region, number of horses on the property (≤2, 3-4, 5-7 and ≥8 horses), whether a movement event of horses from the property had been reported in the past 12 months and the reason for keeping horses on the property. Respondents could keep horses for a variety of reasons. To describe the ownership patterns, the binary variables breeding, competition, pets, racing, recreation, unbroken and work were created to describe the reason respondents kept horses. For example, the variable “breeding” was one if the property kept one or more horse for breeding and zero if there were no horses kept for this reason. The same property could be coded as one for “competition” if they kept at least one horse for competition. Significance of the relationship between survey completion and each of variables was assessed using Chi-squared test statistic.

For each property, the number of visits for each horse professional was determined and results presented as a box plot. Visits to the property by horse professionals and horse health professionals were described using count, percentages, and the percentiles of number of visits, for respondents who reported any visitor. The significance of the relationship between the number of visits by any horse professional and the property-level variables described above was assessed using the non-parametric Kruskal-Wallis test. Similarly, the Kruskal-Wallis test was used to determine the significance of the relationship between property-level variables and the number of visits by a horse health professional.

For each biosecurity question relating to the arrival of horses on the property or visitor protocols, the number and percentage of responses were reported. These questions were not stratified by property-level variables. Univariable and multivariable logistic regression was used to examine the two outcomes relating to biosecurity practices, the relationship between general biosecurity or clinical signs biosecurity, and the property-level variables. A critical probability of $P<0.25$ likelihood ratio test statistic was used to select variables for inclusion in the subsequent multivariable model and were retained in the final model if $P<0.05$. Biologically plausible interaction terms between the main effect variables were considered for inclusion in the multivariable binomial model. The Hosmer-Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow, 2000) and the receiver operating characteristic (ROC) curve were used to assess the fit of the final models. Model diagnostics included the evaluation of the standardised Pearson's residuals and leverage scores for both models.

5.4 Results

5.4.1 Response rates

Of the 791 respondents with horses who completed the original survey, 660 (83.4%) answered at least one question relating to biosecurity or visitor protocols. Non-response to the biosecurity section of the survey did not vary significantly by property size (P=0.78) or the reason for keeping horses (P=0.64). However, response to the biosecurity questions did vary significantly by region (P<0.001). The Manawatu and East Coast regions had the highest proportion of incomplete biosecurity sections, with 36.8% and 32.0%, respectively, compared to an average of 14.8% in other regions. Respondents from properties keeping one or two horses were less likely to respond to the biosecurity section than properties keeping more horses (P<0.001), while properties that did not move horses were less likely to respond to biosecurity questions (P<0.001).

5.4.2 Arriving visitors and visitor protocols

Overall, 79.0% (625/791) of properties reported that a horse professional visited their property between November 2008 and November 2009. The number of times per year that any horse professional visited a property varied significantly (P<0.001), with the farrier visiting a median of eight times (IQR 4 to 8) and the dentist visiting a median of one time (IQR 1 to 2) (Figure 5.1). The number of visits horse professionals made to properties varied significantly with property size (P<0.04), between region (P<0.01) and the number of horses on the property (P<0.001). The farrier visited 84.8% (530/625) of properties that reported having visitors, followed by the veterinarian 57.4% (359/625) and the dentist 27.7% (173/625). Respondents from nine properties (1%), who reported horse professionals visiting, did not have a health professional visit to property. The number of visits by health professionals varied significantly by region (P<0.01), and the number of horses on the property (P<0.001) (Table 5.2).

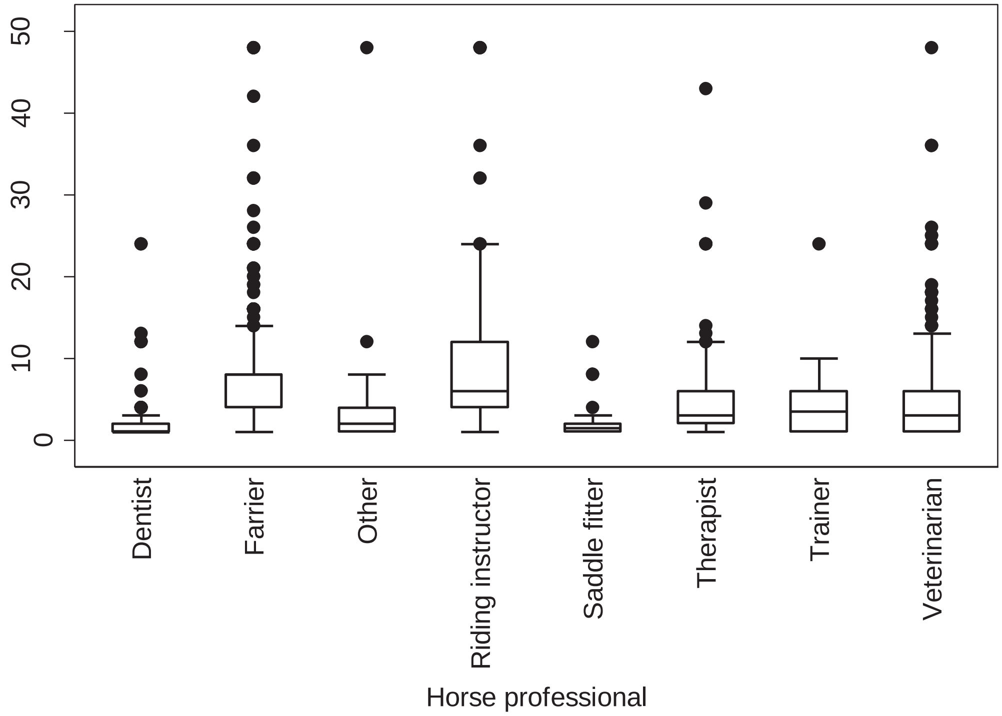

Figure 5.1: Boxplot of the frequency that horse care professionals visited non-commercial horse properties in New Zealand (n=625), stratified by horse care professional (P<0.001). Outliers >50 visits per year were removed (n=4). Data were collected during a postal survey of non-commercial horse properties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

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.

		Horse professional[a]							Health professional[b]						
Variable	Category	No. of properties	Min	25th	50th	75th	Max	P value[c]	No. of properties	Min	25th	50th	75th	Max	P value[c]
Property size[d]															
	Lifestyle	167	1	6	9	16	90	0.05	205	1	4	6.7	9	61	0.25
	Small	168	1	4	8	15	115.5		143	0.5	4	8	13	85	
	Medium	151	0.5	4.5	9.6	17	152		124	1	7	11.5	18	152	
	Large	139	1	4	8	12	124		145	1	8	13	25	124	
Region															
	Auckland	100	0.5	6	10.5	25.5	115.5	0.01	99	0.5	6	9	15	74	0.01
	Bay of Plenty	34	1	4	8	12	62		34	1	4	7.9	10	28.5	
	Canterbury	92	1	6	10	16	114		91	1	4	8.5	14	114	
	East Coast	16	1	4.4	8	8.8	16		16	1	4.4	8	8.8	16	
	Hawkes Bay	29	1	4	7	12	90		28	1	4	6.9	8.5	30	
	Manawatu	57	1	5	8	15.3	41		57	1	4.8	8	12	41	
	Northland	38	1	3	7.4	10	25		38	1	3	7.4	9	18.3	
	Otago	42	1	3	7.4	13.6	152		42	1	3	6	11.6	152	
	Southland	27	1	3	6	9	28.5		25	1	3	6	9	20	
	Taranaki	32	1	5.5	9.5	15	51		32	1	5.5	9.5	14.5	33	
	Waikato	89	1	6	9	17.6	124		87	1	4.5	8.8	15	85	
	Wellington	36	2	6.25	8	15.7	45.2		36	1	6.3	8	12.8	44	
	West Coast	33	1	4	9.5	14	36		31	1	4	8	13	32	

Number of horses															
	≤2	205	1	4	6.7	9	61	0.001	201	1	4	6	9	28	0.001
	3 to 4	143	0.5	4	8	13	85		142	0.5	4	7.9	11	85	
	5 to 7	124	1	7	11.5	18	152		122	1	7	10.5	15	152	
	≥8	145	1	8	13	25	124		143	1	7	12	19	114	
Reason for keeping horses															
Breeding	No	527	0.5	4	8	15	152	0.01	518	0.5	4	8	12	152	0.04
	Yes	97	1	6.9	11	17	69.7		97	1	6	9	14	38	
Competition	No	334	0.5	4	6.9	10	152	0.001	326	0.5	4	6.1	10	152	0.001
	Yes	290	1	8	11.9	18	124		289	1	7	9.6	14	85	
Pets	No	553	0.5	5	9	15.4	124	0.01	546	0.5	4.8	8	13	114	0.04
	Yes	71	1	3	6	12.6	152		69	1	3	6	10	152	
Racing	No	524	0.5	4	8	14	152	0.001	520	0.5	4	8	12	152	0.001
	Yes	100	1	7	12	22.3	114		95	1	6	11	20	114	
Recreation	No	287	0.5	4.5	8.5	16	115.5	0.77	280	0.5	4.3	8	13.8	114	0.35
	Yes	337	1	5	8	14	152		335	1	4	8	12	152	
Unbroken	No	506	0.5	4	8	14	152	0.001	497	0.5	4	8	12	152	0.001
	Yes	118	1	7	12	19	114		118	1	6	10	15.4	114	
Work	No	556	1	5	9	16	124	0.001	548	1	5	8	13	114	0.001
	Yes	68	0.5	2.2	6	8.8	152		67	0.5	2.4	6	9	152	

[a] All horse professionals listed as visiting non-commercial horse properties

[b] Veterinarians, farriers and equine dentists listed as visiting non-commercial horse properties

[c] Kruskal-Wallis analysis of variance

[d] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

The most common reason for non-veterinary therapists to visit a horse property was to provide massage treatment, comprising 30.1% (25/83) of visits followed by chiropractic and physiotherapy with 21.7% (18/83) each. Other types of therapists reported were Bowen 3.6% (3/83), cranial sacral 2.4% (2/83), equine muscle release 2.4% (2/83) and light, laser or thermal imaging 6.0% (5/83).

Although 79.0% (625/791) of properties reported horse professionals visiting the property, only 31.3% (154/495) reported any type of visitor protocol relating to biosecurity (Table 5.3). The most commonly reported visitor protocol requested that the professional washed their hands.

5.4.3 Biosecurity practices for arriving horses

In total, 94.4% (623/660) respondents answered at least one question regarding history of checks conducted on, and the isolation of, newly arriving horses. One quarter of respondents did not isolate newly arriving horses, while 31% isolated horses for more than four days (Table 3).

The results of univariable logistic regression analysis for the two biosecurity outcomes for arriving horses, general biosecurity and clinical signs biosecurity, are presented in Table 4.

Whether a property implemented any general biosecurity practices was significantly associated with property size and the occurrence of a movement event (Table 5). Whether a property had clinical signs biosecurity was significantly associated with movement occurrence ($P<0.001$) (Table 5). In both models, properties with horses moving from them had a higher odds of having biosecurity practices. For the final multivariable models, non-significant variables were retained to allow comparison between the two models and to improve the fit of the models. In both final multivariable models, the likelihood ratio test for each model was P<0.001.

The final model for whether a property implemented general biosecurity practices returned a Chi-squared statistic of 5.57 with 8 degrees of freedom (P=0.70) on a Hosmer-Lemeshow goodness-of-fit test using groups based on the deciles of estimated probabilities. The area under the ROC curve for the final model was 0.77, indicating that the model was a good fit for the data. There were no Pearson's deviance residuals of less than -3 or more than 2 and no properties had leverage values greater than 1 or less than -1, indicating the model was a good fit for the data.

For the model of clinical signs biosecurity, the final model returned a Chi-squared statistic of 12.89 with 8 degrees of freedom (P=0.12) on a Hosmer-Lemeshow goodness-of-fit test using groups based on the deciles of estimated probabilities. The area under the ROC curve for the final model was 0.74 indicating that the model was a good fit for the data. There were no Pearson's deviance residuals of less than -3 or more than 2 and no properties had leverage values greater than 1 or less than -1, indicating the model was a good fit for the data.

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.

Variable	Category	Number of responses	% (95% CI)
Information available on arriving horses (n=598)			
	No information known	105	17.6 (3.4-21.0)
	Origin	349	58.4 (6.1-64.5)
	Previous medical history	236	39.5 (5.0-44.5)
	Strangles vaccination history	125	20.9 (3.7-24.6)
	Tetanus vaccination history	172	28.8 (4.3-33.1)
	Worming history	338	56.5 (6.0-62.5)
	Other information	44	7.4 (2.2-9.6)
Checks for arriving horses (n=595)			
	No health checks are conducted	108	18.2 (3.4-21.6)
	Discharge from eyes or nose	239	40.2 (5.1-45.3)
	Treated for internal parasites	360	60.5 (6.2-66.7)
	Gait or lameness	235	39.5 (5.1-44.6)
	Pyrexia	14	2.4 (1.2-3.6)
	Ill thrift	381	64.0 (6.4-70.4)
Checks on horses with clinical signs of disease (n=598)[b]			
	Discharge from eyes or nose	328	54.8 (5.9-60.7)
	Appetite	359	60.0 (6.2-66.2)
	Call veterinarian	311	52.0 (5.8-57.8)
	Coughing	322	53.8 (5.9-59.7)
	Pulse	104	17.4 (3.3-20.7)
	Respiration	199	33.3 (4.6-37.9)
	Colic	289	48.3 (5.6-53.9)
	Stance	336	56.2 (6.0-62.2)
	Pyrexia	187	31.3 (4.5-35.8)
	Other	42	7.0 (2.1-9.1)
Isolation of arriving horses (n=572)			
	No isolation	147	25.7 (4.2-29.9)
	Up to 24 hours	43	7.5 (2.2-9.7)
	1 to 2 days	55	9.6 (2.5-12.1)
	3 to 4 days	109	19.1 (3.6-22.7)
	More than 4 days	178	31.1 (4.6-35.7)
	Other	40	7.0 (2.2-9.2)
Visitor protocols (n=495)			
	No visitor protocol	341	68.9 (7.3-76.2)
	Change clothes	17	3.4 (1.6-5.0)

Change into overalls	75	15.2 (3.4-18.6)
Clean gear or use gear provided	75	15.2 (3.4-18.6)
Clean or wash boots	24	4.8 (1.9-6.7)
Wash hands	94	19 (3.8-22.8)
Other	15	3.0 (1.5-4.5)

[a] Totals can be more than 100% as respondents could have multiple answers

[b] These checks were conducted in the week after the new horse(s) arrived

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.

		General biosecurity			**Clinical signs biosecurity**[a]		
Variable	**Category**	**OR**	**95% CI**	**P value** [b]	**OR**	**95% CI**	**P value** [b]
Property size [c]		**n=623**			**n=611**		
	Lifestyle	1		0.03	1		0.97
	Small	3.66[d]	0.99-13.54		1.06[e]	0.47-2.36	
	Medium	1.41	0.52-3.8		1.08	0.48-2.46	
	Large	0.70	0.30-1.63		1.23	0.53-2.85	
Horse number		**n=613**			**n=600**		
	1 to 2	1		0.01	1		0.01
	3 to 4	2.29	0.94-5.61		2.83	1.24-6.45	
	5 to 7	4.26	1.23-14.72		3.05	1.22-7.65	
	8 plus	3.88	1.29-11.65		2.39	1.08-5.27	
Movement		**n=623**			**n=611**		
	No	1		<0.001	1		<0.001
	Yes	4.48	2.17-9.26		4	2.19-7.32	
Reason for keeping horses		**n=620**			**n=608**		
Breeding	No	1		0.25	1		0.001
	Yes	1.92	0.58-6.43		9.7	1.32-71.17	
Competition	No	1		<0.001	1		<0.001
	Yes	4.82	1.84-12.63		2.92	1.46-5.83	
Pets	No	1		0.85	1		0.08
	Yes	0.9	0.31-2.65		0.48	0.22-1.03	
Racing	No	1		0.67	1		0.18
	Yes	1.2	0.52-2.75		2.1	0.63-7.01	
Recreation	No	1		0.96	1		0.95
	Yes	1.01	0.56-1.82		0.98	0.49-1.96	
Unbroken	No	1		0.04	1		0.11
	Yes	2.69	0.95-7.65		2.41	0.73-8.04	
Work	No	1		0.73	1		0.02
	Yes	0.86	0.37-1.99		0.37	0.17-0.83	

[a] Inclusion variables include pyrexia, abnormal discharge from eyes or nose, coughing, isolation of horses for more than four days, calling veterinarian if a new horse appeared unwell.

[b] P values shown are Likelihood ratio test

[c] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[d] The odds that a small sized property had general biosecurity practices for newly arriving horses was 3.66 times the odds of a lifestyle size property having general biosecurity practices.

[e] The odds that a small sized property had clinical signs biosecurity practices for newly arriving horses was 1.06 times the odds of a lifestyle size property having clinical signs biosecurity practices.

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.

		General biosecurity			**(n=610)[a]**		**Clinical signs biosecurity [c]**			**(n=597) [d]**	
Variable	**Category**	**Coefficient**	**SE**	**OR**	**95% CI**	**P value [b]**	**Coefficient**	**SE**	**OR**	**95% CI**	**P value [b]**
Property size [e]	Lifestyle	Referent		1			Referent		1		
	Small	1.36	0.68	3.90[f]	1.03-14.74	0.05	0.19	0.42	1.21[g]	0.53-2.78	0.66
	Medium	0.34	0.55	1.40	0.48-4.10	0.54	-0.02	0.44	0.98	0.42-2.32	0.97
	Large	-0.22	0.45	0.80	0.33-1.95	0.63	0.47	0.45	1.60	0.67-3.85	0.29
Number of horses	1 to 2	Referent		1			Referent		1		
	3 to 4	0.57	0.47	1.76	0.70-4.46	0.23	0.74	0.43	2.09	0.90-4.88	0.09
	5 to 7	0.92	0.69	2.52	0.66-9.66	0.18	0.35	0.51	1.42	0.53-3.83	0.49
	8 plus	0.95	0.67	2.60	0.70-9.71	0.16	-0.05	0.45	0.95	0.39-2.31	0.91
Movement	No	Referent		1			Referent		1		
	Yes	0.93	0.45	2.52	1.04-6.14	0.04	1.07	0.37	2.92	1.42-6.02	<0.001
Breeding	No	Referent		1			Referent		1		
	Yes	-0.51	0.74	0.60	0.14-2.58	0.50	1.96	1.05	7.11	0.9-56.02	0.06
Competition	No	Referent		1			Referent		1		
	Yes	0.91	0.57	2.49	0.82-7.61	0.11	0.40	0.40	1.49	0.68-3.27	0.33

[a] Incomplete data for 13 properties (n=610)

[b] P values shown are Wald test

[c] Inclusion variables include pyrexia, abnormal discharge from eyes or nose, coughing, isolation of horses for more than four days, calling veterinarian if a new horse appeared unwell.

[d] Incomplete data for 16 properties (n=597)

[e] Property size as defined as lifestyle (≤5 Ha), small (6 to 20 Ha), medium (21 to 169 Ha), large (>169 Ha)

[f] The odds that a small sized property had general biosecurity practices for newly arriving horses was 3.90 times the odds of a lifestyle size property having general biosecurity practices.

[g] The odds that a small sized property had clinical signs biosecurity practices for newly arriving horses was 1.21 times the odds of a lifestyle size property having clinical biosecurity practices.

5.5 Discussion

The current study found that on non-commercial horse properties few biosecurity practices were implemented that would be protective against infectious disease. Many respondents had some biosecurity practices relating to the arrival of new horses, although there was a large variation in the total number of biosecurity practices implemented and the potential effectiveness of these practices for preventing the spread of disease to resident horses. While most respondents knew the origin and veterinary history of arriving horses, few physically examined new horses for the clinical signs of infectious disease. However, physical examinations for infectious disease would be ineffective as a biosecurity strategy, without the addition of isolating newly arriving horses (Kohn et al., 2006). Three quarters of respondents did isolate horses on arrival, with 31% of properties isolating horses for more than four days. This is less than values reported for Thoroughbred stud managers, 89% of whom reported isolating new horses at some time (Rogers and Cogger, 2010), but greater than values reported for equine boarding facilities in North America, with up to 65% of properties isolating horses (USDA, 2006; Kirby et al., 2010).

The postal survey design resulted in an item non-response rate that was higher on the biosecurity section than the other sections of the questionnaire. Non-completion of the biosecurity section by respondents could have resulted in an overestimation of the level of biosecurity practiced on non-commercial horse properties in the current study. Significant item non-response bias was found for respondents from properties that kept one or two horses and those that did not report movement events from the property, as they were less likely to have completed the biosecurity section of the current survey, compared to earlier sections. Respondents with fewer horses or those that did not move horses from the property may not have taken the time to respond to the biosecurity section of the survey if they did not think it was relevant to them, implying that these types of properties did not have biosecurity practices in place at the time of survey.

A lower proportion of respondents in the Manawatu and East Coast regions completed the biosecurity section compared to the overall survey response rate, indicating the survey may not be representative of the biosecurity practices in these regions, due to item non-response bias. It is not known why the difference occurred in this section for these regions, as the questionnaires were all sent in the same manner. Additionally, there was no difference between the respondents in these regions and the rest of the country in the other sections (Rosanowski et al., 2011a [Chapter Three]). Due to the low levels of biosecurity described countrywide, the non-response of the Manawatu and East Coast was not suggestive of more effective biosecurity practices compared to other regions.

In 2007, there was an EI outbreak in Australia. During this outbreak, certain biosecurity practices were shown to be effective at preventing properties from becoming infected (Firestone et al., 2011a). The current survey occurred after the EI outbreak in Australia, indicating that respondents may have had a heightened awareness of the importance of biosecurity. Due to the low level of biosecurity identified in the current survey, there does not seem to be evidence for heightened awareness, unless the level of biosecurity practiced was even lower before the EI outbreak. Additionally, the low level of biosecurity practices found implies that questions were answered honestly, rather than as a response to please the researcher.

Another potential limitation of this study was recall bias. Recall bias may have affected responses about the visitation of horse professionals who interacted with horses, as these data were collected retrospectively relating to the year prior to survey. Farriers and dentists would visit properties on a regular schedule; therefore, visits would be memorable and easily recalled. Similarly, visits by veterinarians, who visit for unexpected, or acute events, would be easily recalled. However, visits that were not on a regular schedule nor were for an acute event would be most difficult to recall. This would have led to an underestimation of the true number of visitors and would be most apparent for riding instructors, trainers, saddle fitters and other visitors to properties. The questions regarding biosecurity practices would not have been affected by recall bias as the questions were about practices that were currently undertaken on that property, rather than about historical events.

Horse professionals visited 79% (625/791) of the properties in this study. The farrier attended the greatest number of properties at the highest frequency, which is similar to what was found in Australia (Firestone et al., 2011a) and Canada (Christie et al., 2004b). The number and type of equine therapists utilised by horse owners in previous studies has been reported at 30% (Ireland et al., 2011c) and 34% (McGowan et al., 2010) for geriatric horses, 43% for competition horses (Meredith et al., 2011) and 83% for Thoroughbred racehorses in training (Coleman et al., 2006). Although the most common therapists reported in the current and previous studies were similar, the proportion of respondents utilising therapists was far lower in the current study, with 11% reporting therapists visiting the property. The populations under investigation in the current and previous studies were different, as the current study investigated the general horse population, whereas the previous studies investigated equine athletes, racehorses and competition horses, and aged horses, where the use of therapists may be necessary to maintain health and athletic ability.

Even though most properties reported horse professionals visiting, 69% of them did not have biosecurity protocols associated with these visitors. This lack of biosecurity could facilitate disease spread between properties. A similar proportion of properties lacking visitor protocols was found on North American horse properties, with 77% of properties with no protocols for visitors (USDA, 2006) and in the Thoroughbred commercial sector in New Zealand, with 62% of stud farms requiring a change of clothing as the minimum acceptable visitor protocol (Rogers and Cogger, 2010). The importance of horse professionals in facilitating disease spread is exacerbated by the frequency that these individuals are visiting properties. Horse health professionals, farriers, equine dentists and veterinarians, spend time in close proximity to horses when they visit properties to interact with horses, and these professionals would visit many horses on multiple properties each day.

In the current study, more than half of the respondents reported that they would call a veterinarian if a newly arrived horse appeared unwell. A veterinarian would be more likely to diagnose disease compared to horse owners (Ireland et al., 2011a). However, in the case of exotic disease outbreaks with non-specific clinical signs, incorrect diagnosis may be made by clinicians favouring the diagnosis of endemic disease (Poutanen et al., 2003).

Small and medium properties were more likely to have general biosecurity practices compared to lifestyle properties. Moving horses from the property increased the likelihood of having general biosecurity practices and having biosecurity practices to identify the clinical signs of infectious disease. This is similar to findings reported by Traub-Dargatz et al. (in press). As the movement of animals is the highest risk activity for disease introduction (Ortiz-Pelaez et al., 2006), increased biosecurity practices on properties reporting the movement of horses was a positive finding in the current study. Horses were kept for competition on 40% of non-commercial horse properties in New Zealand (Rosanowski et al., 2011a [Chapter Three]), and properties that kept horses for competition had a high movement profile, compared to properties that did not keep horses for this purpose (Rosanowski et al., 2012b [Chapter Four]). However, the current study did not investigate whether biosecurity practices were applied to resident horses returning to the property after competing, instead the current study focused on biosecurity practices for newly arriving horses. Therefore, it cannot be concluded from the current study that effective biosecurity strategies, like isolation, are being applied to returning resident horses in the same manner as newly arriving horses, on properties that reported the movement of horses.

In the current study, properties were coded as yes or no, depending on the biosecurity practices that were implemented on the property. By coding any biosecurity practice applied to arriving horses as a one, or zero for absence, no account has been taken of the effectiveness of these strategies. As the aim of this study was to describe current biosecurity practice and to identify property-level factors associated with having practices, then this methodology was effective. By investigating the biosecurity practices associated with the clinical signs of disease, more importance was placed upon practices that could identify and prevent the spread of disease within a property, but again the true effectiveness of these strategies in an outbreak is unknown. This technique of not weighting biosecurity practices has been applied in other studies (Julio Pinto and Santiago Urcelay, 2003). Other studies have used various methods to weight biosecurity practices for further analysis, either with the presence of each practice being additive (Van Steenwinkel et al., 2011) or by characterising biosecurity on scales of high, medium or low (Schemann et al., 2011). However, in the current study no judgement was made about the effectiveness of biosecurity strategies, as any judgement about effectiveness of strategies can be subjective. Additionally, there is limited evidence available about the effectiveness of specific biosecurity strategies for the control of infectious disease in horses upon with to base any judgement.

The findings of the current study have highlighted that the baseline application of biosecurity on non-commercial horse properties in New Zealand is poor and needs improvement to be effective against endemic and exotic diseases. At the current time, there are no plans to improve biosecurity practices to control disease, although based on the findings of the current study, the development of a strategy to improve biosecurity practices is recommended. It is not known whether the lack of biosecurity practices is due to a knowledge gap about the importance of biosecurity or how to implement biosecurity practices, or whether horse property owners are aware of the importance of biosecurity, but choose not to implement effective practices. However, the current study has highlighted two groups that could receive targeted education to increase awareness about the importance of biosecurity: health professionals and properties that reported moving horses. Farriers, veterinarians and equine dentists visit equine properties regularly and have direct contact with horses on each property that they visit. As few visitor protocols were found on properties, targeting education programmes regarding the importance of biosecurity protocols for health professionals, to these professionals, would decrease their disease spread potential. Additionally, the identification of properties that move horses, a high-risk activity in terms of disease spread, enables this group to be targeted through attendance at equine events, particularly competitions.

5.6 Conclusion

This study of non-commercial horse properties in New Zealand highlighted the lack of effective biosecurity practices and visitor protocols currently in place. Biosecurity is the most effective way to prevent infectious disease from entering a property and spreading to resident horses. The current study showed that most non-commercial equine properties practiced some form of biosecurity for arriving horses, although the effectiveness of these strategies, if tested by a disease outbreak, may be limited. Some properties had biosecurity practices that specifically related to identifying or preventing the spread of infectious disease, like identifying horses with the clinical signs of disease, isolating horses or calling a veterinarian if a new horse became unwell. Most properties had at least one horse professional visiting the property and few properties had biosecurity protocols in place for these visitors. Horse professionals can travel to multiple properties in a day, potentially acting as highly effective facilitators of disease spread. Knowledge of the biosecurity practices currently in place on New Zealand non-commercial horse properties is important for informing infectious disease control strategies, including targeting the at risk groups at equestrian events for education regarding the importance of biosecurity.

Further research is important in the area of biosecurity, for both endemic and exotic disease control. The current study did not investigate biosecurity practices associated with sick horses resident on the property, but rather focussed on newly arriving horses. The practices of respondents may differ between new horses and horses with which respondents have a more intimate history.

Chapter Six

The movement pattern of horses around race meetings in New Zealand

Chapter Six is the first of two chapters to describe the movement of horses involved in the racing industry. This chapter has not been submitted for publication.

6.1 Abstract

Using retrospective records of all Thoroughbred and Standardbred race meetings held in 2009, and trainers and horses in attendance, 39 Thoroughbred and 42 Standardbred race meetings were randomly selected. Selected races were compared to the total race meetings held in 2009, while the number of trainers and horses attending selected race meetings were compared to the total number of trainers and horses in 2009. The distance travelled by each trainer to the selected race meeting was calculated using Google Maps (www.google.co.nz). Summary statistics included Chi-square and the non-parametric Kruskal-Wallis test. During 2009, 45% (228/507) of Thoroughbred races were held in the Northern region, while 64% (326/596) of Standardbred races were held in the Southern Region (326/506). The trainers attending selected race meetings represented 50% (1,135/2,287) of all registered trainers in 2009. There was no seasonal pattern of when race meetings were held between racing codes (P=0.18) or by race type (P=0.83). There were significant differences in the distance travelled by trainers to race meetings, by racing code (P<0.001). Thoroughbred trainers travelled a median of 91 km (IQR 40 to 203 km), while Standardbred trainers travelled a median of 45 km (IQR 24 to 113 km) (P<0.001). Within each racing code, trainers travelled further to attend premier races than other types of race meetings (P<0.001). The findings from the current study have implications for the control of infectious disease outbreaks, as there is higher potential for more widespread disease dissemination from premier race meetings compared to other types of race meetings. Additionally, as race meetings did not follow a seasonal pattern, widespread outbreaks could occur at any time of the year. Widespread disease dissemination would increase the logistic effort required for effective infectious disease control and has the potential to increase the time required to achieve control.

6.2 Introduction

The movement behaviour of a population can have a profound impact on the transmission and maintenance of infectious disease (Ortiz-Pelaez et al., 2006). For horses, one key route for the spread of disease is through events, such as race meetings (Christley and French, 2003) and competitions. The initial widespread dissemination of equine influenza (EI) during the Australian outbreak, in 2007, can be attributed in part to the virus infecting horses an equestrian event in Maitland (Callinan, 2008; Cowled et al., 2009). In the 2007 outbreak of EI, one race meeting was implicated in the spread of disease before movement restrictions were in place (Cowled et al., 2009), and consequently after the disease was detected race meetings were cancelled to prevent transmission (Smyth et al., 2011).

Having accurate information about movement patterns is critical for the development of decision support tools, such as stochastic models, for use during an infectious disease outbreak. Decision support tools must be developed before a disease outbreak occurs, particularly in areas where disease is not endemic in the population (Garner et al., 2007; Ward et al., 2009), so that any disease control measures can be implemented quickly to limit further disease spread. The development of decision support tools allows for the development of targeted disease control strategies focussing on the high risk groups or individuals in the population; control strategies that can be initiated as soon as disease is detected (León et al., 2006).

Where decision support tools are developed to predict the behaviour of a disease outbreak in a naïve population, the accuracy of the model parameters are critically important (Garner et al., 2007). Within the New Zealand equine population, the racing industry is economically important (Anon, 2010c). Horses kept for racing are a group at an increased risk of spreading disease in an outbreak, due to the movement characteristics of this group. In a previous study, horses kept for racing and competition have been found to move more frequently compared to horses used for other purposes (USDA, 2006), with 36% of movements to races or competitions occurring at least once a month (Vanderman et al., 2009). In contrast to this study, a study in Australia investigated racing and competition movement characteristics separately. When it was mandatory to record the movement of horses to equestrian events, in New South Wales between 2007 and 2008, 17% of all horse movements recorded were attributed to the movement of racehorses to race meetings (Bell and Drury-Klein, 2011). The study by Bell and Drury-Klein (2011) identified that there are differences between the number of Standardbred and Thoroughbred trial races held.

There is no specific knowledge about the movement of horses to and from Thoroughbred and Standardbred race meetings in New Zealand. Given the importance of this information in the development of decision support tools to evaluate control strategies, it is essential that such information be collected. The aim of the current paper is to describe the movement characteristics of Thoroughbred and Standardbred racehorses attending premier, regional, trial or workout race meetings and describe the implications of movement characteristics on the potential spread and control of infectious disease.

6.3 Materials and methods

6.3.1 Sample selection and data collection

The complete racing and trainer data for the 2009 calendar year were extracted from electronic databases maintained by New Zealand Thoroughbred Racing (NZTR) and Harness Racing New Zealand (HRNZ). For each race, the following information was recorded: name of the horses entered in the race; trainer of the horses; location and type of race and race meeting and date of race. Three race meeting types were defined for Thoroughbreds and four types for Standardbreds, which reflected the type of race meeting the trainers attended. The first type of race meeting was a workout; a low grade unofficial race for Standardbred horses with no prize money offered. Workouts are often used by a trainer to quantify the progress of the training preparation. Trial races are a more formal version of a workout and are often used to evaluate race readiness. For Standardbreds, a qualifying trial must be run before entering an official race (Tanner et al., 2011), while this is not the case for Thoroughbreds (Bolwell et al., 2010). Regional race meetings, defined as regional, are moderate grade race meetings with average prize money on offer. Premier race meetings include one or more elite races ("Group or Listed status") and offer more prize money than other race meetings. Generally, only one premier race meeting is run per week and only one on any day when racing is scheduled. For one race meeting, multiple races were held. Therefore, for selected race meetings, all races held on that day and data regarding horses racing in any race on that day were recorded. The unit of interest was trainers attending each selected race meeting, as one trainer could have multiple horses at one race meeting, but it was assumed that these horses were transported together to the race meeting. For each trainer, the distance travelled to the race meeting was calculated using Google Maps (www.google.co.nz) as the unidirectional distance, in kilometres (km), from the trainer's stable address to the race track, taking the shortest possible route.

The sample was selected by stratifying the total number of Thoroughbred and Standardbred race meetings held in 2009 by the proportion of premier, regional, trial and workouts race meetings held in that year, which were then randomly selected using a random number generator function in Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA, USA).

6.3.2 Statistical analysis

For all statistical analyses, significant differences were assessed between the Thoroughbred and Standardbred racing codes and within each code by race type: premier, regional, trial or workout (for Standardbred race meetings).

Chi-square or Fisher's exact test was used to compare the number of Thoroughbred and Standardbred race meetings in 2009, both between Thoroughbred and Standard racing codes and within each code by race type, stratified by region and month of the race meeting.

As trainers who attended multiple race meetings could take the same horse or horses to more than one race meeting, the total number of horses starting in a race for each trainer were called starters. Using data obtained from The New Zealand Racing Board (Anon, 2010c), the total number of starters and trainers in the sample population were described as a percentage of the total number of starters and trainers attending race meetings in 2009, between Thoroughbred and Standardbred racing codes and within code by race type.

The number of trainers and starters attending the selected race meetings was described using percentiles, minimums and maximums and compared using the non-parametric Kruskal-Wallis test, between Thoroughbred and Standardbred racing codes and within code by race type.

The distance travelled by trainers was stratified by a distance category (≤20 km, 21 to 100 km, 101 to 200 km, 201 to 300 km, 301 to 400 km and >400 km) and presented for each racing code. Distance was selected to account for the possible movement within the local area, regional area and out of region movements to race meetings. These data were presented as counts and percentages of Thoroughbred and Standardbred trainers in the sample population. Associations between race type and distance travelled were determined using Chi-square test statistic, both between each racing code and within code by race type. The distance travelled by Thoroughbred and Standardbred trainers to race meetings was described as minimum, maximum and percentiles, and the difference between the median distance travelled and race type was determined using the non-parametric Kruskal-Wallis test, both between racing codes and within code by race type. Data were stored in Microsoft Excel 2007 (Microsoft Corporation, Redmond, WA, USA) and manipulated using Stata version 11.2 (Statacorp LP, College Station, Texas, USA).

6.4 Results

In 2009, there were 47 premier, 332 regional and 128 trial race meetings held for Thoroughbred racehorses, and 53 premier, 239 regional and 214 trial race meetings held for Standardbred racehorses (Table 6.1). The number of each type of race meeting varied significantly between Thoroughbred and Standardbred racing code (P<0.001). Between racing codes, there were no significant seasonal fluctuations in the number of race meetings held (P=0.83) although more premier race meetings were held in January than any other month, for both racing codes (Figure 6.1). There were no significant seasonal fluctuations by race type (P=0.18) (Figure 6.1). Racing was regionally distributed with 45% (228/507) of Thoroughbred race meetings held in the Northern region, while 64% (326/506) of Standardbred race meetings were held in the Southern region. Regional variation differed significantly by Thoroughbred and Standardbred racing codes (P<0.001). Within each code, the region where a race meeting was held varied significantly by race type (P<0.001) (Table 6.1).

In total, 42 Standardbred and 39 Thoroughbred race meetings were randomly selected from all race meetings held in 2009 (Table 6.1). Trainers with horses racing in the selected Thoroughbred race meetings represented 57% (679/1,199) of all registered

Thoroughbred trainers, while 42% (456/1,088) of all registered Standardbred trainers had horses racing in the selected race meetings. The starters in the selected Thoroughbred race meetings represented 38% (5,835/15,300) of all Thoroughbred starters in 2009, while 40% (3,174/7,938) of Standardbred starters were represented by the selected races (Table 6.2).

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

		Population			Sample			
Racing code	**Region**	**Premier**	**Regional**	**Trial**	**Premier**	**Regional**	**Trial**	**Workout**[a]
Thoroughbred	Northern	21	140	67	1	15	6	-
	Central	18	106	22	3	11	1	-
	Southern	8	86	39	0	4	1	-
Standardbred	Northern	22	61	57	1	8	2	0
	Central	0	25	15	0	0	0	0
	Southern	31	153	142	2	12	14	3

[a] An unofficial trial with no stakes money offered, Standardbreds only. As a workout is unofficial, no information is stored on the HRNZ calendar regarding these events

The median number of starters and trainers attending race meetings varied significantly between Thoroughbred and Standardbred racing codes (P<0.001). For Standardbred race meetings, the type of race meeting was significantly associated with the median number of trainers (P<0.001) and starters (P<0.001) attending. The median number of trainers attending a premier race meeting was 61 (IQR 53 to 95), compared to a median of 15 (IQR 8 to 23) for trial race meetings. For Thoroughbred race meetings, the number of trainers attending varied significantly by race type (P<0.03) (Table 6.2).

Overall, 64% of Standardbred trainers travelled less than 100 kilometres to attend premier race meetings compared to 44% of Thoroughbred trainers who travelled less than 100 kilometres to attend a premier race meeting. Twenty-two percent of Standardbred trainers travelled more than 400 km to attend premier race meetings compared to 12% of Thoroughbred trainers, and the difference in distance travelled to race meetings varied

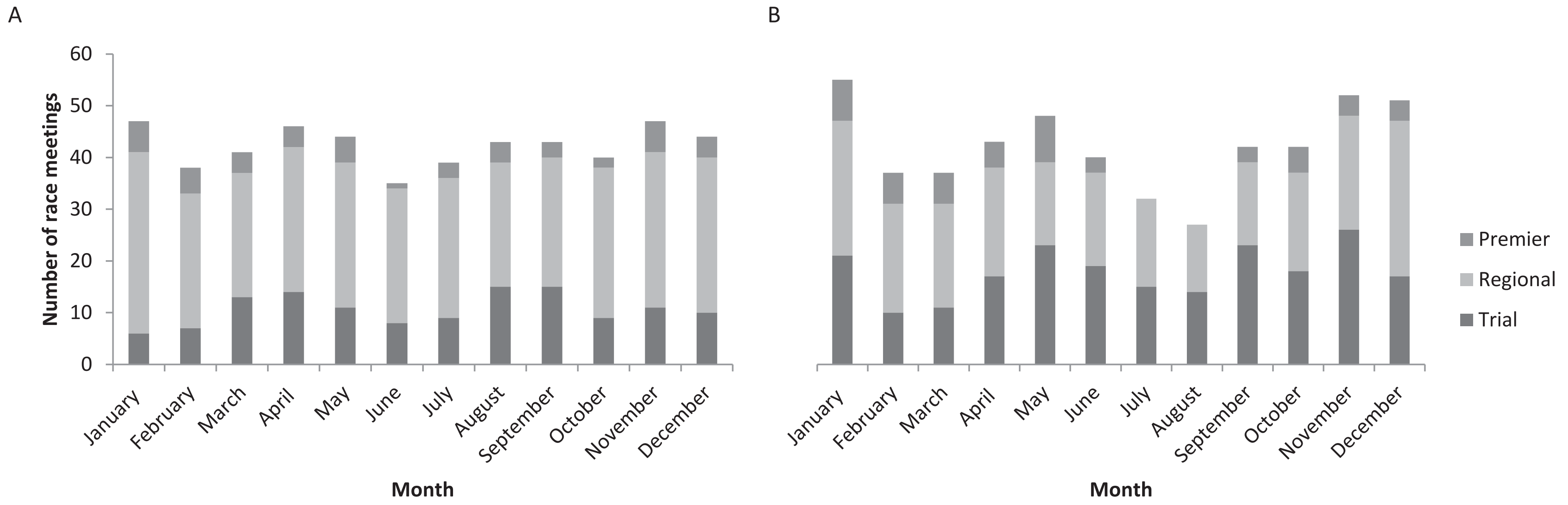

Figure 6.1: The number of Thoroughbred (A) and Standardbred (B) race meetings held in the 2009 calendar year, stratified by type of race meeting, premier, race or trial. Data were collected from Harness Racing New Zealand and New Zealand Thoroughbred Racing.

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.

		Trainers							Starters						
Racing code	**Race type**	**Number**	**Min**	**25th**	**Median**	**75th**	**Max**	**P value[a]**	**Number**	**Min**	**25th**	**Median**	**75th**	**Max**	**P value[a]**
Thoroughbred	**Premier**	239	4	68	75	83	91.5	0.03	643	4	135	147.5	163	174	0.52
	Regional	629	27	32	63	77	90		4,140	27	82	115	143	177	
	Trial	257	8	20	32	46.5	66.5		1,052	8	41	72.5	131	189	
Standardbred	**Premier**	143	53	53	61	95	95	0.001	384	106	106	112	166	166	0.001
	Regional	408	37	57.5	67	70.5	91		2,315	51	94.5	124.5	140	149	
	Trial	195	3	7.5	14.5	23	42		469	7	13.5	25.5	44	59	
	Workout[b]	6	1	1	1	4	4		6	1	1	1	4	4	

[a] Kruskal-Wallis analysis of variance

[b] An unofficial trial with no stakes money offered, Standardbreds only

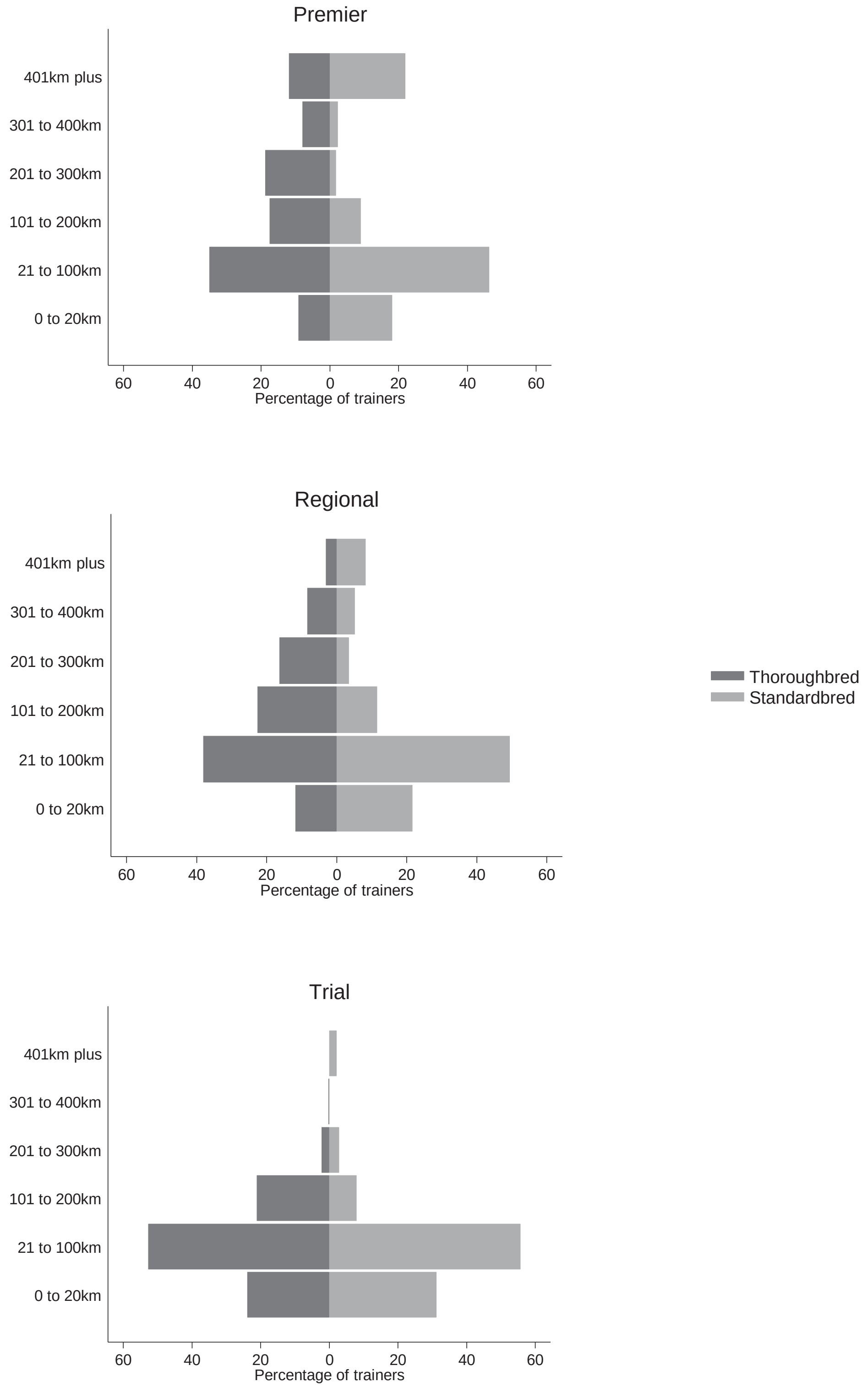

Figure 6.2: The distance travelled (km) by trainers to premier, regional and trial race meetings held in New Zealand in 2009, stratified by the racing code. Data were collected from randomly selected Thoroughbred (n=39) and Standardbred (n=42) race meetings

significantly between racing codes (P<0.001). Within each racing code, the distance travelled to race meetings varied by the type of race meeting, at a significance level of P<0.001 for both Thoroughbreds and Standardbreds (Figure 6.2). For Standardbred workouts, no trainer travelled further than 100 km to attend.

There were significant differences between Thoroughbred and Standardbred racing codes and the median distance travelled to race meetings (P<0.001). Overall, the median distance travelled by Standardbred trainers was 45 km (IQR 24 to 113 km) compared to Thoroughbred trainers with a median of 91 km (IQR 40 to 203 km) (Table 6.3). Within each racing code, there were significant differences between the median distance travelled by trainers to race meetings and the type of race meeting attended, for both Thoroughbred (P<0.001) and Standardbred (P<0.001) trainers (Table 6.3).

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.

Breed	Race type	Min	25th	Median	75th	Max	P value[a]
Thoroughbred	Premier	0	40	122	285	922	<0.001
	Regional	0	49	101	208	1,436	
	Trial	0	23.5	62	99	319	
Standardbred	Premier	2	30	65	273	1,639	<0.001
	Regional	0	26	45.5	129	1,659	
	Trial	0	14	38	67	973	
	Workout[b]	0	9	30	62	75	

[a] Kruskal-Wallis analysis of variance

[b] An unofficial trial with no stakes money offered, Standardbreds only

6.5 Discussion

The current study aimed to describe the movement patterns of racehorses travelling to Thoroughbred and Standardbred race meetings held in New Zealand. The current study identified that movement patterns around race meetings were not homogeneous and that significant differences in movement behaviour occurred both within and between each racing code. Specifically, more movements occurred to premier race meetings and trainers attending this type of race meeting would travel horses greater distances to race. When the two racing codes were compared, there were regional differences in the occurrence of race meetings, but throughout the year there were no significant differences between the months that race meeting were held and racing code.

Previous studies have identified the prominence of racehorses in the movement characteristics of the equine population (USDA, 2006; Vanderman et al., 2009). In a study of all horse movements to events, nearly one fifth of all recorded horse movements were the movement of horses to race meetings (Bell and Drury-Klein, 2011). Properties that kept horses for the racing industry were twice as likely to have a movement event, compared to properties that did not keep horses for racing (Rosanowski et al., 2012b [Chapter Four]). However, none of the previous studies focused solely on the movement of horses in the racing industry and the unique characteristics of this industry, so comparison with the current study is not possible. However, Bell and Drury-Klein (2011) did identify differences between the number of Thoroughbred and Standardbred trial races held, a finding that is comparable to the current study.

A random sampling method, stratified by racing code and race type, was used to select the sample race meetings included in the current study. Despite the methodology, few race meetings were selected in the Southern region for Thoroughbreds and in the Central region for Standardbreds. However, this lack of selection reflected a true difference in the number of races run for each code, in these regions. This under-representation of racing code in each region would not have affected the result that trainers travelled further to attend premier race meetings, as trainers would travel to these types of races regardless of region, due to the stakes offered. Additionally, as a significant difference was found between racing code and type of race meetings, under-representation of race meetings by region should not affect the results found in the current study.

The current study has described the movement patterns around race meetings, and therefore provides an insight into the movement behaviour of part of the racing industry. Movement events associated with racehorses that were not captured by the current study include movement of horses between different trainers, the movement of horses away from trainers due to interruptions in training regimens and the movement of horses into training from pre-trainers, stud farms or owners. Additionally, the current study did not take into account several factors inherent in training racehorses, particularly Thoroughbreds. Perkins et al. (2004) identified that half of Thoroughbred trainers had more than 50 horses in training between 1996 and 1999. In addition, trainers were found to congregate their training operations around race tracks or training venues and trainers would have more horses in training than just horses actively attending race meetings. More horses and the aggregation of horses leads to a greater potential for disease spread, both within a training stable and between trainers than has been accounted for in the current study. By failing to account for trainer factors, this study may have underestimated the true potential for disease spread within the racing industry, but has accounted for the movement of horses to race meetings.

One strength of this study is that Euclidean distance was not used. Instead, the trainer’s stable and each race track address were known, and the distance, by road, was calculated for each selected race the trainer attended. This method allowed for a more accurate representation of the distance travelled to attend race meetings, rather than Euclidean distance, which underestimates distance travelled through the calculation of the shortest distance between centroid points (León et al., 2006). However, trainers could have used commercial transport to take horses to race meetings, potentially combining transportation with other trainer's horses. This would lead to increased distances travelled by horses to attend race meetings, if the truck detoured to pick up horses from different trainers. Additionally, although the distance travelled from the trainer's stable to the race track may have been accurate, no account was taken of trainers leaving horses at the race track or with local trainers between closely spaced race meetings held at the same race track. Therefore, the movement of horses, particularly those travelling between two or three regions, could be an overestimate of some of the long distance travel reported in the current study. In a study of horses attending National Hunt races in the United Kingdom it was found that horses that had travelled further to attend the race meeting or were attending multiple race meetings run across several non-consecutive days were more likely to stay overnight at the racecourse (Pinchbeck et al., 2004). Such data were not readily available for racehorses in New Zealand.

While the current study does have limitations, two key findings have been identified that have direct implications on the potential for disease to spread within New Zealand's racing industry. The identification of heterogeneous movement patterns, for both Thoroughbred and Standardbred racehorses, and the differences in travel patterns between race types, are important findings in the context of infectious disease spread within the population. Christley and French (2003), in a study of small world networks of Thoroughbred trainers in the United Kingdom, found that heterogeneous contacts between trainers led to an outbreak of EI when compared to a homogenous contact network. The heterogeneity of movement patterns identified in the current study indicates that in the event of an outbreak, disease would be widespread. A more widespread outbreak would lead to increased difficulty, and cost, to control disease as tracing infected properties and applying control methods is more logistically difficult over larger geographical distances.

The second key finding is the lack of seasonal patterns associated with the number of race meetings held in year, so the potential for disease spread is uniform throughout the year. Regardless of the time of year, the racing industry always has the potential to propagate a widespread disease outbreak, particularly if multiple premier race meetings for both codes were held close to the detection of infectious disease. This is in contrast to the commercial breeding industry in New Zealand, which has a defined breeding season (Rogers et al., 2009; Van Rijssen et al., 2010).

The current study has investigated the movement of horses to race meetings, and as such, inferences can be made about the impact that that movement behaviour would have on disease spread by race meetings held in New Zealand, in the event of an outbreak. However, there are other important aspects of disease within the racehorse population, including contact patterns of horses at race meetings, the within yard spread of disease, and the effect of transport and the subsequent mixing of horses on individual horse immunity. Further work would be needed to describe these factors.

6.6 Conclusion

There were significant differences between the distances travelled by Thoroughbred and Standardbred trainers to different types of race meetings in 2009. These differences varied significantly by racing code, as well as by type of race meeting within racing code. Additionally, the median distance travelled to each race meeting varied by racing code and type of race meeting. These findings have important implications for the control of infectious disease during an outbreak.

Chapter Seven

An investigation of the movement patterns and biosecurity practices on Thoroughbred and Standardbred stud farms in New Zealand

S.M. Rosanowski, N. Cogger, C.W. Rogers

Chapter Seven is the final chapter describing the movement of horses involved in the racing industry. The focus of this chapter is on the breeding sector of the racing industry and the data are collected by face-to-face interview. This manuscript has been submitted to Preventive Veterinary Medicine

7.1 Abstract

Utilising a face-to-face interview of stud managers, a survey was conducted to investigate the movement patterns around, and biosecurity practices on, Thoroughbred and Standardbred stud farms. Eligible stud farms (n=60) were identified from the 2009 Thoroughbred stallion register and 2009 Standardbred stallion register, and stud managers were asked to participate in the interview. In total, 27 stud managers agreed to participate in the study, and participating stud farms included 38% of Thoroughbred and 60% of Standardbred mares mated in 2009. All stud managers reported the movement of horses to and from their stud farm. The median number of movement events per year was 127 (IQR 83 to 300). The frequency of movement events from a stud farm was not associated with the breed of horse managed on the stud farm, however Thoroughbred horses travelled further than Standardbred horses during these movement events ($P<0.001$). The movement patterns of horses around stud farms showed a strong seasonality associated with the commercial breeding season of each breed. While 26 (96%) of stud managers reported having procedures in place for checking newly arriving horses, only 6 (22%) stud managers reported isolating horses on arrival as a standard protocol. The main reason for isolating horses on properties, where isolation was not a standard procedure, was in response to strangles outbreaks on other stud farms (n=10). Only 2 (7%) stud managers reported implementing visitor protocols, and these protocols only applied to visiting veterinarians, but not to farriers. These findings have important implications for the control of both endemic and exotic infectious disease outbreaks within the New Zealand breeding population as the high frequency of movement around stud farms, the high number of visitors to stud farms and the lack of effective biosecurity practices or visitor protocols will be critical factors in the spread of equine influenza during an outbreak.

7.2 Introduction

The production of horses for the racing industry, for both flat and harness racing, is of economic importance to New Zealand. Annually, approximately $NZ224.5 million is generated from the export of racehorses mainly to Australia, and Asian racing nations (Anon, 2010c). The two largest studbooks in New Zealand are for Thoroughbred and Standardbred horses, with approximately 7,000 and 4,000 active broodmares respectively (Anon, 2010c). Both studbooks are closed, and only horses with records held in the respective studbook are eligible to race. The use of assisted reproductive technology is not allowed for Thoroughbreds, while artificial insemination (AI) is allowed in Standardbreds (Rogers et al., 2007; Rogers et al., 2009). Stallions, particularly Thoroughbred stallions, are imported into New Zealand from Northern Hemisphere countries to allow greater genetic diversity and to add international bloodlines into New Zealand racehorses. Typically shuttle stallions return to their country of origin allowing them to service mares in both hemispheres in one calendar year (Pickett and Voss, 1998; Pickett et al., 1998).

The international movement of horses has been recognised as a risk for the spread of infectious equine diseases (Sluyter, 2001). The introduction of equine influenza virus (EI) into the highly susceptible Australian equine population in 2007, was traced back to a quarantine centre housing shuttle stallions and mares imported from Japan, at the time Japan was experiencing an EI outbreak (Callinan, 2008; Gilkerson, 2008). The release of EI from quarantine resulted in a widespread outbreak that affected all sectors of the Australian equine population in the states of New South Wales and Queensland.

Within New Zealand, the movement of breeding mares has been identified as having the potential to facilitate the spread of infectious disease, with mares from different origins arriving at stud farms for mating (Rogers and Cogger, 2010). The movement of mares to stud for breeding follows a seasonal pattern because the goal of commercial breeding is to produce horses born close to the official Southern Hemisphere birth date of the 1st of August, in readiness for the yearling sales in January or February the following year (Van Rijssen et al., 2010). The commercial breeding season for Thoroughbreds and Standardbreds differs slightly, with Thoroughbreds producing foals between September and December (Rogers et al., 2007; Van Rijssen et al., 2010) and Standardbreds between October and February (Dicken et al., 2011). Knowledge of movement characteristics, particularly for the commercial breeding sector of the equine industry, is important in the development of decision support tools to evaluate control options and in determining policy responses should New Zealand experience an EI outbreak. To date, no previous studies have characterised the movement patterns associated with stud farms.

Planning for an infectious disease outbreak would also be enhanced by understanding biosecurity practices on farms because these measures can be an effective barrier to prevent transmission of infectious disease when horses are moved onto equine properties (Firestone et al., 2011a; Gildea et al., 2011a). A survey by Rogers and Cogger (2010) reported that stud managers were aware of the need for biosecurity, but only a small number of operations implemented biosecurity practices that would prevent the spread of an infectious disease such as EI or strangles. The study by Rogers and Cogger (2010) was conducted prior to the outbreak of EI in Australia and it is possible that biosecurity practices have now changed. Furthermore, the study provided no information about practices at Standardbred stud farms in New Zealand. This paper describes the movement characteristics and biosecurity practices of Thoroughbred and Standardbred stud farms in New Zealand two years after the EI outbreak in Australia.

7.3 Methods

7.3.1 Sample selection

Eligible stud farms (n=60) were identified from the 2009 Thoroughbred stallion register and 2009 Standardbred stallion register, as both registers contained the full contact details of the stud managers. Stud farms were considered to be eligible for selection based on whether they were located in the Canterbury, Central Districts, Southland, Waikato or Auckland regions, as these are the main regions where stud farms are located. Stud managers were contacted by telephone and invited to participate in a face-to-face interview. If the stud manager was unable to be contacted after three attempts, or could be contacted but were unable to participate, they were omitted from sampling.

7.3.2 Data collection

A face-to-face survey of Thoroughbred and Standardbred stud managers was conducted to collect data about horse movement and the biosecurity practices used on those farms. The survey was conducted in November 2009 and comprised twenty-three open and closed questions divided into three sections: i) characteristics of the property; ii) movements of horses and people to and from the property; and iii) biosecurity practices. A copy of the survey is found in Appendix B.

As the movement data would be used to inform an InterSpread Plus disease model, the key movement variable of interest was movements of horses from the stud farm (off movements). However, information regarding movements of horses and people to the stud farm were also collected. Stud managers were asked to describe the number, month and reason for horses arriving on the stud farm and the proportion of horses arriving from each point of origin; Auckland, Waikato, Central Districts, Canterbury, Southland and other locations. For off movements, stud managers were asked to describe the average number of horse movements from the stud farm on a weekly basis, for each month of the year and to describe the distance travelled during these movement events. Horse movements were defined as the arrival or departure of transport vehicles (floats or trucks), rather than the movement of individual horses. The arrival of people to the stud farm was described by type of visitor, frequency of visits and month of arrival.

For each breeding operation the number of stallions standing, the number of mares serviced and the number of live foals born in the 2009 breeding season was collected from the New Zealand Thoroughbred Racing (NZTR) and Harness Racing New Zealand (HRNZ) studbook databases.

7.3.3 Statistical analysis

The breeding horse population was classified as stallions, number of mares mated and number of foals born in the 2009 breeding season, stratified by breed and region. The proportion of horses under the care of stud masters in the current survey was presented.

The proportion of properties with shuttle stallions or those that acted as broodmare bases was determined and results were stratified by breed and region. A broodmare base is a stud farm that does not stand a stallion. Significance was assessed using Fisher's exact test.

The number of stallions on each farm was summarised using minimum, maximum and percentiles. Similarly, the number of mares on the farm at the time of the interview and the number of mares served in the 2009 season were summarised using minimum, maximum and percentiles. Results were presented stratified by breed and region and significance was assessed using the non-parametric Kruskal-Wallis test.

For each month, the proportion of stud farms that had dry mares, wet mares, walk-in mares, walk-out mares, mares for foaling down service, yearlings and stallions arriving onto the stud farm were determined and the results presented as a line graph, stratified by breed. Dry mares did not have a foal in the 2009 breeding season, wet mares had produced a foal in the 2009 breeding season and walk-in mares were either wet or dry mares being sent from a property of origin to the stud to be served by the stallion (or by AI) for a very short term basis, generally the same day. Walk-out mares leave the stud for service at another stud farm and return to the stud farm of origin on the same day. Mares for foaling down service included mares arriving for additional breeding associated services including scanning, weaning or foaling of horses not mated or resident on the stud. Significance between breed and the type of horses arriving onto the stud farm and between breed and the month of the movement event was determined using the Chi-squared or Fisher's exact test, as appropriate.

The relationship between the annual number of movements and the explanatory variables of breed, region, presence of shuttle stallions, broodmare base, number of stallions, number of mares and month that the movement event occurred was assessed. . The number of stallions was treated as a categorical variable with four levels; 0, 1-3, 4-9,>9, based on the quartiles of number of stallions. Similarly, the number of mares was treated as a categorical variable with three levels; ≤75, 76-200 and >200, based on the tertiles of number of mares. Significance of the relationship between number of movements and each of the explanatory variables was assessed using the non-parametric Kruskal-Wallis test.

The distance travelled, in kilometres (km), during each movement event was treated as a categorical variable with four levels; ≤50, 51-150, >150 and Interisland. The categories of greater than 150 km and Interisland were mutually exclusive, and greater than 150 km was defined as the movement of horses further than 150 km, but that did not go between the North and South Island, whereas Interisland travel was any distance, but horses were transported between the two islands. The number and proportion of movements in each distance category was determined. The relationship between the number of movements in each distance category and the explanatory variables breed region, broodmare base, the presence of shuttle stallions, month of the movement event and the two categorical variables; number of stallions and number of mares, were explored. Significance of these relationships was assessed using the Chi-squared or Fisher's exact test, as appropriate.

The relationship between the number of days a week veterinarians and farriers visited stud farms was determined, stratified by breed. Visits per week by veterinarians were described both in the breeding season and outside the breeding season. The commercial breeding season was defined as occurring between August and January for Thoroughbreds and between August and February for Standardbreds. These seasons were longer than those previously described from both breeds, as the current study was investigating the increased activity around stud farms relating to breeding, rather than investigating months when foals were born (Rogers et al., 2007; Van Rijssen et al., 2010; Dicken et al., 2011). The number of visits per week was summarised using minimum, maximum and percentiles and significance of breed differences assessed using non-parametric Kruskal-Wallis test.

Biosecurity practices were investigated. The number and percentage of properties that undertook a particular practice was determined and stratified by the explanatory variables of breed, region, categorical variables of number of mares and stallions, presence of shuttle stallions, broodmare bases and number of movement events per year (≤130 or >130). Significance was assessed using the Chi-squared or Fisher's exact test, as appropriate.

Data were imputed and stored in a Microsoft Excel 2007 spreadsheet (Microsoft Corporation, Redmond, WA, USA). All statistical analyses were performed using Stata version 11.2 (Statacorp LP, College Station, Texas, USA).

7.4 Results

7.4.1 Sample population

Twenty-seven stud managers participated in the study: 18 from properties breeding Thoroughbreds and nine from properties breeding Standardbreds. Table 7.1 describes the number of stallions, mated mares and foals under the care of the 27 surveyed stud managers.

The proportion of properties that stood a shuttle stallion was 30% (8/27), while 22% (6/27) of properties acted as broodmare bases. The proportion of stud farms with shuttle stallions did not vary significantly by breed, nor did the proportion of stud farms acting as broodmare bases.

The location of properties varied significantly by breed (P<0.001), with 56% (10/18) Thoroughbred stud farms located in the Waikato region, while 67% (6/9) Standardbred stud farms were located in the Canterbury region. The location of broodmare bases varied between regions, with three bases located in Waikato and South Island (P<0.01), while the presence of shuttle stallions did not vary significantly between regions (P<0.23). The median number of mares (P<0.68) and stallions (P<0.38) did not vary significantly between the regions.

Summary information for the number of stallions, mares on the property at the time of interview and the number of mares mated per property is shown in Table 7.2.

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.

		Thoroughbred (n=18)		Standardbred (n=9)	
		Population	Sample	Population	Sample
Horse type	**Location**	**n**	**n (%)**	**n**	**n (%)**
Mares	North Island	5,941	2,662 (44.8)	891	450 (50.5)
	South Island	1,246	150 (12.0)	2,706	1756 (64.9)
	Total[a]	7,350	2,812 (38.3)	3,700	2206 (59.6)
Stallions	North Island	135	41 (30.4)	15	11 (73.3)
	South Island	36	2 (5.6)	56	19 (33.9)
	Total[b]	171	43 (25.1)	97	30 (30.9)
Foals	North Island	3,718	1,547 (41.6)	666	240 (36.0)
	South Island	572	100 (17.5)	1,905	781 (41.0)
	Total[c]	4,409	1,647 (37.4)	2,640	1021 (38.7)

[a] Total number of mares includes overseas mares

[b] Total number of Standardbred stallions includes those overseas whose semen was available in New Zealand in 2009

[c] Total number of foals includes foals born overseas

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.

			Percentiles				
Horse type	**Breed**	**Min**	**25th**	**Median**	**75th**	**Max**	**P value**[a]
Stallions	Thoroughbred	0	1	2	4	6	0.86
	Standardbred	0	0	2	7	9	
Mares[b]	Thoroughbred	8	85	130	177	500	0.34
	Standardbred	30	51	200	250	650	
Mares served[c]	Thoroughbred	2	68	127	309	561	0.94
	Standardbred	26	46	396	578	912	

[a] Kruskal-Wallis analysis of variance

[b] Mares on the property at time of interview

[c] Number of mares served by the stallions present on the stud farms in the 2009 breeding season

7.4.2 Movement behaviour

The arrival of horses onto the property for breeding

As part of the breeding operation, dry mares arrived on 89% (n=24) of stud farms, mares with foals at foot (wet mares) on 93% (n=25) of stud farms, walk-in mares on 52% (n=14) of stud farms, shuttle stallions on 30% (n=8) of stud farms and yearlings arrived to be prepared for the January yearling sales on 30% (n=8) of stud farms. Thoroughbred wet mares arrived onto stud farms earlier in the year than Standardbred wet mares ($P<0.03$) (Figure 7.1), but there were no significant differences between breeds and months when dry mares ($P<0.15$), walk-in mares ($P<0.51$), stallions ($P<0.68$) or yearlings ($P<0.8$) arrived onto stud farms.

Eight studs (30%) offered foaling down service. Significantly more Standardbred 67% (n=6) than Thoroughbred 11% (n=2) operations offered foaling down services ($P<0.004$), although there were no significant differences between breed and months when foaling down mares arrived onto stud farms ($P<0.78$).

The departure of horses from the stud

All stud managers reported movement of horses from their stud farm. The total number of movements did not vary significantly by breed ($P<0.24$), with a median of 127 (IQR 83 to 300) movement events per year. Table 7.3 summarises the number of movements on to a stud farm in the 2009 breeding season. When Thoroughbred and Standardbred stud farms were analysed together, the number of movement events was significantly higher on those stud farms with shuttle stallions (median=305) than those without (median=114) ($P<0.01$). There were significant differences in the frequency of movement events from a stud farm and the number of stallions ($P<0.05$), number of mares

(P<0.001) on the stud farm. The month of the movement event was significantly associated with the frequency of movement events (P<0.001).

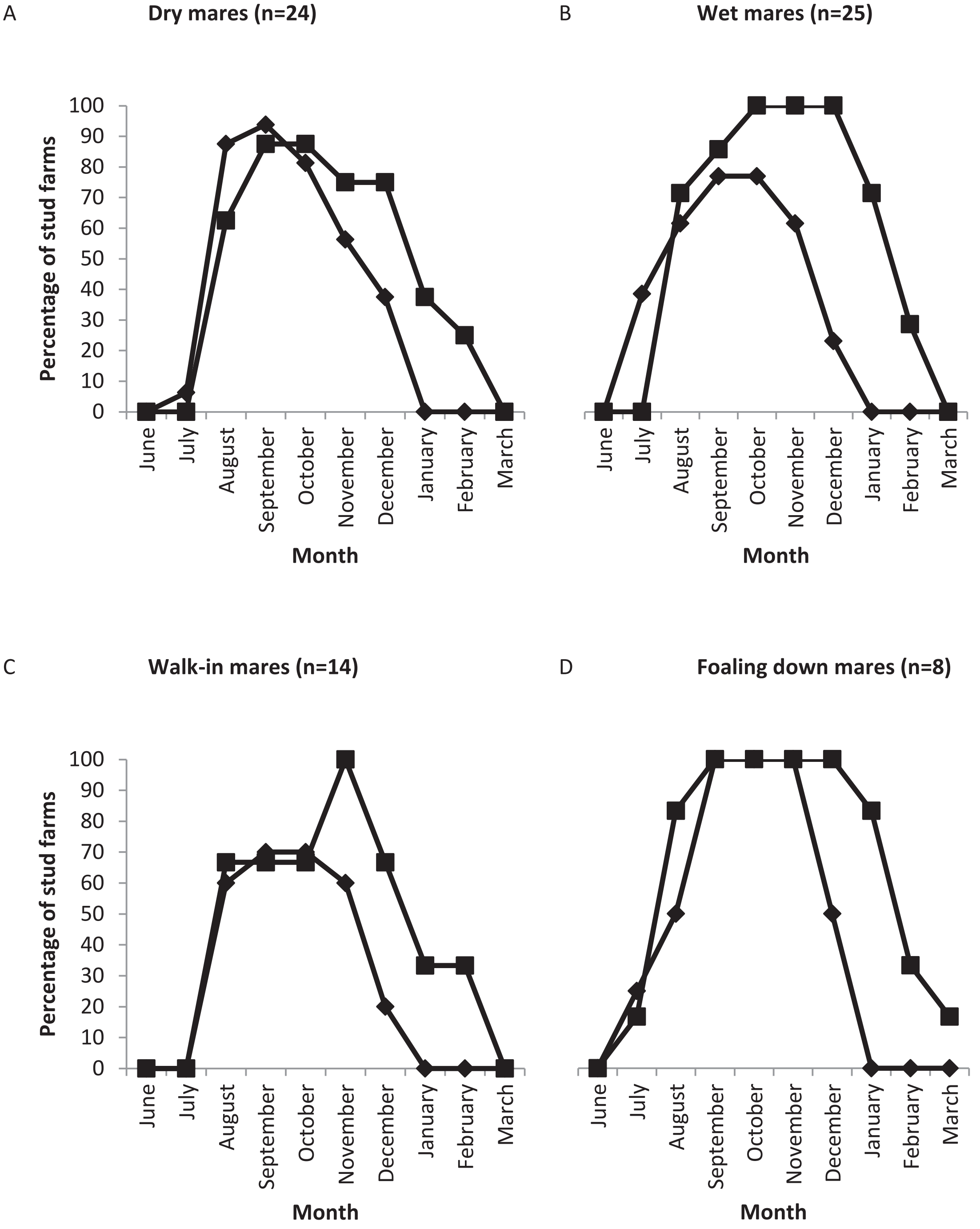

Figure 7.1: Percentage of Thoroughbred (■) or Standardbred (◆) stud farms with mare arrivals, by month of arrival. Data collected during a face-to-face survey of Thoroughbred and Standardbred stud managers in November 2009.

Overall, 63% (3,441/5,449) of the total number of movement events, when Thoroughbred and Standardbred movements were combined, were less than 50 km, while 4% (242/5,449) were Interisland movement events. The distances travelled during movement events are shown in Table 7.4. Horses leaving Thoroughbred stud farms travelled significantly further than horses leaving Standardbred stud farms (P<0.001).

The movement of horse health professionals

Two types of horse health professionals were identified by the respondents as entering commercial breeding operations: veterinarians and farriers. Two stud managers did not respond to questions regarding horse health professionals. On one stud farm, the stud manager was a registered veterinarian who did all the veterinary work in the breeding season. On another stud farm, the stud manager was a registered veterinarian who did all the veterinary work for the stud farm outside of the breeding season but used the services of another veterinarian during the breeding season. One stud manager conducted the hoof care on stud farm horses and, therefore, did not use a farrier. Another stud manager also reported never using a farrier for the horses on the stud farm. All other managers reported using farriers (92%, n=23).

The median number of visits per week by a veterinarian in the breeding season was 7 (IQR 3.5 to 7), compared to the median number of visits outside of the breeding season with a weekly median of 1 (IQR 0.25 to 2) (P<0.001). Outside of the breeding season, four stud managers reported the veterinarian coming to the stud farm occasionally or for emergencies. The median number of visits farriers made to stud farms in a week was 1 (IQR 0.375 to 2). There were no significant difference between breed and the number of visits by veterinarians in the breeding season (P<0.99), by veterinarians outside the breeding season (P<0.76) and by farriers (P<0.46).

7.4.3 Biosecurity practices

Overall, 96% (n=26) of studs had a biosecurity procedure in place for arriving mares. The biosecurity practices in place on Thoroughbred and Standardbred stud farms are described in Table 7.5. The proportion of stud farms with any procedures in place for arriving mares did not vary significantly between breed (P<0.67), region (P<0.37), number of mares (P<0.99), number of stallions (P<0.99), with the presence of stallions (P<0.70) or if a property acting broodmare base (P<0.77). The total number of movement events from a property did not affect the implementation of biosecurity practices for arriving mares (P<0.70).

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

		Total number			Percentiles				
Variable	**Category**	**Properties**	**Movements**	**Min**	**25th**	**50th**	**75th**	**Max**	**P value[a]**
Breed	Thoroughbred	18	1552	14	61	93	258	497	0.24
	Standardbred	9	3897	70	87	152	310	538	
Shuttle stallion[b]	No	19	2956	14	72	114	211	497	0.01
	Yes	8	2493	93	190	305	437	538	
Broodmare base[c]	No	21	4600	50	87	127	310	538	0.23
	Yes	6	849	14	70	140	211	274	
Number of stallions	None	6	849	14	70	140	211	274	0.05
	1 to 2	11	1484	50	77	114	177	376	
	3 to 6	7	2061	83	93	310	497	538	
	7 to 9	3	1055	258	258	300	497	497	
Number of mares	≤75	7	753	14	61	72	83	376	<0.001
	76 to 200	12	1705	50	90	120	194	310	
	201 plus	8	2991	208	266	360	497	538	

Region	Auckland	4	524	93	93	121	310	310	0.59
	Central	5	709	87	114	119	177	214	
	Christchurch	7	1336	14	55	78	279	497	
	Southland	1	208	208	208	208	208	208	
	Waikato	10	2673	70	83	243	420	538	
Month	January	25	603	0	6	22	29	82	<0.001
	February	22	350	0	1	9	13	90	
	March	22	276	0	1	4	13	45	
	April	22	261	0	1	4	11	42	
	May	22	240	0	1	4	11	43	
	June	19	197	0	0	4	10	40	
	July	20	141	0	0	3	9	29	
	August	21	359	0	0	3	16	70	
	September	23	501	0	2	9	30	70	
	October	24	719	0	7	16	43	99	
	November	27	924	4	13	28	42	132	
	December	27	879	2	13	28	42	99	

[a] Kruskal-Wallis analysis of variance

[b] Stallions imported into New Zealand to stand for the 2009 breeding season and then returned to the northern hemisphere.

[c] Stud farms that did not stand a stallion in 2009 or acted as a base for broodmares to be served by artificial insemination (Standardbreds only) or as a base for broodmares to travel to the stallion (Thoroughbreds only).

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

		Distance travelled				
Variable	**Category**	**≤50 km**	**51-150 km**	**>151 km**[a]	**Interisland**	**P value**[b]
Breed	Thoroughbred	2,288 (42.0)	793 (14.6)	613 (11.2)	201 (3.7)	<0.001
	Standardbred	1,153 (21.2)	190 (3.5)	168 (3.1)	42 (0.8)	
Shuttle stallion[c]	No	1,723 (31.6)	558 (10.2)	507 (9.3)	166 (3.1)	<0.001
	Yes	1,718 (31.5)	425 (7.8)	274 (5.0)	76 (1.4)	
Broodmare base[d]	No	2,842 (52.2)	777 (14.3)	748 (13.7)	234 (4.3)	<0.001
	Yes	600 (11)	206 (3.8)	33 (0.6)	9 (0.2)	
Number of stallions	None	600 (11.0)	206 (3.8)	33 (0.6)	9 (0.2)	<0.001
	1 to 2	854 (15.7)	284 (5.2)	247 (4.5)	99 (1.8)	
	3 to 6	1,217 (22.3)	377 (6.9)	374 (6.9)	94 (1.7)	
	7 to 9	771 (14.2)	116 (2.1)	127 (2.3)	41 (0.7)	
Number of mares	≤ 75	622 (11.4)	80 (1.5)	36 (0.7)	10 (0.2)	<0.001
	76 to 200	771 (14.2)	480 (8.8)	340 (6.2)	116 (2.1)	
	>201	2,048 (37.6)	423 (7.8)	404 (7.4)	116 (2.1)	
Region	Auckland	365 (6.7)	283 (5.2)	116 (2.1)	18 (0.3)	<0.001
	Central	290 (5.3)	167 (3.1)	196 (3.6)	56 (1)	
	Canterbury	798 (14.7)	67 (1.2)	137 (2.5)	75 (1.4)	
	Southland	185 (3.4)	23 (0.4)	0 (0)	0 (0)	
	Waikato	1,803 (33.1)	442.9 (8.1)	332 (6.1)	93 (1.7)	

Month	January	354 (6.5)	111 (2)	95 (1.7)	45 (0.8)	<0.001
	February	243 (4.5)	58 (1.1)	40 (0.7)	10 (0.2)	
	March	195 (3.6)	46 (0.8)	28 (0.5)	6 (0.1)	
	April	206 (3.8)	29 (0.5)	20 (0.4)	5 (0.1)	
	May	198 (3.6)	16 (0.3)	19 (0.4)	6 (0.1)	
	June	159 (2.9)	10 (0.2)	23 (0.4)	4 (0.1)	
	July	108 (2)	10 (0.2)	20 (0.4)	3 (0)	
	August	211 (3.9)	92 (1.7)	46 (0.8)	11 (0.2)	
	September	308 (5.6)	108 (2)	71 (1.3)	14 (0.3)	
	October	423 (7.8)	140 (2.6)	124 (2.3)	32 (0.6)	
	November	529 (9.7)	194 (3.6)	149 (2.7)	53 (1)	
	December	509 (9.3)	170 (3.1)	146 (2.7)	55 (1)	

[a] All movements of horses greater than 150 km, but that did not go between the North and South Island of New Zealand

[b] Chi-square test statistic

[c] Stallions imported into New Zealand to stand for the 2009 breeding season and returned to the northern hemisphere.

[d] Stud farms that did not stand a stallion in 2009 or acted as a base for broodmares to be served by artificial insemination (Standardbreds only) or as a base for broodmares to travel to the stallion (Thoroughbreds only).

When stud managers were asked if they had ever isolated a mare, 85% (n=23) had isolated newly arriving mares. Reasons for isolation included strangles outbreaks on other properties (n=10), the mare looked unwell (n=7), because isolation was a standard procedure on the stud farm (n=6), the mare came from Australia (n=5) or the mare was of unknown origin (n=2). Other reasons for isolating a mare, only reported by single stud managers, were that the mare was a racehorse or from the North Island (n=1), the mare was in light condition (n=1), the mare was within three weeks of giving birth (n=1), or was a walk-in mare (n=1). On three properties reasons for isolation were not stated. Multiple criteria for isolation were used on eight properties (35%) with isolation procedures. On stud farms where mares were isolated on arrival, 70% received a physical examination while in isolation (Table 7.5). When asked for the reasons for not isolating mares on a regular basis, stud managers stated the reasons were: limited space to isolate mares from other horses on the stud farm (n=7), the disease free status of New Zealand (n=8), limited time (n=4), isolating was not important (n=2) or unnecessary (n=3) or impractical (n=2). Two stud mangers were not concerned if sick new arrivals infected resident horses and two stud managers did not isolate newly arriving horses as they knew the origin of new arrivals. Nine Thoroughbred and one Standardbred stud manager did not answer this question.

In the week prior to survey, six stud managers (22%) had isolated a newly arriving mare, although not all stud farms received new mares in the week prior to survey. Of these six stud managers, two isolated mares on arrival as standard practice, while two stud managers isolated mares as at the time of survey there was a strangles outbreak on another stud farm where walk-in mares had been sent. In the week prior to survey, the length of isolation ranged from 36 hours to 14 days. All of the stud managers that had isolated mares in the week prior to survey had more than 130 movement events per year. The total number of movement events from six stud farms where mares were isolated in the week prior to survey was significantly different from the 22 stud farms that did not isolate mares during this time ($P<0.03$).

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.

Category	**Variable**	**Thoroughbred n (%)**	**Standardbred n (%)**
Biosecurity practice for arriving mares[ab]			
	Physical examination	10 (55.6)	5 (55.6)
	Check vaccination status	12 (66.7)	3 (33.3)
	Vaccinate on arrival	1 (5.6)	4 (44.4)
	Check drenching history	16 (88.9)	6 (66.7)
	History of recent illness	11 (61.1)	3 (33.3)
	Observe for coughing	12 (66.7)	6 (66.7)
	Observe for nasal discharge	15 (83.3)	7 (77.8)
	Check and trim feet	15 (83.3)	9 (100)
	Observe body weight	6 (33.3)	3 (33.3)
	Body condition score	12 (66.7)	4 (44.4)
	Take a photograph	11 (61.1)	4 (44.4)
Procedures for isolated mares[bc]			
	Physical examination	10 (71.4)	6 (75.0)
	Drench	12 (85.7)	5 (62.5)
	Separated isolation[d]	14 (100)	6 (75.0)
	Rotate isolation yards/paddocks	14 (100)	4 (50.0)
	Use disinfectant in isolation yards/paddocks	6 (42.9)	6 (75.0)
	Prevent contact with resident mares	14 (100)	5 (62.5)
	Prevent contact with other walk-in mares	13 (92.9)	5 (62.5)
	Clean or change clothes and shoes	8 (57.1)	2 (25.0)
	Clean head collars or separate gear	13 (92.9)	3 (37.5)

[a] One Thoroughbred stud farm did not have any practices in place for arriving mares
[b] More than one action could be taken per stud
[c] Five stud managers reported never isolating mares, Thoroughbred (n=4) and Standardbred (n=1)
[d] Each mare was isolated from all other isolated horses

When there was no disease outbreaks on farm, four stud farms (15%) had policies for hand washing, cleaning or changing of clothes, cleaning or changing of shoes or cleaning of equipment between different groups of horses on the stud farm (Table 7.6). When disease was present on stud farms, there were no policies in place to prevent disease spread between groups on two stud farms (7%).

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.

Disease status	Policy	Thoroughbred n (%)	Standardbred n (%)
Absent	Hand washing	1 (5.9)	0 (0)
	Clean shoes	2 (11.8)	0 (0)
	Clean equipment	2 (11.8)	1 (11.1)
	Change shoes	1 (5.9)	0 (0)
	Change clothes	2 (11.8)	8 (88.9)
	Muck-out foaling paddock	17 (100)	5 (55.6)
	Clean crush	16 (94.1)	8 (88.9)
Present	Hand washing/ change clothes	16 (94.1)	8 (88.9)
	Isolate horses	16 (94.1)	9 (100)

Visitor protocols for veterinarians, farriers, owners and other visitors to the stud were absent on 93% (n=25) of stud farms. Two stud farms had protocols for the visiting veterinarians including hand washing, wearing gloves and cleaning equipment. Of the studs with no protocols, 56% (n=14) expected the stud farm veterinarian to follow protocols set by the veterinarian, rather than a protocol set by the stud farm. However, it was unclear whether the visiting veterinarians did have these protocols in place.

7.5 Discussion

The current study found the New Zealand breeding industry is completely vulnerable to infectious disease outbreaks, with limited biosecurity practices in place for arriving horses, high frequency of movements from stud farms, particularly in the breeding season, and a high number of visits from veterinarians and farriers. The frequency of movement events was associated with the number of horses on the stud farm, the presence of shuttle stallions and the month. The seasonality of movement patterns, combined with the lack of biosecurity on stud farms would enable disease to disseminate widely between stud farms. While Thoroughbred and Standardbred stud managers reported similar movement frequencies, the distance travelled by horses from Thoroughbred stud farms was further than that travelled by horses from Standardbred stud farms. Specifically, Thoroughbred horses travelled greater distances from stud farms than Standardbred horses, with more movements between the North and South Islands. Thoroughbreds must be bred using live service (Rogers et al., 2009), therefore the increased travel by Thoroughbreds from stud farms was not surprising. In contrast, the distance travelled by horses from Standardbred stud farms was shorter. As Standardbred mares are allowed to be mated using AI (Rogers et al., 2007; Rogers et al., 2009), mares do not have to travel to stud farms to receive AI. Instead, owners of Standardbred mares can choose whether they will send their horse to a stud farm for AI, and stud farms can also choose to offer to mate mares using semen from stallions not resident on the stud, factors that could contribute to the shorter distances travelled by Standardbred mares from stud farms. The differences in movement distances suggest that if an infectious disease was to enter the Thoroughbred breeding population, disease would be more widely disseminated than if it had entered the Standardbred breeding population.

Month was associated with the frequency of movement events, this finding in the current study highlights the seasonality of breeding horses for the racing industry. In New Zealand the official birth date for horses is the 1st of August (Anon, 2011b). Commercial drivers to produce foals close to this date have led to a defined breeding season, for both Standardbreds and Thoroughbreds. In previous studies, this seasonality was defined by the months when foals were born (Rogers et al., 2007; Van Rijssen et al., 2010; Dicken et al., 2011). Compared to the previous studies where the breeding season was much shorter, the current study identified there was increased activity around stud farms associated with the production of both Thoroughbred and Standardbred racehorses, with the arrival of mares for mating starting as early as June. This activity continued until January for

Thoroughbreds and February for Standardbreds, to coincide with yearling sales. If a disease outbreak was to occur in the breeding season, it would be difficult to control disease without disrupting the breeding season, and this would particularly affect Thoroughbred stud farms, due to the strict use of live service.

The finding that more movement events occurred on properties with shuttle stallions is not surprising. Shuttle stallions must be economically viable, due to the lease fees and added costs associated with importing stallions to stand at stud during the Southern Hemisphere breeding season. Therefore, to be commercially viable, a shuttle stallion would need to serve a full book of mares. In New Zealand, the average number of mares served by a New Zealand resident stallion is 43, so shuttle stallions would need to serve more mares than this, meaning more mare movement to stud farms with shuttle stallions (Rogers et al., 2009).

While a convenience sample was used, it is noteworthy that the current study achieved broad coverage of both the Standardbred and Thoroughbred stud farms, with 38% of Thoroughbred mares and 60% of Standardbred mares mated in 2009 included in the current study. However, a limitation of this study is the methodology used for the collection of retrospective movement patterns during a face-to-face interview. This could introduce information bias that could have biased estimates of movements and distances. However, this method was considered the most feasible to collect data in a small, but spatially diverse breeding industry. A more robust way to collect movement data would have been to use a diary method, as described by Sanson (2005). However this method was not suitable for the collection of movement patterns in the current study because stud managers had expressed an unwillingness to complete the diary given the high volume of horse movements from stud farms.

A further weakness of this study was asking stud managers to average the weekly number of movement events of horses from stud farms. The simplicity associated with averaging the weekly number of movement events was necessary to limit the time spent during the interview and consequently ensure stud managers would agree to participate. Some loss of detail occurred using this method, particularly regarding the number of horses involved in each movement event and when in the week movement events were occurring. However, this method did demonstrate the well-defined patterns of horse movement associated with stud farms. The data collected in the current study were collected for use in an InterSpread Plus model of disease spread and no other movement data were available. Thus, the purpose of collecting data were to generate a reasonable estimate for simulation modelling rather than a detailed description of all aspects of horse movement patterns around stud farms. The objective of developing an InterSpread Plus model using the data described in the current study necessitated the collection of more detailed information regarding the movement of horses from properties, compared to the movement of horses onto stud farms.

In the current study, 22% of stud managers reported isolating mares in the week prior to survey. Overall, 85% of stud managers reported ever isolating a mare and of these, only 22% isolated mares as a standard operating procedure. The isolation of a mare was not associated with whether the stud farm kept Thoroughbreds or Standardbreds. The results of the current study are comparable to a survey of Thoroughbred stud managers in New Zealand, conducted prior to Australia’s EI outbreak, where 89% of stud managers had isolated mares at some time previously, while only 15% had isolated mares in the week prior to survey (Rogers and Cogger, 2010).

This study supports earlier work in the Thoroughbred industry that it is uncommon for properties to have protocols in place for veterinarians and farriers to prevent the indirect transmission of disease between farms. This is of concern because the current study identified that during the breeding season veterinarians were visiting stud farms on a daily basis, and only two stud managers had visitor protocols for veterinarians. Additionally, more than half of stud managers expected the visiting veterinarian to have a protocol to protect stud horses, but could not say what those protocols would be. No stud managers reported any visitor protocols in place for farriers, who visited stud farms at least once a week. Both veterinarians and farriers interact closely with horses and would visit multiple properties in a day; therefore they are the greatest concern for indirect transmission during an infectious disease outbreak.

No data are available regarding the prevalence of endemic disease, particularly strangles, in the New Zealand breeding population. However, anecdotal evidence collected during this study found that outbreaks of strangles were relatively common during the 2009 breeding season. One third of interviewed stud managers reported isolating horses due to strangles outbreaks on other stud farms. Thus, the implementation of biosecurity practices on stud farms was reactive to known outbreaks in the breeding population, rather than having biosecurity in place as a standard operating procedure. If the current biosecurity practices and protocols in place on stud farms have limited effectiveness against endemic disease, these protocols are unlikely to be effective against an exotic disease like EI, which will spread more rapidly through the population, with little warning to react with an effective biosecurity strategy.

7.6 Conclusion

The current study identified significant movement heterogeneity associated with Thoroughbred and Standardbred stud farms. The frequency of movement events from stud farms was associated with the number of horses on the property and the breeding season, rather than whether the stud farm bred Thoroughbred or Standardbred horses. However, during movement events, horses from Thoroughbred stud farms moved further than those from Standardbred stud farms. Therefore, the spread of disease would be far greater in the Thoroughbred breeding population due to the greater distances travelled during movement events.

The biosecurity practices and visitor protocols identified in the current study were uniformly poor, and in the event of an exotic disease outbreak, would be unlikely to be effective at preventing disease transmission. The ineffectiveness of biosecurity practices and visitor protocols was compounded by the high frequency of both horse and people movement around stud farms.

These findings have important implications for the control of infectious disease within the New Zealand breeding population and highlights the need for prospective data collection regarding horse movement behaviour, particularly for stud farms as the frequency of movement around stud farms will be a critical factor in the spread of EI during an outbreak

Chapter Eight

Evaluating the effectiveness of strategies for the control of equine influenza virus in the New Zealand equine population

In Chapter Eight the findings of Chapters Three to Seven are used as the parameters of the InterSpread Plus disease model to evaluate the effectiveness of control strategies for equine influenza. This chapter has been prepared for submission to Preventive Veterinary Medicine.

8.1 Abstract

The New Zealand equine population has never experienced an equine influenza (EI) outbreak, and consequently is naïve to the EI virus. The 2007 EI outbreak in Australia showed that in a naïve population EI could spread rapidly and substantial control efforts will be needed to achieve control. Due to the speed at which EI would spread, strategies for control and eradication will need to be implemented rapidly. For this to be achieved, decisions regarding control strategies should be in place prior to an EI outbreak. A spatially explicit stochastic simulation model, InterSpread Plus, was used to evaluate EI control strategies for the New Zealand situation. The control strategies considered were movement restriction on the day EI was detected and movement restriction in combination with three vaccination strategies beginning on day 14; protective, suppressive or targeted. A protective strategy involved vaccination in a three km radius around infected properties, while a suppressive strategy involved vaccination in a seven to ten km ring around infected properties. Targeted vaccination involved the vaccination of all breeding and racing properties within 20 kilometres of an infected property. Sensitivity analysis was conducted to determine the impact of timing of vaccination and earlier detection on the size of and duration of the outbreak and the number of vaccinated properties. All three vaccination strategies implemented at day 14 resulted on average in 62% fewer infected properties ($P<0.001$) and an epidemic that was 70 days shorter ($P<0.001$), compared to movement restriction alone. Any vaccination strategy implemented on day seven resulted in fewer properties infected with EI, compared to vaccination implemented on days 14 or 21. Overall, the suppressive vaccination strategy resulted in fewer infected properties. The findings suggest that any vaccination strategy, if combined with complete movement restriction could be effective for the control of EI, if an outbreak was to occur in New Zealand. Additionally, if an outbreak were to occur, a simulation model has now been created that could be used to assist in decision-making using data from the actual outbreak.

8.2 Introduction

The New Zealand equine population has never experienced an outbreak of the highly infectious, respiratory disease equine influenza (EI), and consequently the equine population is naïve to infection (Anon, 2011f). In August 2007, an outbreak of EI occurred in a similarly naïve equine population, in Australia (Callinan, 2008; Anon, 2009). The Australian EI experience has highlighted that in a naïve population, EI will spread rapidly. Due to the rapid, widespread dissemination of EI in Australia, a substantial, national effort was needed in order to achieve control, and subsequent eradication by December 2007. The EI control effort was implemented rapidly, with restrictions on the movement of horses implemented within two days of infection being officially diagnosed in the population. Another key control method was vaccination, which began one month after movement restrictions were implemented, although New South Wales and Queensland used different types of vaccination strategies. After the Australian EI outbreak, the effectiveness of vaccination beginning one month after the outbreak began was questioned, as movement restriction alone appeared to prevent the spread of EI (Cowled et al., 2009).

To ensure that control strategies can be implemented rapidly upon disease detection, policies regarding control need to be in place prior to an outbreak. One way to develop policies is to investigate the effectiveness of control strategies through simulation modelling. Simulation modelling has been used after outbreaks have occurred (Yoon et al., 2006; Garner et al., 2011) or in areas where disease is not present (Bates et al., 2003a; Ward et al., 2009). After the EI outbreak in Australia, simulation modelling was used to model the implementation of vaccination strategies at seven days after official EI detection (Garner et al., 2011). The Australian EI simulation was based on the Australian outbreak data, and found that if vaccination had been implemented seven days after the outbreak was detected, it would have been more effective than movement restriction alone, even with limited vaccination resources. Four vaccination strategies were investigated, two suppressive, one protective and one targeted. The suppressive vaccination strategies targeted properties in a radius of one or three kilometres around identified infected properties. In contrast, protective vaccination targeted properties in a seven to ten kilometre ring around identified infected properties, at a distance that will prevent disease from spreading beyond the ring. Targeted vaccination focused on properties with more than ten horses within a 20 kilometre radius of an infected property. When compared to movement restriction alone, any vaccination strategy in conjunction with movement restriction was predicted to reduce the number of infected properties by 60%, reduced the predicted duration of the epidemic and the total land area affected by the outbreak. Vaccinating all properties within a three kilometre radius of an infected property was the most effective vaccination strategy, if there were no limitations on resources for vaccination. However, if vaccination resources were limited, vaccination at a one kilometre radius was more effective than vaccinating in a seven to ten kilometre band or only vaccinating horses on larger horse properties (>10 horses).

In New Zealand, basing decisions regarding control solely on the experience of the Australian EI outbreak (Callinan, 2008; Anon, 2009; Cowled et al., 2009; Garner et al., 2011) may be misleading due to differences between the two equine populations, the density of horse properties and the geography of New Zealand. These differences have the potential to alter the disease spread. Therefore, decisions regarding EI control in New Zealand must be based on data unique to the New Zealand situation. The aim of the current study was to develop a stochastic simulation model. This model could then be applied as a decision support tool to assist policy formation relating to the detection and control of EI during a disease incursion in New Zealand. The impact of movement restriction and three types of vaccination strategies (protective, suppressive and targeted) on the size and duration of outbreak and the number of vaccinated properties was investigated. Additionally, the impact of altering the day that vaccination commenced or enhanced surveillance to allow earlier detection on the predicted epidemic size, duration and the number of vaccinated properties was explored.

8.3 Materials and methods

The North and South Islands of New Zealand were the geographic area of interest, because if an outbreak of EI was to occur in New Zealand it was unlikely that the separation of the two islands would create a natural barrier for disease spread. The registration of horses is not mandatory in New Zealand, although the rural database AgriBase$^{(TM)}$ (Sanson and Pearson, 1997), does maintain records of rural properties including the Cartesian coordinates, and denotes if horses are present.

8.3.1 Model description

InterSpread Plus has previously been used to model the spread of Foot-and-mouth disease (FMD) spread in the United Kingdom (Sanson, 1993; Morris et al., 2001). InterSpread Plus is a stochastic, state-transition model with susceptible, latent, infected and recovered (SLIR) states. For the model the unit of interest is the property-level. The model has both spatial and temporal elements. Temporal, as the time steps are for each day of the outbreak and spatial, as property location based on coordinate data. InterSpread Plus version 2.1.12.20 was used for all model simulations.

Spread parameters

The New Zealand EI model was parameterised with demographic and movement data collected during postal survey (Rosanowski et al., 2011a [Chapter Three]; Rosanowski et al., 2012b [Chapter Four]), database analysis (Chapter Six) and face-to-face interviews with stud managers (Rosanowski et al., 2012a [Chapter Seven]).

Parameters regarding EI infection characteristics including time until detection, infectivity, control strategies, local spread characteristics and the timeliness of control implementation were based on experiences gained during the Australian outbreak (Cowled, B., personal communication; Firestone, S., personal communication; Garner, G., personal communication).

Demographic and movement parameters

Horse properties were categorised as five property types and two race track types (Table 8.1). A total of 11 different movement types were specified. On an individual property, the type of movement event that could occur depended on the type of property. The input values for each movement type used in the model including the probability of a movement event, distance travelled during a movement event, number of direct and indirect contacts from a movement event and probability of infection can be found in Appendix C.

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

Item	Category	Description
Property types	General horse	Northing and Easting coordinates of equine properties not classified as either breeding or training
	Thoroughbred training	Northing and Easting coordinates of equine properties listed as training operations that could be matched to a list of Thoroughbred trainers
	Thoroughbred breeding	Northing and Easting coordinates of equine properties listed as breeding operations that could be matched to a list of Thoroughbred breeders
	Standardbred training	Northing and Easting coordinates of equine properties listed as training operations that could be matched to a list of Standardbred trainers
	Standardbred breeding	Northing and Easting coordinates of equine properties listed as breeding operations that could be matched to a list of Standardbred breeders
Contact location[ab]	Thoroughbred race track	Northing and Easting coordinates and names for Thoroughbred race tracks were derived from the New Zealand Thoroughbred Racing website (www.nztr.co.nz)
	Standardbred race track	Northing and Easting coordinates and names for Standardbred race tracks were derived from the Harness Racing New Zealand website (www.hrnz.co.nz)

[a] An area where the mixing of horses can take place that is not an equine property. Defined as a market place in InterSpread Plus

[b] Point locations determined using Google Earth (www.google.com)

Time until detection

The time until detection is the time, in days, between infection being present in the population and the official identification of an exotic disease incursion. In the model, in order to achieve detection at approximately 12 days from EI occurring on the seed property, pre-outbreak passive surveillance was set as a two percent probability of detecting EI. The time until detection parameter was based on the arrival of the last group of horses into the Eastern Creek quarantine facility in Sydney, New South Wales, on the 11th of August 2007, six days prior to the detection of EI in the facility, and the official identification of EI in an equestrian centre on the 24th of August (Callinan, 2008; Cowled et al., 2009). Based on this timeline, the time until detection during the Australian outbreak was 12 days. For the New Zealand EI model, it was assumed that a similar sequence of events would exist during an incursion of EI into New Zealand.

Local spread characteristics

The spread of infectious disease among susceptible individuals in a population is dependent on the distance and the time from an infected source animal (Sanson, 1994). This type of disease spread mechanism is defined as local spread and is the daily probability of infection, given the distance an equine property is from an infected equine property, up to a maximum of ten kilometres. In the model, local spread included spread through fomite transmission, illegal movements, windborne spread and other mechanisms not accounted for by other parameters within the model. Unlike FMD (Norris and Harper, 1970; Donaldson and Alexandersen, 2002), there are no published data regarding the windborne spread of EI, so windborne spread was included within the local spread parameter.

The probability of equine properties becoming infected through local spread varied by distance from an infected property and time since the source property was infected with EI. Local spread commenced three days post infection, with properties less than one kilometre from an infected property having a 5% probability of infection (Table 8.2). Local spread characteristics were based on spread characteristics reported in Australia (Cowled et al., 2009; Davis et al., 2009; Firestone et al., 2011bin press; Garner et al., 2011). The local spread characteristics of EI remained constant throughout all model simulations.

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.

Distance from an infected property	**Days since property was infected**					
	1 to 2	**3 to 4**	**5 to 6**	**7**	**8 to 9**	**10 onward**
≤1,000 metres	0	0.0500	0.0400	0.0300	0.0200	0.0001
1,000 metres to 3,000 metres	0	0.0040	0.0030	0.0020	0.0010	0.0001
3,001 meters to 5,000 metres	0	0.0020	0.0010	0.0010	0.0010	0.0001
5,001 metres to 7,500 metres	0	0.0009	0.0004	0.0003	0.0001	0.0001

Latent, infectious and recovered periods and the infectivity of EI

The latent period is defined as a time between when an individual horse is exposed to EI and when it becomes infectious to other horses, with infectiousness associated with viral shedding in nasal secretions. For EI, the latent period is described as the time between exposure to the virus and the clinical signs of illness, as the occurrence of the clinical signs occur in conjunction with the occurrence of viral shedding and infectivity (Lunn et al., 2001; Park et al., 2003; Paillot et al., 2006b; Quinlivan et al., 2007). The period between exposure and the clinical signs of EI, including pyrexia, coughing and nasal discharge, have been reported in studies as between one and seven days (Paillot et al., 2006b; Soboll et al., 2010; Happold and Rubira, 2011). To account for the uncertainty in time between exposure and infectiousness, latent period was included in the model as a beta pert distribution with a minimum of one day, a mode of two days and a maximum of seven days.

The infective period for EI begins once clinical signs are evident. Infectivity lasts from two to ten days in individual, unvaccinated horses (Paillot et al., 2006b; Bryant et al., 2010). During the EI outbreak in Australia, on large breeding properties the property-level infectious period was found to be an average of 14 days, with a maximum of 30 days for all horses on the property to become infected and then for clinical signs to resolve (Happold and Rubira, 2011). As the number of horses on New Zealand horse properties was not known, a single infectious period was used for all equine properties, with properties infected and infectious from day three until day ten.

If a horse from an infected property was in direct contact with a susceptible horse during the infectious period, there was a 30% probability of transmitting infection. Direct contact of infectious and susceptible horses occurred through movement events.

Once horses had been infected, they were not able to be re-infected, nor were they able to be infectious to others after the initial infectious period, for the remainder of the simulation modelling.

Post outbreak contact tracing and surveillance

Contact tracing, the identification of properties that had been in-contact with identified, infectious properties (Kiss et al., 2008), began on the first day of detection and occurred for the next seven days. The probability that EI would be detected on a property involved in contact tracing was 70%. The probability that a movement event from a property was recalled during contact tracing was 95%. After the official detection of EI, passive surveillance levels also increase. On the first day after official detection, the probability of detection is 20% until day seven and then 75% until day 100 and at 5% from 100 days until the end of the simulation (Garner et al., 2011).

8.3.2 Control strategies

Movement restriction

The control strategy of movement restriction began on the first day of detection and continued for the remainder of the simulation. The compliance rate for movement restriction was 98% from the first day of implementation (Table 8.3). This was considered a valid approximation as during the EI outbreak in Australia, once movement restriction was in place, there were few new clusters of disease in geographically distinct areas (Cowled et al., 2009). Rather, disease spread in the phase after movement restriction was in place was in local clusters, indicating that spread was not due to the illegal movement of horses, movements that would disperse disease beyond local clusters.

Table 8.3: Description of the control strategies investigated in the InterSpread Plus equine influenza model

Strategy	Type	Description
Baseline		
	Movement restriction	All movement from horse properties restricted, with 98%compliance from implementation
Vaccination[a]		
	Suppressive	Vaccination of all premises with horses in a 3 km radius of a known infected property
	Protective	Vaccination of all premises with horses in a band 7 to 10 km around known infected property
	Targeted	Vaccination of breeding and training operations within a 20 km radius of a known infected property

[a] All vaccination strategies implemented with movement restriction

Vaccination strategies

All vaccination strategies were implemented over and above the movement restriction with 98% compliance starting on the first day of detection (Cowled et al., 2009). Three vaccination strategies were investigated, suppressive, protective and targeted and these are summarised in Table 8.3. All vaccination strategies were implemented at 14 days after official detection.

To be effective during an exotic disease outbreak, the vaccine used for emergency vaccination must encourage host immunity quickly and reduce the time and infectivity of the vaccinated host. The canary-pox vaccine has been shown to be effective, during the Australian EI outbreak, at reducing the clinical signs of EI and viral shedding in horses that had only received one dose of the vaccine and were subsequently exposed to EI (Kannegieter et al., 2011). The canary-pox vaccine showed efficacy after seven days with vaccinated horses displaying reduced clinical signs of EI, although total protection was not achieved. As host immunity occurs rapidly, in an outbreak situation, assuming there is some homogeneity between the strain of the virus that is circulating in the population and the strains in the vaccine, the canary-pox vaccine would be an effective vaccination option. In the model, vaccination offered no protection from infection until day seven, when the probability of infection if exposed was reduced by 50%. On day 14, the probability of infection, if exposed was reduced by 70% and on day 21 until the end of the simulation, protection from vaccination reduces the probability of infection by 90% (Garner et al., 2011).

Optimal vaccination resources were modelled. From the first day of vaccination, the resources available for vaccination increased linearly. On the first day, 50 properties were able to be vaccinated per day, increasing to day 26, when 250 properties were able to be vaccinated per day. Priority was placed on vaccinating properties located in the Auckland and Waikato regions, as these areas have been shown to have the greatest density of horse properties (Rosanowski et al., 2011a [Chapter Three]) as well as being close to the site of the seed property and probable entry point of EI into New Zealand through the Auckland international airport. Additionally, most of the veterinary resource is located in this region. Priority was allocated to the Auckland and Waikato regions as five properties in these regions were vaccinated to one horse property in the other areas of New Zealand. During the 2007 EI outbreak in Australia, veterinary resources were a limiting factor for the implementation of a vaccination strategy (Anon, 2009).

8.3.3 Sensitivity analysis

Timeliness of vaccination

For each vaccination strategy, protective, suppressive or targeted, the timeliness of vaccination implementation was investigated. Vaccination was implemented at seven, 14 and 21 days after official EI detection. Each vaccination strategy was implemented over and above the movement restriction with 98% compliance starting on the first day of detection.

Enhanced surveillance strategies

The pre-outbreak surveillance strategy of the baseline model was enhanced so that EI was detected two and seven days earlier than the baseline strategy. Pre-outbreak surveillance was increased from a probability of detection of 2% to a probability of detection of 5% and 26%, so that EI would be detected on a median of day ten and five respectively.

8.3.4 Model simulations and outcome variables

For each scenario investigated, one hundred iterations were run for 180 days. Each control strategy was evaluated in terms of the number of infected properties and the rate of spread over the period of the simulation. Additionally, vaccination control strategies were evaluated in terms of the number of vaccinated properties. For every iteration the first case of EI occurred on a Thoroughbred breeding property located in the Waikato region (Figure 8.1A).

8.3.5 Statistical analysis

Control strategies

Four outcomes were determined for the movement restriction strategy. Firstly, an epidemic curve was constructed to describe the median and 25th and 75th percentiles for the number of infected properties on each day of the outbreak. Secondly, the number and percentage of iterations that lasted less than 180 days. Thirdly, the percentage of iterations where infected properties were in the South Island on day 12 and day 180, and finally the percentiles of infected properties in the South Island on day 12 and day 180.

The movement restriction strategy and the three vaccination strategies implemented 14 days after official detection were summarised using minimum, maximum and percentiles. For the three vaccination strategies, the number of vaccinated properties was summarised using the minimum, maximum and percentiles. The non-parametric Kruskal-Wallis test was used to determine if the duration of epidemic, number of infected properties and the number of vaccinated properties differed significantly between the strategies.

Sensitivity analysis

The minimum, maximum and percentiles of the duration of the epidemic, number of infected properties and the number of vaccinated properties were presented stratified by the vaccination strategy and the day vaccination was implemented. Within each vaccination strategy, a non-parametric Kruskal-Wallis test was used to determine if there was a significant association between the three outcomes and the day vaccination was implemented.

The minimum, maximum and percentiles of the number of days until detection, duration of the epidemic and number of infected properties were presented stratified by surveillance strategies. Associations were assessed using the non-parametric Kruskal-Wallis test. All statistical analyses were performed using Stata version 11.2 (Statacorp LP, College Station, Texas, USA).

Spatial analysis

Descriptive spatial analyses were conducted to describe the distribution of properties for the control strategy of movement restriction alone. Easting and northing coordinates of the farm centroid was available for all properties listed in the AgriBase$^{(TM)}$ database. As the density of infected properties varied across New Zealand, adaptive edge corrected Gaussian kernel density estimation was used to smooth the location data (Bowman and Azzalini, 1997). The smoothing technique was used to visualise the number of infected properties for the control strategy of movement restriction alone at day 12 and at day 180. As there were 100 iterations of the movement restriction control strategy, all infected properties were divided by the number of iterations they were present in. All maps were created using R version 2.13.0 (R Development Core Team, Vienna, Austria) using the library “sparr” (Davies et al., 2011).

8.4 Results

8.4.1 Control strategies

For the movement restriction control strategy, the predicted duration of outbreaks was 170 (IQR 150 to 180) days and the median predicted number of infected properties was 3,136 (IQR 2,853 to 3,370). In 61% of all movement restriction only model iterations, control was achieved before 180 days. At day 12 when EI was officially detected in the population, in 40% of iterations the EI outbreak had progressed to the South Island, infecting a median of 3 (IQR 1 to 3) properties. At day 180, in every iteration EI was detected in the South Island with a median 688 (IQR 618 to 762) infected properties (Figure 8.1). The epidemic curve for movement restriction only is shown in Figure 8.2.

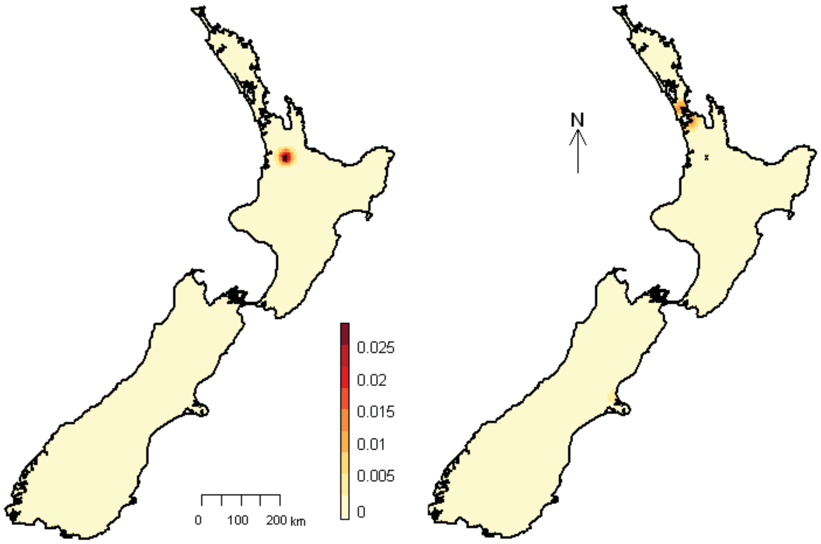

Figure 8.1: Gaussian edge corrected kernel intensity function of the number of infected horse properties on the day of EI detection (median=21) (A) and infected properties on day 180 of the epidemic (median=3,136) (B) for the movement restriction control strategies. Data described as infected properties per 10 km^2 in New Zealand. X marks the location of the seed property in the Waikato

There were significant differences between the predicted epidemic duration and whether only movement restrictions were implemented or movement restriction plus vaccination were implemented (P<0.001) (Table 8.4). The median duration of outbreaks controlled using movement restriction alone was 178 days, in contrast the median duration of outbreaks for vaccinated strategies ranging from 88 for suppressive to 145 for targeted.

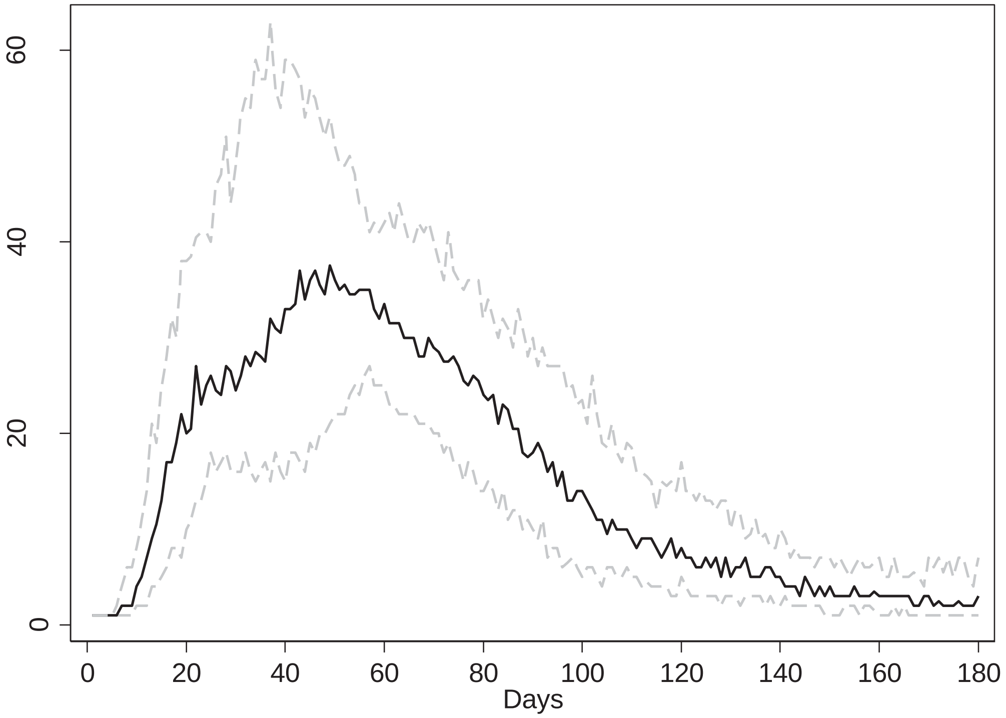

Figure 8.2: Epidemic curve of the median (dark line) and 25th and 75th (grey lines) of the number of infected properties on each day when movement restriction alone was implemented. Data from an InterSpread Plus model with 100 iterations and the seed property located in the Waikato

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.

	Duration of outbreak					
Control strategy	**Min**	**25th**	**Median**	**75th**	**Max**	**P value**[a]
Movement restriction only	96	150	178	180	180	<0.001
Suppressive vaccination [b]	55	78	88	107	156	
Protective vaccination [c]	54	79	92	104	160	
Targeted vaccination [d]	95	118	145	167	180	

[a] Kruskal-Wallis analysis of variance

[b] Vaccination in a 3km radius of an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

[c] Vaccination in a 7 to 10km ring around an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

[d] Vaccination of all properties involved in the racing industry (training and breeding) in a 20km radius of an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

Compared to the movement restriction strategy, all three vaccination strategies were effective in reducing the predicted number of infected properties in an outbreak ($P<0.001$) (Table 8.5). The suppressive vaccination strategy had the fewest number of infected properties of all the control strategies, with 1,209 while the median number of infected properties for movement restrictions alone was 3,136.

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.

	Number of infected properties					
Control strategy	**Min**	**25th**	**Median**	**75th**	**Max**	**P value**[a]
Movement restriction only	1948	2853	3136	3370	3828	<0.001
Suppressive vaccination [b]	118	465	793	1209	2858	
Protective vaccination [c]	151	447	846	1451	2971	
Targeted vaccination [d]	905	1665	1946	2246	3348	

[a] Kruskal-Wallis analysis of variance

[b] Vaccination in a 3km radius of an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

[c] Vaccination in a 7 to 10km ring around an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

[d] Vaccination of all properties involved in the racing industry (training and breeding) in a 20km radius of an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

There were significant differences between the number of vaccinated properties for all three vaccination strategies ($P<0.001$) (Table 8.6). The targeted vaccination strategy had the fewest number of vaccinated properties of all the control strategies, with 853 while the median number of vaccinated properties for the protective strategy was 4,502.

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.

	Number of vaccinated properties					
Control strategy	**Min**	**25th**	**median**	**75th**	**Max**	**P value**[a]
Suppressive vaccination [b]	544	2039	2726	3433	4204	<0.001
Protective vaccination [c]	979	2992	4502	5602	6726	
Targeted vaccination [d]	387	664	853	983	1160	

[a] Kruskal-Wallis analysis of variance

[b] Vaccination in a 3km radius of an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

[c] Vaccination in a 7 to 10km ring around an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

[d] Vaccination of all properties involved in the racing industry (training and breeding) in a 20km radius of an infected property starting 14 days after official detection, strategy included movement restriction starting on the first day of EI detection

8.4.2. Sensitivity analysis

Timeliness of vaccination

Table 8.7 shows the descriptive statistics for the predicted epidemic duration for the three vaccination strategies. There were significant differences between the day of implementation and predicted epidemic duration for the protective strategy (P<0.03), but not the suppressive or targeted strategies.

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.

Control strategy	Vaccination start day[a]	Duration of epidemic (days)					P value[b]
		Min	25th	Median	75th	Max	
Suppressive vaccination [c]	7	47	76	89	108	179	0.1
	14	55	78	88	107	156	
	21	48	82	96	112	173	
Protective vaccination [d]	7	33	75	85	99	157	0.03
	14	54	79	92	104	160	
	21	67	82	91	105	179	
Targeted vaccination [e]	7	68	115	135	162	180	0.29
	14	95	118	145	167	180	
	21	83	122	137	169	180	

[a] After the first day of detection

[b] Kruskal-Wallis analysis of variance within each vaccination strategy

[c] Vaccination in a 3km radius of an infected property, strategy included movement restriction starting on the first day of EI detection

[d] Vaccination in a 7 to 10km ring around an infected property, strategy included movement restriction starting on the first day of EI detection

[e] Vaccination of all properties involved in the racing industry (training and breeding) in a 20km radius of an infected property, strategy included movement restriction starting on the first day of EI detection

Descriptive statistics of the predicted number of infected properties for the three vaccination strategies are shown in Table 8.8. Within each strategy there was a significant positive association between the number of infected properties and the day vaccination commenced.

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.

		Number of infected properties					
Control strategy	**Vaccination start day**[a]	**Min**	**25th**	**50th**	**75th**	**Max**	**P value**[b]
Suppressive vaccination [c]	7	44	350	608	1053	2658	<0.001
	14	118	465	793	1209	2858	
	21	150	629	1033	1613	3194	
Protective vaccination [d]	7	30	367	619	1244	2826	0.002
	14	151	447	846	1451	2971	
	21	227	577	1066	1755	3255	
Targeted vaccination [e]	7	218	1649	1870	2123	3263	0.01
	14	905	1665	1946	2246	3348	
	21	550	1764	2074	2403	3624	

[a] After the first day of detection

[b] Kruskal-Wallis analysis of variance within in each vaccination strategy

[c] Vaccination in a 3km radius of an infected property, strategy included movement restriction starting on the first day of EI detection

[d] Vaccination in a 7 to 10km ring around an infected property, strategy included movement restriction starting on the first day of EI detection

[e] Vaccination of all properties involved in the racing industry (training and breeding) in a 20km radius of an infected property, strategy included movement restriction starting on the first day of EI detection

Protective vaccination at 14 days had the greatest predicted number of vaccinated properties, with 4,502, while targeted vaccination at 21 days had the fewest with 839. On average, 1,522 fewer properties were vaccinated under the suppressive vaccination, compared to the protective strategy and 3,376 fewer under the targeted strategy that under the protective strategy. The results of the number of vaccinated properties are summarised in Table 8.9.

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.

		Number of vaccinated properties					
Control strategy	**Vaccination start day**[a]	**Min**	**25th**	**Median**	**75th**	**Max**	**P value**[b]
Suppressive vaccination [c]	7	352	1725	2547	3450	4883	0.75
	14	544	2039	2726	3433	4204	
	21	471	2190	2872	3375	3873	
Protective vaccination [d]	7	541	2817	3953	5644	7017	0.86
	14	979	2992	4502	5602	6726	
	21	1686	3385	4256	5299	5955	
Targeted vaccination e	7	174	671	893	1087	1268	0.09
	14	387	664	853	983	1160	
	21	391	666	839	946	1195	

[a] After the first day of detection

[b] Kruskal-Wallis analysis of variance within in each vaccination strategy

[c] Vaccination in a 3km radius of an infected property, strategy included movement restriction starting on the first day of EI detection

[d] Vaccination in a 7 to 10km ring around an infected property, strategy included movement restriction starting on the first day of EI detection

[e] Vaccination of all properties involved in the racing industry (training and breeding) in a 20km radius of an infected property, strategy included movement restriction starting on the first day of EI detection

Effect of enhanced surveillance

A summary of the predicted number of days until detection, predicted epidemic duration and predicted number of infected properties for the movement restriction strategy, and the two strategies with enhanced surveillance are shown in Table 8.10. For the movement restriction strategy, the median number of days until EI was detected was 12 (IQR 9 to 15 days). Compared to the movement restriction strategy, there were significantly fewer predicted infected properties at the end of the simulation for the two day and seven day enhanced surveillance strategies (P<0.001).

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.

Variable	**Surveillance strategy**	**Min**	**25th**	**50th**	**75th**	**Max**	**P value**[a]
Days until detection							
	2% probability [b]	4	9	12	15	60	<0.001
	5% probability [b]	3	7	10	13	60	
	26% probability [b]	3	4	5	7	11	
Duration of epidemic							
	2% probability [b]	96	150	178	180	180	0.03
	5% probability [b]	1	165	180	180	180	
	26% probability [b]	1	173	180	180	180	
Number of infected properties							
	2% probability [b]	1,948	2,853	3,136	3,370	3,828	<0.001
	5% probability [b]	1	2,749	3,068	3,194	3,465	
	26% probability [b]	1	2,361	3,001	3,160	3,446	

[a] Kruskal-Wallis analysis of variance

[b] Probability of detection with complete movement restriction starting on the day of first detection

8.5 Discussion

The current study based on simulation modelling, identified that the size and duration of an EI outbreak in the New Zealand equine population can be reduced, if movement restriction and vaccination are implemented. The results from the EI model suggest that the restriction of movement from horse properties, if implemented with no other control strategies, may not result in control in less than six months of an outbreak occurring. Regardless of the vaccination strategy implemented, the predicted length of the epidemic was shorter, and number of properties affected fewer, than if movement restriction alone was applied. Pre-outbreak surveillance, to enable earlier detection of an EI outbreak, did decrease the number properties infected during an outbreak.

In agreement with a previous EI modelling study (Garner et al., 2011), the current study has shown that the use of vaccination, along with movement restriction, could reduce the total number of horse properties affected by EI during an outbreak. Additionally, vaccination and movement restriction shortened the duration of the epidemic, compared to movement restriction alone. The current study identified on average 62% fewer infected properties if any vaccination strategy is applied, compared to movement restriction as the only control method. This is similar to previous studies based on the Australian EI outbreak, where at day 28 of the control program, any of the examined vaccination strategies resulted in 60% fewer infected properties than the baseline strategy of movement restriction alone (Garner et al., 2011).

Both the current study and Garner et al. (2011) found that suppressive vaccination resulted in fewer numbers of infected properties and shorter outbreaks. The Australian EI model found that suppressive vaccination in a three kilometre radius of an infected property was the most effective strategy (Garner et al., 2011). However, when the number of properties that could be vaccinated per day was limited, a one kilometre suppressive strategy was a more effective strategy, provided vaccination began seven days post detection. Similarly, the current study found that a suppressive vaccination strategy, in a three kilometre radius around infected properties was more effective that ring vaccination. The current study identified that the implementation of any control strategy that included vaccination would decrease the duration of the epidemic by between 35 and 92 days. Implementing vaccination at day seven resulted in fewer infected properties and shorter epidemics, than vaccination implemented at 14 or 21 days after official detection. The Australian and the New Zealand EI models, while based on unique population data and using similar local spread parameters, have both led to consistent recommendations regarding vaccination. Consistency in recommendations between the two models can be used to increase the confidence in the model predictions to support the development of disease control strategies (Dubé et al., 2007).

In the current study, enhancing surveillance to reduce the days to detection did result in a significant reduction in the duration of the outbreak and number of infected properties. However, the magnitude of the changes were relatively small and as such, it is questionable if there will be a benefit to investing in the enhanced surveillance. In previous studies, decreasing time until detection by increasing the pre-outbreak surveillance, has affected the duration of the epidemic or the number of infected properties, so there would be a benefit in investing in enhanced surveillance. In a study of a FMD outbreak in Korea, decreasing the number of days until detection by five days decreased the duration of the epidemic, the number of infected and depopulated properties and decreased the variability inherent in the outbreak (Yoon et al., 2006). Similarly, in a predictive model of FMD outbreaks in cattle in Texas, North America, early detection at seven days post incursion led to decreased epidemic length, regardless of what type of cattle holding was used as the disease seeding property (Ward et al., 2009). Additionally, early detection decreased the number of depopulated farms. As all infected farms would be depopulated during a FMD outbreak, this measure acted as a proxy for the number of infected properties.

The accuracy of simulation modelling is predicated on the accuracy of the supporting data. Prior to 2009, no movement or demographic data had been collected. In the current study, the data regarding the movement of horses is based on information collected retrospectively in 2009 (Rosanowski et al., 2012a [Chapter Seven]; Rosanowski et al., 2012b [Chapter Four] and [Chapter Six]). While these data have provided a baseline evaluation of control methods for EI, in the event of an EI outbreak, the assumption that the movement behaviour of the New Zealand equine population is the same as 2009 could be questionable. In the event of an EI outbreak affecting the New Zealand equine population, the ability to inform the model with movement data collected from all sectors of the equine industry prospectively would greatly enhance the accuracy of the model outputs and overall productive capacity of the model.

In 2012, the National Animal Identification and Tracing (NAIT) scheme will be deployed for food production animals in New Zealand to enhance biosecurity response, and provide lifetime animal traceability (Anon, 2012d). This system requires the mandatory registration of cattle and deer and the recording of animal movement. Not being food production animals horses fall outside of this mandate, however, the system could be expanded to collect data on other animals. This will ensure the on-going accuracy of model predictions, and will aid in contact tracing during a disease outbreak. Also, the registration of horses and recording of movements should be made mandatory. Mandatory movement data for horses are already collected in Spain (Martínez-López et al., 2011b). After the Australian EI outbreak, the registration and collection of data regarding the movement of horses to events were collected, to allow an easing of movement restriction and disease tracing if necessary (Bell and Drury-Klein, 2011). However, once Australia was declared free of EI in December 2008, the registration of events and movement was no longer enforced. New Zealand needs to implement the collection of data regarding the movement of horses. If continuous, mandatory reporting of all horse movements proved too difficult to implement, consideration should be given to periodic recording of horse movements to ensure model parameters reflect the current movement patterns. However, periods may need to be chosen carefully to ensure representativeness of seasonality and other factors (Owen et al., 2011).

As the New Zealand EI model is a predictive model, a limitation of this study that is common with all studies of this type, is the inability to validate model assumptions against an EI outbreak in New Zealand. The importance of the findings reported here does not lie in the ability to provide a definitive prediction of where EI will spread, if it was to enter the

New Zealand equine population. Rather, the importance of the New Zealand EI model is the availability of the model in the event of an outbreak and the trends predicted by the model (Dubé et al., 2007). In the event of an outbreak, the model can be updated based on outbreak data, allowing for the implementation of control based on the most accurate data. The model identified important trends about disease spread and the effectiveness of control strategies. In particular, vaccination would lead to smaller outbreaks compared to movement restriction alone, and in the majority of simulated outbreaks the South Island was infected prior to outbreak detection. Consequently, control strategies cannot consider the Cook Strait, a body of water between the North and South Islands as a natural disease barrier.

When considering control options, the use of a simulation model to evaluate control strategies is just one decision support tool. Additional consideration needs to be given to the political or national climate, as well as the opinions of horse and property owners and veterinarians regarding the implementation or methods of EI control. At a national level, the favourable strategy for control would be more risk adverse, to try and control EI as quickly as possible, while there is an associated level of pressure to manage the cost of any control strategy. However, the adoption of the most risk adverse strategy may not suit the individual horse owner, the racing industry or veterinarians, who will be directly involved for caring for sick animals during the outbreak or directly bear the cost of control.

The findings of the current study suggest that suppressive vaccination at three kilometres and a total movement standstill for the entire duration of the outbreak will be the effective option to control EI. The model does not take into account the financial impact that this control option, particularly movement restriction, will have on the equine industry. Movement restriction will severely impact the commercial activity and economic viability of the racing industry, with the cancellation of races and interruptions to the breeding season, as mares will not be able to be transported to stud farms for mating. Therefore, targeted vaccination of racing and breeding horses, to allow the movement of horses to stud and the running of race meetings could be considered. If a six month movement standstill was in place for part or all of the period from July to January, this would disrupt the breeding season for that year, which in turn could financially decimate the Thoroughbred and to a lesser extent, Standardbred breeding sectors, through lost production. Therefore, some movement would need to be allowed for these sectors to continue. However, as the current study did not investigate the financial impact of EI on the racing or breeding sectors, or the cost of vaccination, and it is unknown whether the cost of vaccination would outweigh the benefit gained by shortening the epidemic duration.

8.6 Conclusion

This study has shown that vaccination is an effective option for the control of EI, if it is implemented with movement restriction. The sooner vaccination is implemented after official detection, the more the effective vaccination strategies would be, based on the decrease in the size and duration of the epidemic. Of the three vaccination strategies evaluated, suppressive vaccination at a three kilometre radius around identified infected properties was most effective in decreasing outbreak duration and number of infected properties. Additionally, control was achieved with fewer vaccinated properties than the protective seven to ten kilometre ring strategy. However, the results of this simulation model relied upon movement data collected retrospectively in 2009. Therefore it is unknown whether these data are a true reflection on the current movement of horses in New Zealand. In the event of an EI outbreak affecting the New Zealand equine population, the ability to inform the model with movement data collected from all sectors of the equine industry prospectively would greatly enhance the accuracy of the model outputs, as would including an evaluation of the financial benefits of vaccination.

Chapter Nine
General Discussion

The aim of this thesis was to develop an infectious disease model to evaluate control strategies for equine influenza virus (EI) in the New Zealand horse population. The model was developed in InterSpread Plus and a series of epidemiological studies were conducted to provide information about the New Zealand horse population that could be used to inform the model. These studies included the description of the demographic characteristics, movement behaviour, biosecurity practices and visitor protocols implemented on properties keeping horses and the movement patterns of horses around race meetings.

9.1 Key findings

9.1.1 Identification of horse owners and properties

Horses involved in the racing industry must be registered with their respective racing code, Harness Racing New Zealand (HRNZ) for Standardbreds, and New Zealand Thoroughbred Racing (NZTR) for Thoroughbreds. Horses used for competition can be registered with Equestrian Sports New Zealand (ESNZ), but registration is not mandatory except when horses are competing at the highest levels. Horses registered with ENSZ are elite competition horses and it would be reasonable to assume that they travel more than unregistered competition horses, although this has not been investigated in this thesis. While the registration of horses with HRNZ, NZTR and ESNZ would help to identify horse owners, it is noteworthy that these databases do not actually record the location of the horse. Consequently, using the data to create of list of potential horse properties during a disease outbreak would be problematic. Furthermore, the timeliness of access to these records in the event of a rapidly spreading EI outbreak is unclear.

While registration is a feature of racing and competition horses, registration is not mandatory for horses kept for other reasons. Consequently, the horses that are currently registered may only account for a small proportion of the total number of horses in New Zealand. Therefore, any infectious disease control strategy must take into account that not all horses in New Zealand are registered and, of the horses that are registered, access to these data may be difficult. As a consequence, people who own horses and properties with horses that are not involved in racing or registered competition may be difficult to locate. In the logistic regression model (Chapter Four), properties keeping horses for recreation were twice as likely to have a movement event as those that did not, highlighting the importance of locating these properties. Therefore, some way to find horses kept for recreation in the event of a disease outbreak must be devised.

AgriBase$^{(TM)}$ is one tool currently available, which records the location of rural properties and the presence of horses on these properties (Sanson and Pearson, 1997). The AgriBase$^{(TM)}$ database was used in Chapters Three, Four and Five as a means to identify non-commercial horse properties. The use of Agribase$^{(TM)}$, which contains the coordinate data for all listed properties, allowed the use of a generalised random-tessellated stratified (GRTS) design to select a spatially balanced sample. However, there were limitations in using this database, particularly inaccuracies associated with the recorded contact details and misclassification of properties with horses. In Chapter Three, of the non-commercial horse properties selected from AgriBase$^{(TM)}$, 24% of respondents reported not having horses. Additionally, 6% of the sent surveys were returned with incorrect address information, despite extra address validation being conducted using the New Zealand postal service and online databases. These inaccuracies will substantially limit a response to an EI outbreak.

9.1.2 Movement

In order to develop an InterSpread Plus model for the evaluation of control strategies for EI, knowledge of the movement patterns of the New Zealand horse population was important. The movement of horses from non-commercial properties was associated with keeping horses for racing, recreation or competition, as respondents keeping horses these purposes were more likely to report a movement event than respondents that did not keep horses for these purposes (Chapter Four). Chapter Three identified that many non-commercial horse properties kept horses for either competition, recreation, racing or a combination of the three, although only 62% of non-commercial horse properties had horses moving from them. The occurrence of movement from non-commercial properties was also associated with the number of horses kept on the property, although this was not linear with a maximum probability being achieved at six or more horses.

For the commercial breeding industry, the movement of horses from stud farms was also associated with property-level characteristics (Chapter Seven). The movement data from stud farms were not compared to the movement data from non-commercial properties, however, all stud farms reported movement events in the year prior to survey and the frequency of events were higher than for non-commercial properties. Stud managers reported more movement events from stud farms with greater numbers of mares and stallions. Additionally if a stud farm stood a shuttle stallion, more movement events were reported compared to stud farms that did not stand shuttle stallions. This is not surprising given shuttle stallions are imported from the Northern Hemisphere to serve mares in the Southern Hemisphere breeding season (Pickett and Voss, 1998) and consequently to be economically viable need to be mated to more mares than domestic stallions. Interestingly, the frequency of movements off stud farms was not significantly different for Thoroughbred and Standardbred farms. However, Thoroughbreds travelled further from stud farms than Standardbreds, with 11% of Thoroughbred movements greater than 150 kilometres, compared to 3% for Standardbred movement events.

An investigation of the movement patterns around Thoroughbred and Standardbred race meetings was presented in Chapter Six. Unlike the previous chapters describing the non-commercial sector of the New Zealand equine industry and breeding sectors, this study was not conducted at the property-level. Rather, data regarding race meetings were collected from Harness Racing New Zealand (HRNZ) and New Zealand Thoroughbred Racing (NZTR). Regardless of the type of race meeting held: premier, regional or trial, Thoroughbreds travelled further to attend race meetings than Standardbreds. Within each racing code, horses travelled further to attend premier race meetings, compared to other types of race meetings. The use of racing data collected by HRNZ and NZTR reduced the recall bias associated with collecting information regarding the movement of horses to race meetings from trainers. However, a limitation of not examining training properties at a property-level, as was done with stud farms and non-commercial properties, were that some movements of racehorses were missed. These movements would include the movement of horses between different trainers, the movement of horses away from trainers due to interruptions in training regimens and the movement of horses into training from pre-trainers, stud farms or owners.

9.1.3 Biosecurity and visitor protocols

This thesis identified that the level of biosecurity practiced on properties that kept horses in New Zealand is low. Furthermore, descriptions of the biosecurity practices on non-commercial horse properties (Chapter Five) and stud farms (Chapter Seven) failed to identify the use of biosecurity practices that would be effective at preventing the transmission of infectious disease from newly arriving horses to resident horses. Associations were identified between implementing biosecurity and the frequency of movement from a property, with properties with movement or more frequent movement events more likely to have biosecurity practices than properties with no or less movement.

There are limitations regarding the collection of biosecurity data undertaken in this thesis. Information was only collected about the arrival of new horses onto properties. Equally important is the return of horses from other properties or equestrian events. Ultimately, there may be differences in the way property owners or stud managers treat newly arriving horses compared to returning horses that are resident on the property. Stud managers reported treating mares arriving from known owners differently from those arriving from owners not known by the stud manager, indicating that there is a hierarchy relating to the level of biosecurity practiced. In a previous study, properties where horses were kept for competition were more likely to be infected with EI during the EI outbreak in Australia (Firestone et al., 2011a). Competition horses would be more likely to be moving from properties to attend competitive events. On return to the property of origin if the competitive horse did not experience the same isolation practices as for a newly arriving horse, then the risks of transmission to that property would be much higher than if a new horse had arrived. Biosecurity practices for all horses on a farm, whether resident or new, need to be investigated in further detail.

The frequency that veterinarians and farriers visit properties is an important consideration for the spread of disease, as both are in close contact with horses as part of their job. On stud farms, veterinarians were reported to visit daily during the breeding season. Farriers were reported to visit stud farms weekly, while on non-commercial properties the farrier visited a median of 8 (IQR 4 to 8) times per year. As few respondents reported having visitor protocols for veterinarians or farriers, on either breeding or non-commercial properties, there is potential for the unhindered transmission of EI between properties.

9.1.4 Control of equine influenza

Drawing on the findings from Chapters Three to Seven, a spatial stochastic model, Interspread Plus, provided predictions on epidemic duration and number of infected and vaccinated properties, enabling the evaluation of different vaccination and surveillance strategies for the control of EI (Chapter Eight). Similar to the findings of Garner et al. (2011), vaccination was more effective at decreasing both epidemic duration and size, than movement restriction implemented as the sole control method. Of the control strategies evaluated in Chapter Eight, vaccination starting on day seven, at a three kilometre radius around an infected property was the most effective control strategy. However, this strategy was investigated with movement restriction from first day of detection and maintained for the entire length of the outbreak. This may not be an acceptable strategy for the racing industry, which relies on the movement of horses for business continuity.

The New Zealand EI model did not account for all the factors investigated in the other chapters of this thesis, including the movement of horse professionals around horse properties or the effect of enhanced biosecurity on the spread of EI. As biosecurity practices were limited (Chapter Five and Chapter Seven), the modelling of enhanced biosecurity was unrealistic. As biosecurity that would be effective in preventing EI spread is not practiced routinely, by the time EI is officially detected, the spread of disease would not have been limited by biosecurity. If enhanced biosecurity was implemented after official detection, there would probably be a decrease in the number of infected properties and epidemic duration.

Horse professionals could have been included in the InterSpread Plus model as an explicit input parameter, rather than have been included within the local spread variable. Early in an EI outbreak, horse professionals will play a role in indirect spread between properties, with many properties visited and limited visitor protocols to prevent disease spread. Unfortunately, the frequency of visitation was not foreseen, so data were not collected in a way in which horse professionals could be inputted into the model as a movement event or movement route. Modelling horse professionals as a separate parameter would have led to larger, and potentially more widespread, outbreaks than were modelled in the current thesis.

9.2 Implications for the control of equine influenza

9.2.1 Establishment of a database of equine properties

One of the important implications identified by this thesis is the lack of accurate data about the number and location of horses in New Zealand. In the event of an exotic disease incursion affecting horses, the ability to rapidly locate and target properties for control could be the difference between disease eradication and allowing the disease to have endemic status. During the Australian EI outbreak in 2007, the lack of information available about the number and location of horses slowed the implementation of control strategies (Anon, 2009). However, experience from the United Kingdom with the National Equine Database (Robin et al., 2010) and in North America with National Equine Identification (Vanderman et al., 2009) have highlighted the difficulty of getting horse owner or equine industry participation. The initiation of a national equine database in New Zealand may be met with resistance, particularly if the benefits of registration do not appear to be outweighed by the cost.

In 2011, the decision was made by the Ministry of Agriculture and Forestry (MAF) to replace AgriBase$^{(TM)}$ with an online database, called Farms Online (Anon, 2012c). Farms

Online has been developed to allow rapid response to disease outbreaks in stock and crops. To be useful to the New Zealand equine industry in the event of an EI outbreak, Farms Online would need to include accurate address and coordinate data, and information regarding the number and reason for keeping horses on the property. This is possible within the framework provided by Farms Online.

Farms Online is potentially more accessible than AgriBase$^{(TM)}$, through the online delivery method. As it is online, regular updating by property owners is also possible, so changes in horse numbers can be rapidly updated. The equine industry should take proactive steps to ensure the registration of properties with horses onto a suitable database, and Farms Online is currently available. Additionally, the internet platform of Farms Online would allow updating during an outbreak, when the benefit of registration for horse owners would be highest. The ability to update during an outbreak would lead to more real time population data during an outbreak.

The usefulness of Farms Online as a database of horse properties is yet to be tested, but if proactive steps were taken now, then the usefulness of Farms Online would be assured. Additionally, the availability of a New Zealand horse database would be an invaluable research tool.

9.2.2 Collection of movement data

If all horse properties in New Zealand were registered and recorded on a database like Farms Online, then the collection of movement data would be easier. Additionally, the collection of movement data would be less critically important if property-level data were available. Mandatory movement data for horses are already collected in Spain (Martínez-López et al., 2011b), although this is probably not a realistic option for New Zealand. In New Zealand, the National Animal Identification and Tracing (NAIT) scheme will be deployed in 2012 (Anon, 2012d). The NAIT scheme will require the mandatory registration of cattle and deer and recording of animal movement with the aim of enhancing biosecurity response. However, horses are currently not included within the scope of NAIT.

During and immediately after the EI outbreak in Australia, the reporting of all instances of the movement of horses in New South Wales was mandatory (Bell and Drury-Klein, 2011). The registration of movement events was to allow for contact tracing of horses for disease control. Once the EI free status was regained in Australia in 2008, the mandatory reporting of movement events was phased out as it was difficult to maintain in a non-outbreak situation, even though it had a simple online delivery system.

In New Zealand, the continuous, mandatory reporting of all horse movements would be a difficult to implement. This difficulty is associated with the high frequency of horse movements as identified by this thesis and the potential for strong stakeholder resistance. To decrease the resistance to recording movement events, and given the high number of movement events that would be occurring, the periodic recording of movement may be more feasible. The periodic recording of horse movements would provide data that are not currently available, and be more up-to-date for use in the event of an outbreak. However, periods may need to be chosen carefully to ensure representativeness of seasonality and other factors inherent in movement behaviour (Owen et al., 2011).

As the movement and mixing of horses is a high risk activity for disease spread (Bryant et al., 2009; Firestone et al., 2011a; Gildea et al., 2011a), any information that can be gained about events where horses mix will be invaluable. Currently, HRNZ and NZTR have datasets regarding the movement of racehorses to race meetings (Chapter Six), and it would be helpful if the scope of this data collection is extended to competitive events. Equestrian Sports New Zealand maintains a database of registered horses and some of the events attended, however this is not complete. Unregistered horses can attend large competitive events like Agricultural and Pastoral shows. At large events run by ESNZ or under ESNZ rules, like Horse of the Year, unregistered horses can attend but are required to have day registration (Anon, 2012b). Day registration includes details such as ownership, including address, horse and use information. If day registration was mandatory for all events with a certain number of horses in attendance, and these data were stored on a central database, then contact tracing in the event of an outbreak would be easier.

9.2.3 Education relating to biosecurity

Protecting horses from endemic disease by increasing biosecurity practices and visitor protocols will increase the overall health of New Zealand horses. However, to be effective, biosecurity practices will need to be applied to both newly arriving horses and to horses returning to the property of origin. The benefit to horse owners and stud managers of better horse health through enhanced biosecurity will probably need to come with a financial incentive for the racing and breeding sectors. An investigation into the financial benefit offered by enhanced biosecurity should be undertaken. However, any analysis must account for the differing opinions regarding biosecurity of those in the equine industry. The results presented in Chapter Seven showed differing levels of biosecurity practices in the New Zealand breeding sector. Each stud manager employed different biosecurity practices in line with their tolerance of the risk of a disease outbreak on their stud farm.

One of the factors inhibiting the implementation of biosecurity could be financial. An economic analysis of biosecurity practices on commercial stud farms and a targeted education campaign for stud managers should be conducted. Within the New Zealand equine population, commercial breeders are most heavily impacted by infectious disease outbreaks, whether endemic or exotic.

In the current thesis the effectiveness of biosecurity practices and visitor protocols as control strategies for infectious disease were not able to be investigated. However, certain practices would be likely to reduce the ability for infectious disease to transmit both between and within horse properties during an outbreak. The isolation of newly arriving and of resident horses that are returning from events where they have been in contact with other horses, for at least a week, would be strongly advised. Isolation would need to include the complete separation from other horses, including separate gear for isolated horses and hygiene between isolated and not isolated horses. The reporting of sick horses, to allow for accurate action in the event of an outbreak is also important. However, even during the EI outbreak in Australia delays between the onset of the clinical signs of disease and reporting were noted (Garner et al., 2011). Therefore, in New Zealand, educating horse owners about reporting the clinical signs of infectious disease, for equine welfare and national biosecurity is important.

9.2.4 Formulating policy

The development of a disease model for the control of EI in the New Zealand equine population provides a tool to instigate discussions regarding control. Since 2009, the New Zealand Government, through the Ministry for Agriculture and Forestry (MAF), has been developing Government Industry Agreements (GIA) for biosecurity readiness (Anon, 2011c). The GIA will develop a partnership between representatives and stakeholders from the equine industry, to enable decision-making and cost sharing regarding biosecurity during an exotic disease incursion. The EI disease model will enable discussion regarding the use of vaccination and movement restriction as control strategies. The benefit to the industry of implementation of control strategies, particularly movement restriction, measured as the reduced length of the epidemic and number of infected properties will need to be considered in terms of the impact on the industry and disruption to business continuity.

This thesis has identified that the most effective strategy to achieve control of EI, by decreasing the duration and number of infected properties, was the implementation of vaccination seven days after official detection. Therefore, a response to an outbreak will need to be mounted rapidly. To mount an effective response in seven days, the decision to implement of vaccination will need to be made prior to a disease outbreak. These decisions will need to include access to international vaccine supplies, and the development of supply chains and systems to allow vaccination to be applied and the identification of vaccinated horses. This is where a GIA between the equine industry and the Government is important. A response plan for the control of EI in the New Zealand equine population, including the possible control strategies, timeliness of implementation of control strategies and cost sharing agreements needs to be in place now. Failure to reach decisions regarding control strategies when disease is not present could potentially lead to delays in implementing control strategies during and outbreak. These delays could lead to larger and longer outbreaks, and greater economic impact, or in the worst case, a failure to control and EI becoming endemic in the New Zealand equine population.

One key difficulty encountered during this thesis, which will impact on the success of a GIA, is the identification of key stakeholders in the equine industry. Key stakeholders that are easily identifiable include the New Zealand Racing Board (NZRB), HRNZ, NZTR, ESNZ and veterinarians. However, these stakeholders only comprise a small proportion of the horses in New Zealand, albeit the most economically important sectors (Anon, 2010c). Key stakeholders from the non-commercial sector of the industry, while more difficult to identify, must be included in any decisions regarding control strategies. The impact on non-commercial horse owners is different to those involved in the racing industry. More research is needed to identify key stakeholders in the New Zealand equine industry and to understand their motivations for the control of EI.

9.3 Future research

9.3.1 Extended disease modelling

The New Zealand EI InterSpread Plus model could be extended to examine control strategies targeted at the racing industry. These strategies would allow the movement of horses after vaccination, to allow the continuity of racing industry business; breeding horses, race meetings, wagering and gambling, before the end of the outbreak has occurred. Alongside targeted strategies, an economic analysis of the model needs to be conducted to combine the benefit of vaccination, in less infected properties and shorter epidemics, with the cost of vaccination. An economic model would support decisions regarding control, particularly in the racing industry, which would be most economically affected by an outbreak. An epidemiological model without an economic model only tells half the story for disease control (Rich et al., 2005a).

9.3.2 Climate change and the changing infectious disease landscape

Over the next 30 to 40 years, the climate of New Zealand is expected to change, with increasing temperatures and differences in rainfall patterns (Anon, 2012a). Increases in temperature and rainfall will make New Zealand more habitable for insects, particularly infectious disease vectors like mosquitoes. Climate change, coupled with importation of horses from countries where vector borne disease are endemic, increase the risk of vector borne disease outbreaks affecting New Zealand horses. The importation of horses also increases the risk of importing new and emerging infectious diseases, some of which may have zoonotic potential. The development of the InterSpread Plus EI model, will be important if an EI outbreak was to occur. This model has additional benefits in the event of another exotic disease outbreak affecting horses as it could be adapted for other infectious diseases.

9.4 Conclusions

The work undertaken in this thesis highlights the complexity inherent in developing a disease model to support the development of policies for the control of exotic disease outbreaks. The work is considered to represent the first epidemiological study encompassing the different sectors of the equine industry in New Zealand, and provides a valuable resource for the development of disease control models and a reference for future research. Studies contained within this thesis have identified that there is considerable movement heterogeneity both within and between different sectors of the New Zealand equine population. Movement behaviour was associated with the property-level characteristics like the number of horses, the type of horses and the reason for keeping horses on the property. This thesis identified that biosecurity practices implemented on non-commercial and commercial breeding properties were unlikely to prevent the spread of infectious disease. The lack of biosecurity implemented for newly arriving horses highlights the need for further research on overall on-farm biosecurity practices and education. Of particular interest is the implementation of biosecurity on properties for resident horses returning from competitive events or race meetings. The most effective strategy for the control of EI, in terms of the shortest outbreak and least number of infected properties, was vaccination in a three kilometre radius of an infected property starting on day seven. This thesis has identified the importance of accurate data for informing disease models. The most accurate way to collect these data is using a property and movement database similar to what will be available for food producing animal species in New Zealand like NAIT or Farms Online. The industry will need to take a proactive approach to ensure that this occurs.

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Appendix A
Non-commercial horse property questionnaire

This appendix contains the questionnaire pack sent to the selected non-commercial horse property owners. The questionnaire pack included a cover letter, instruction page and the questionnaire, which was divided into five sections; i) confirming the address details and presence of horses, ii) the demographic characteristics of horses on the property, iii) the movement of horses from the property, iv) the movement of horse professionals onto the property and v) biosecurity practices.

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{Date survey was sent}

Dear {Property owners name here}

I am inviting you to participate in a research project that aims to prepare New Zealand for an outbreak of equine influenza (EI). To do this, information needs to be collected about rural properties, specifically those that have horses. We need accurate information about how many properties keep horses, the total number of horses, what they are used for and how often they are transported. This information is key to building disease control strategies if there is an outbreak of EI. In New Zealand, this information has never been collected before.

This research was prompted by the outbreak of EI in Australia in 2007, which had a disastrous effect on the Australian equine industry, with the cancellation of races and shows and a restriction on the movement of all horses. EI is a highly infectious respiratory illness that infects horses. New Zealand has never had a case of EI, so it would spread quickly and infect many horses. It is therefore vital that we have effective strategies to control EI based on the New Zealand horse industry and this is why the Epicentre, Massey University with funding from the Ministry of Agriculture and Fisheries (MAF) is conducting this research.

You may have seen articles about this research in the August Horse and Pony magazine or on the www.horsetalk.co.nz website.

Please note, EI infects all equids. This includes horses, ponies, donkeys, mules and zebras. In this questionnaire, the word horse has been used to describe all of the equids mentioned above, not specifically horses. If you have any equids on your property, please fill in this questionnaire.

How you were selected

Your property has been randomly selected from the AsureQuality AgriBase™ database. This database is the most accurate record of rural properties and will be used by MAF in the event of a disease outbreak to contact property owners and aid in outbreak management.

What to do

Attached to this letter is a short questionnaire with questions about you and your property, your horses, what you do with your horses and how often you move them. Please complete the questionnaire and send it back, in the prepaid envelope. It should take you about 10 minutes to complete. Even if you do not have horses on your property it is important that you still fill out the first three questions and return the questionnaire. Included in the survey pack are a Freddo Frog and a tea bag to thank you for your participation.

Confidentiality

Your return of this survey indicates your consent to participate in this study. Please be assured that your responses will be held in the strictest confidence. When the results of this study are written for publication, no identifying information will be used.

I hope that you will be able to participate in this study and do not hesitate to contact me with any questions about the survey or if you would like more information.

Sincerely
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Epicentre
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Palmerston North
06 350 5855
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New Zealand horse demographics and movement survey
Is New Zealand prepared for an outbreak of EI?

Please read the following instructions before answering the questions

1. Please enjoy a cup of tea and a Freddo Frog while you complete this survey
2. Some questions require you to write the answer in the space provided and others require you to cross out answers. All other questions require you to tick your answer in a box. If you make a mistake please fill in the box in which you made the mistake and tick the correct one.

An example of how to mark the questionnaire

Where did the horse(s) go?	Frequency of movements	Month/months of travel	Approximate travel time to the destination i.e. travel time one way	Number of horses from another property at the destination
Riding Lessons	__1___ time(s) per ~~week/~~month~~/year~~	December to March	_30__ km or _____ ~~hour(s)~~	☐0 ☑1–20 ☐21–99 ☐100+

3. This questionnaire will take you no longer than 10 minutes to complete, enough time to enjoy your cup of tea.
4. Please remember, EI infects all equids. This includes horses, ponies, donkeys, mules and zebras. In this questionnaire, the word horse has been used to describe all equids, not specifically horses. If you have any equids on your property, please fill in this questionnaire.
5. It is important that you fill in this questionnaire even if you do not have horses on your property; the first 4 questions still apply to you.
6. If you are having difficulty with this survey please fill out the question below

☐ I am having difficulty completing this form please contact me (contact details and preferred time for contact in the box below.)

New Zealand horse demographics and movement survey

1) Please write down today's date

/ / 2009

2) Please confirm that your property details on the AgriBase™ database are correct (please correct them if they are not)

{Property address and contact details for the property owner} ☐ Yes I am responsible for this property and the above details are correct	☐ No, I am not longer responsible for this property. (Please provide contact details below, if known) ☐ Yes, I am responsible for this property but the details are incorrect. (Please provide new details in space below) ☐ I am willing to be contacted for follow up questions

3) How many neighbours that you share a boundary fence with have horses?

☐ None ☐ _______ (number) boundary neighbours ☐ I do not know

4) Are there horses on this property?

☐ Yes (please continue)

☐ **No. (End survey here and return in pre paid envelope).**

5) Please enter the numbers of horses in each class that you have typically had on your farm in the last 12 months (please include horses that are not owned by you or your household)

Horse Type	**Numbers**	**Horse Type**	**Numbers**
Foals (0 - 9 months)		Mares	

Weanlings (9 – 12 months)		Geldings	
Yearlings (12 -24 months)		Stallions	

6) What are horses on your property used for? Please tick all answers that apply.

☐ Thoroughbred racing
☐ Thoroughbred breeding
☐ Standardbred racing
☐ Standardbred breeding
☐ Breeding horses not used for either Standardbred or Thoroughbred racing events
☐ Unbroken horses destined for racing or sports/leisure
☐ Sports/ Leisure horses
☐ that go to events less than 6 times per year
☐ that go to events more than 6 times per year
The best description of the main activities attended with your horse(s) is...
☐ Show jumping ☐ Competitive trail riding
☐ Dressage ☐ Treking
☐ Eventing ☐ Western
☐ Pony club ☐ Showing
☐ Adult riding club ☐ Hunting
☐ Endurance ☐ Other (please specify)________
☐ Donkeys
☐ Other (please specify) _______________

7) Do you currently have horses on your property that are not owned by you or your household?

☐ Yes (How many? ________) ☐ No

8) What other animals do you currently have on your property? (Please tick as many as apply to you).

☐ None ☐ Pigs ☐ Cattle ☐ Alpacas ☐ Sheep
☐ Goats ☐ Chickens ☐ Cats ☐ Dogs
☐ Other (please specify) __________

9) Which statement best describes the importance of horses to your lifestyle?

☐ I have horses on my property and they are my primary income (eg trainer)
☐ I have horses on my property and they are not my primary income (eg do sell some horses)
☐ I have horses on my property and I do not get an income for this activity (competitive rider)
☐ I keep horses for recreation
☐ I keep horses to aid my farming operation (eg sheep farmer with large station)
☐ Other (please specify) __________

10) Please fill in the table below to describe how often horses have been transported off your property in the last 12 months.

In this table please include all events that you or people that keep horses on your property have attended in the last year. This could include competitions, pony club or adult riding club rallies, riding lessons, group hacks or treks, or natural horsemanship clinics. It also includes horses transported for breeding or sale (to name a few possibilities).

If you are moving horses for the same type of event but these events were in different areas (i.e. different distances were travelled) please fill in separate entries on the form. See Pony Club ODE in the example.

(Examples on how to fill out the form in the shaded area)

☐ I am having difficulty completing this form please contact me (contact details and preferred time for contact in the box below.) **Please continue survey at question 10 and return questionnaire in pre paid envelope**

Where did the horse(s) go?	**Frequency of movements**	**Month/months of travel**	**Approximate travel time to the destination i.e. travel time one way**	**Number of horses from another property at the destination**
Track	__6___ time(s) per week~~/month/year~~	*All year*	_30__ km or _____ hour(s)	☐0 ☑1–20 ☐21–99 ☐100+
Riding lesson at instructors property	__1__ time(s) per week~~/month/year~~	*June, July*	_30__ km or _____ hour(s)	☐0 ☑1–20 ☐21–99 ☐100+
Pony club ODE	__2___ time(s) per ~~week/~~month/~~year~~	*March, April*	_____ km or __1__ hour(s)	☐0 ☐1–20 ☑21–99 ☐100+
Pony club ODE	__1__ time(s) per ~~week/~~month~~/year~~	*April*	_____ km or __4__ hour(s)	☐0 ☐1–20 ☑21–99 ☐100+
Horse sold	__1___ time(s) per ~~week/month/~~year	*December*	_____ km or __6__ hour(s)	☐0 ☑1–20 ☐21–99 ☐100+
Natural horsemanship clinic	__2___ time(s) per ~~week/month/~~year	*August, September*	_30__ km or _____ hour(s)	☐0 ☑1–20 ☐21–99 ☐100+
Show jumping	__10__ time(s) per ~~week/month/~~year	*September to March*	_130__ km or _____ hour(s)	☐0 ☐1–20 ☑21–99 ☐100+

Riding lesson (off property)	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Pony club	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
A and P show	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Horse sold	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Show jumping competition	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Dressage competition	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Eventing competition	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Hunting	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Group trek	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Race meet	☐ No or _____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify) ____________________	_____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify) ____________________	_____ time (s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify) ____________________	_____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify)	_____ time(s) per		____ km or	☐0

___________________	week/month/year		____ hour(s)	☐1–20 ☐21–99 ☐100+
Other (please specify) ___________________	_____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify) ___________________	_____ time (s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify) ___________________	_____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+
Other (please specify) ___________________	_____ time(s) per week/month/year		____ km or ____ hour(s)	☐0 ☐1–20 ☐21–99 ☐100+

If you need more space to fill in this question please feel free to attach another page to this questionnaire.

11) Over the last 12 months, how often have horse professionals visited your property? Horse professionals include vets, farriers, and dentists, riding instructors, massage therapists and saddle fitters. Other people may have attended to your horses in the last year. **(Examples on how to fill in the table are in bold)**

	Spring	**Summer**	**Autumn**	**Winter**
Vet	**_2_ visit(s) per ~~day/~~week/ ____ ~~weeks~~**	**_1_ visit(s) per ~~day/week/~~ _4_ weeks**	**_1_ visit(s) per ~~day/week/~~ _6_ weeks**	**__ visit(s) per day/week/ ____ weeks**
Other horse care professional (please specify) **Dentist**	**__ visit(s) per day/week/ ____ weeks**	**_1_ visit(s) ~~per day/week/~~ ____ ~~weeks~~**	**__ visit(s) per day/week/ ____ weeks**	**__ visit(s) per day/week/ ____ weeks**
Vet	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks
Farrier	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks
Riding Instructor	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks
Other horse care professional (please specify) ___________	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks
Other horse care professional (please specify) ___________	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks
Other (please specify) _____________	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks	__ visit(s) per day/week/ ____ weeks

If you need more space to fill out this table, please feel free to attach another page to this questionnaire.

12) What information is usually known about new horses when they arrive onto your property?

☐ Previous medical history
☐ Tetanus vaccination history
☐ Strangles vaccination history
☐ Other (please specify) _________
☐ Point of origin
☐ Worming history
☐ No information is usually known

13) What health checks are carried out on horses when they arrive on your property?

☐ None
☐ Rectal temperature taken
☐ Visually observed for obvious abnormalities
☐ Checked for abnormal discharge from the eyes and nose
☐ Drenched
☐ Lameness / gait checked

14) Are new horses separated from other horses when they arrive on your property?

☐ No
☐ Yes, up to 24 hours
☐ Yes, 1 to 2 days
☐ Yes, 2 to 4 days
☐ Yes, more than 4 days
☐ Other (please specify) _________

15) If a horse that had come onto your property in the last week was observed to be "off colour", what would you check or monitor?

☐ Temperature
☐ Respiratory rate and effort
☐ Coughing
☐ Pulse
☐ Abnormal discharge from the eyes and nose
☐ Call vet immediately
☐ Signs of colic
☐ Appetite
☐ Stance or posture
☐ Other (please specify) _________

16) Are there any specific protocols veterinarians, farriers and other horse professionals are asked to follow before they interact with the horses? (tick all that apply)

☐ Hand washing
☐ Change clothes
☐ Change into overalls
☐ None of the above
☐ Clean gear or use your own gear
☐ Wash or change boots
☐ Other (please specify) ________

17) How does your property manage insect pests? (tick all that apply)

☐ Insecticide applied to horse
☐ Insecticide in the environment
☐ Fly sheets and/or face masks on horses
☐ None of the above
☐ Insect traps
☐ Supplements
☐ Other (please specify) ________

18) How does your property manage rodent pests? (tick all that apply)

☐ Traps
☐ Bait stations
☐ Cats
☐ Rodent proof containers for feed
☐ None of the above
☐ Other (please specify) _______

☐ Please tick this box if you do not wish to be contacted for follow up questions

Thank you for taking the time to complete this survey. Let me remind you that this survey held in the strictest confidence and will help us to better understand the New Zealand horse population and aid in preparation for an EI outbreak.

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher is responsible for the ethical conduct of this research. If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher, please contact Professor Sylvia Rumball, Assistant to the Vice Chancellor (Research Ethics), telephone (06) 350 5249, email humanethics@massey.ac.nz.

If you would like more information about this survey or EI, please feel free to contact Sarah Rosanowski, email s.rosanowski@massey.as.nz or telephone (06) 350 5855.

Appendix B
Stud managers questionnaire

This appendix contains the interview sheet used when the selected stud managers were interviewed regarding movement and biosecurity practices.

Questions asked of Thoroughbred stud managers during face-to-face interviews

Horse Movement Patterns and Biosecurity Practices

Date:

Stud:

Breed:

Name of person answering:

1. How many horses do you have on your property today?

Horse type	**Number**
Broodmares	
Stallions Resident Shuttle Teaser	
Foals	
Weanlings	
Yearlings	
Other ie racehorses/ sports horses	

2. What other activities does your stud farm undertake?

Do you spell horses? ☐ Yes ☐ No	Do you pre train horses? ☐ Yes ☐ No	Do you break horses? ☐ Yes ☐ No
If yes, what are the contact details of the person responsible for these activities for later follow up: ____		
Are horses kept for reasons other than breeding or the above activities on the property? ie eventing horses, hunters, or horses in training for racing ☐ Yes comment _____________________________ ☐ No		

3. Describe the movement of horses onto the stud farm

Horse Type	Months on	Number	Origin
Dry mares			
Wet Mares			
Yearling preparation			
Shuttle stallions			
Weaning only			
Foaling only			
Walk-in mares			
Scan only			
Other			

4. Describe the movement of horses off the stud farm

Horse Type	Months off	No. off movements/ week	Destination
Empties sent home			
Yearling sales			
Other sales			
Weaning			
Shuttle stallions			
Walk-in mares			
Mares sent home			
Horses to other stud farms			
Spelling horses			
Horses to training			
Other			

5. Movements of people off your farm in the last 12 months

This includes the vet, farrier, dentist, employees (especially those with other horses or horse related activities), etc.

How often do people attend the horses in the breeding/non-breeding season?

Person	Breeding season	Non-breeding season
Veterinarian		
Farrier		
Other		

Biosecurity Questions

1. **Do you ever isolate stallions on arrival?**

Yes ☐ If yes:

On what basis do you make the decision to isolate a stallion?

……

Do you typically do the following at arrival of outside stallions on the stud?

Check	**Yes**	**Comment**
Physical examination by vet	☐	
Test for infectious diseases (blood tests)	☐	
Test for STD's at the beginning breeding season	☐	
Test for STD's during breeding season	☐	
Clean penis after serving	☐	

2. **In the last week, when an outside mare arrived did you do the following?**

Check	**Yes**	**Comment**
Check respiration	☐	
Check circulation	☐	
Take temperature	☐	
Check mucous membranes	☐	
Check lymph nodes	☐	
Check vaccination status	☐	
Check drenching history	☐	
Check history of recent illness	☐	
Check for coughing	☐	

Check for nasal discharge	☐	
Check/trim feet	☐	
Body weight	☐	
Score condition	☐	
Take a photograph	☐	
Other	☐	

3. In the last week, have you isolated any mares on arrival?

Yes ☐ No ☐

If yes: For how long ……………days/weeks

Why? ....

4. Do you ever isolate mares on arrival?

Yes ☐ If yes:

On what basis do you make the decision to isolate a mare?

……

No ☐ (Proceed with question No 8)

5. If answered yes to question 4 and/or 5. Which of the following do you activities do you typically do on isolated animals? (Tick as many as applicable)

Check	**Yes**	**Comment**
Clinical examination	☐	
Drenching of the walk-in mares	☐	
House walk-in mares in separate quarantine yards/paddocks	☐	

Rotation of the yards/paddocks	☐	
Use of disinfectants for the quarantine yards/paddocks	☐	
Prevent contact with resident mares (seeing, nose contact, full contact) and teaser	☐	
Prevent contact with other walk-in mares (seeing, nose contact, full contact)	☐	
Clean shoes or change clothes/shoes when entering quarantine yards/paddocks	☐	
Cleaning of the name-tag a/o head-collars	☐	

6. In case you do have a quarantine protocol, do you normally act according to the quarantine protocol at arrival of walk-in mares or do you find it is hard to maintain consistency of the protocols?

Comment:……

………

7. If never isolate mares. Why do you not isolate recent walk-in mares?

Comment:……

………

Reason	**Yes**	**Comment**
Not enough time	☐	
Not enough space	☐	
No necessity because of disease free country	☐	
Did not know importance	☐	

Other	☐	

8. When walking around on your stud do you normally do the following between visiting different groups of horses?

	Yes	**If yes, when**
Wash hands	☐	
Clean shoes	☐	
Clean equipment	☐	
Change shoes	☐	
Change clothes	☐	
Wash/change when illness on farm (e.g. scours)	☐	
Isolate when illness on farm (e.g. scours)	☐	
Clean crush	☐	
Use disinfectants for crush	☐	
Clean foaling paddocks	☐	

9. Do visitors of the stud have to follow a protocol before entering the stud property?

Protocol	**Veterinarian**	**Farrier**	**Owners of outside mares**	**Other**
Wash hands	☐	☐	☐	☐
Clean shoes	☐	☐	☐	☐
Clean equipment	☐	☐	☐	☐

Change shoes	☐	☐	☐	☐
Change clothes	☐	☐	☐	☐
Use studs own equipment	☐	☐	☐	☐

Appendix C

InterSpread Plus modelling parameters

This appendix contains the movement input parameters used for the equine influenza InterSpread Plus model.

Movement input parameters used for the equine influenza InterSpread Plus model

For the equine influenza InterSpread Plus model, horse properties were categorised as one of five groups; general horse, Thoroughbred stud farms, Standardbred stud farms, Thoroughbred training and Standardbred training. Horses from Thoroughbred or Standardbred training properties could meet together at Thoroughbred or Standardbred race tracks.

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.

Movement type	Description
General horse	Defines the level of movement of horses off all general equine properties
Thoroughbred breeding	Defines the level of movement of horses off all Thoroughbred stud farms properties for breeding
Standardbred breeding	Defines the level of movement of horses off all Standardbred stud farms properties for breeding
Thoroughbred training	Defines the level of movement of horses off all Thoroughbred training properties for training
Thoroughbred spelling	Defines the level of movement of horses off all Thoroughbred training properties for spelling
Thoroughbred to races	Defines the level of movement of horses off all Thoroughbred training properties for racing
Thoroughbred from races	Defines the level of movement of horses from Thoroughbred race tracks, returning to Thoroughbred training properties
Standardbred training	Defines the level of movement of horses off all Standardbred training properties for training
Standardbred spelling	Defines the level of movement of horses off all Standardbred training properties for spelling
Standardbred to races	Defines the level of movement of horses off all Standardbred training properties for racing
Standardbred from races	Defines the level of movement of horses from Standardbred race tracks, returning to Standardbred training properties

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.

Movement name	No. of movement events	No. of contacts	Probability of transmission
General horse	Poisson(0.07)	10	Constant (0.3)
Thoroughbred breeding	Poisson (0.36)	1	1
Standardbred breeding	Poisson (0.41)	1	1
Thoroughbred training	Poisson (0.8)	Poisson (10)	Constant (0.3)
Thoroughbred spelling	Poisson (0.05)	1	1
Thoroughbred to races	Poisson (0.1)	40	1
Thoroughbred from races	Poisson (0.1)	-	Constant (0.3)
Standardbred racehorses	Poisson (0.5)	Poisson(10)	Constant (0.3)
Standardbred spelling	Poisson (0.05)	1	1
Standardbred to races	Poisson (0.05)	30	1
Standardbred from races	Poisson (0.05)	-	Constant (0.3)

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.

	Distance travelled			
Movement name	1 to 50 km	51 to 150 km	151 to 350 km[a]	Interisland[b]
Thoroughbred breeding	0.65	0.18	0.12	0.05
Standardbred breeding	0.72	0.15	0.09	0.04
Thoroughbred spelling	0.72	0.15	0.09	0.04
Standardbred spelling	0.55	0.2	0.1	0.15

[a] All movements of horses that went between the North and South Island of New Zealand, regardless of number of kilometres travelled (modelled as movement event greater than 500 km)

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.

	Distance travelled					
Movement name	≤20 km	21-100 km	101-200 km	201-300 km	301-400 km	>400 km
Thoroughbred training	1					
Thoroughbred to races	0.15	0.4	0.2	0.15	0.05	0.05
Thoroughbred from races	0.15	0.4	0.2	0.15	0.05	0.05
Standardbred training	1					
Standardbred to races	0.55	0.2	0.1	0.05	0.05	0.05
Standardbred from races	0.55	0.2	0.1	0.05	0.05	0.05

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

Distance travelled	Probability
0 to 5 km	0.175
6 to 25 km	0.24
26 to 50 km	0.16
51 to 100 km	0.17
101 to 200 km	0.16
>201 km	0.08

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.

	Destination properties				
Movement name	**General horse**	**Thoroughbred Stud farm**	**Standardbred stud farm**	**Thoroughbred training**	**Standardbred training**
General horse	Yes	Yes	Yes	Yes	Yes
Thoroughbred breeding	0.92	0.008	-	0.07	-
Standardbred breeding	0.93	-	0.002	-	0.068
Thoroughbred spelling	0.92	0.008	-	0.072	-
Standardbred spelling	0.93	-	0.02	-	0.068